metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

METRO VANCOUVER REGIONAL DISTRICT
REGIONAL PLANNING COMMITTEE

MEETING

Friday, April 5, 2024
1:00 pm
28th Floor Committee room, 4515 Central Boulevard, Burnaby, British Columbia
Webstream available at https://www.metrovancouver.org

A G E N D A[1]

A. ADOPTION OF THE AGENDA

1. April 5, 2024 Meeting Agenda
That the Regional Planning Committee adopt the agenda for its meeting scheduled for April 5, 2024 as circulated.

B. ADOPTION OF THE MINUTES

1. March 8, 2024 Meeting Minutes *pg. 5*
That the Regional Planning Committee adopt the minutes of its meeting held March 8, 2024 as circulated.

C. DELEGATIONS

D. INVITED PRESENTATIONS

1. Dr. Lawrence Frank, Urban Design 4 Health
Subject: Where Matters II

E. REPORTS FROM COMMITTEE OR CHIEF ADMINISTRATIVE OFFICER

1. Where Matters II – Final Report *pg. 10*
That the MVRD Board:
a) receive for information the report dated March 13, 2024, titled "Where Matters II – Final Report"; and
b) forward the "Where Matters II – Final Report: Walkability and Greenspace Relationships with Health and Climate Change" report to member jurisdictions for information with an offer of presenting the report findings to councils.

[1] *Note: Recommendation is shown under each item, where applicable.*

2. **Metro 2050 Climate Policy Enhancement Study - Recommendations** *pg. 495*

That the MVRD Board direct staff to prepare a bylaw to amend *Metro 2050* for consideration based on the following recommendations and as described in Table 2 of the report dated March 13, 2024, titled "*Metro 2050* Climate Policy Enhancement Study – Recommendations" to:

a) develop a revised definition for the regional Rural land use designation;
b) encourage the protection and restoration of trees and other ecosystems on lands with a non-urban regional land use designations and lands outside the Urban Containment Boundary;
c) require environmental and climate change-related analyses as part of all M*etro 2050* amendment applications;
d) encourage the development of local hazard and risk data that meets key requirements;
e) add new climate-related performance monitoring metrics; and
f) increase intersection density and permeability of the urban street grid.

3. **Tree Canopy Cover and Impervious Surface – 2020 Update** *pg. 511*

That the MVRD Board:

a) receive for information the report dated March 15, 2024 titled "Tree Canopy Cover and Impervious Surface – 2020 Update"; and
b) share the findings and datasets with member jurisdictions with an offer of a staff presentation to Council upon request.

4. **Metro Vancouver Tree Regulations Toolkit Update** *pg. 522*

That the MVRD Board:

a) receive for information the report dated March 8, 2024, titled "Metro Vancouver Tree Regulations Toolkit Update"; and
b) forward the "Metro Vancouver Tree Regulations Toolkit Update" to member jurisdictions for information with an offer of a presentation to Councils upon request.

5. **2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver** *pg. 684*

That the MVRD Board:

a) receive for information the report dated March 15, 2024, titled, "2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver"; and
b) forward the "2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver" and its attachment to member jurisdictions for information with an offer for Council presentations upon request.

6. **Regional Affordable Housing Strategy Update (Housing 2050: A Roadmap to Implement Metro 2050's Housing Goal) – Scope of Work** *pg. 732*

That the Regional Planning Committee receive for information the report dated March 18, 2024, titled "Regional Affordable Housing Strategy Update (Housing 2050: A Roadmap to Implement *Metro 2050*'s Housing Goal) – Scope of Work".

7. Regional Hazard, Risk, and Vulnerability Analysis Options Assessment – Scope of Work *pg. 738*
That the Regional Planning Committee receive for information the report dated March 15, 2024, titled "Regional Hazard, Risk, and Vulnerability Analysis Options Assessment – Scope of Work".

8. Economic Value of Industrial Lands Study Update – Scope of Work *pg. 742*
That the Regional Planning Committee receive for information the report dated March 15, 2024, titled "Economic Value of Industrial Lands Study Update – Scope of Work".

9. Manager's Report *pg. 745*
That the Regional Planning Committee receive for information the report dated March 15, 2024, titled "Manager's Report".

F. INFORMATION ITEMS

1. Provincial Housing Legislation Provincial Advocacy and Supportive Roles *pg. 749*

G. OTHER BUSINESS

H. RESOLUTION TO CLOSE MEETING

Note: The Committee must state by resolution the basis under section 90 of the Community Charter on which the meeting is being closed. If a member wishes to add an item, the basis must be included below.

I. ADJOURNMENT

That the Regional Planning Committee adjourn its meeting of April 5, 2024.

Membership:

Woodward, Eric (C) – Langley Township
Kruger, Dylan (VC) – Delta
Bligh, Rebecca – Vancouver
Carreras, Korleen – Maple Ridge
Girard, Angela – North Vancouver City
Hodge, Craig – Coquitlam
Hurley, Mike – Burnaby
Johnstone, Patrick – New Westminster
Knight, Megan – White Rock
Lahti, Meghan – Port Moody
Lambur, Peter – West Vancouver
Locke, Brenda - Surrey
McEwen, John – Anmore
West, Brad – Port Coquitlam

METRO VANCOUVER REGIONAL DISTRICT
REGIONAL PLANNING COMMITTEE

Minutes of the Regular Meeting of the Metro Vancouver Regional District (MVRD) Regional Planning Committee held at 1:00 pm on Friday, March 8, 2024 in the 28th Floor Committee Room, 4515 Central Boulevard, Burnaby, British Columbia.

MEMBERS PRESENT:
Chair, Mayor Eric Woodward, Langley Township
Vice Chair, Councillor Dylan Kruger, Delta
Councillor Rebecca Bligh, Vancouver* (arrived at 1:03 pm)
Councillor Korleen Carreras, Maple Ridge
Councillor Angela Girard, North Vancouver City
Councillor Craig Hodge, Coquitlam
Mayor Mike Hurley, Burnaby
Mayor Patrick Johnstone, New Westminster
Mayor Megan Knight, White Rock* (arrived at 1:02 pm)
Mayor Meghan Lahti, Port Moody*
Councillor Peter Lambur, West Vancouver
Mayor Brenda Locke, Surrey*
Mayor John McEwen, Anmore
Mayor Brad West, Port Coquitlam*

MEMBERS ABSENT:
None

OTHERS PRESENT:
Siljia Hund, PhD, Hydrologist and Risk Analyst, Ebbwater Consulting
Don Iveson, Principal, Civic Good, Co-Chair, Task Force for Housing & Climate
Yinlue Wang, Hydrotechnical Specialist, Ebbwater Consulting

STAFF PRESENT:
Jerry W. Dobrovolny, Chief Administrative Officer*
Jonathan Cote, Deputy General Manager, Regional Planning and Housing
Rapinder Khaira, Legislative Services Coordinator, Board and Information Services
Jessica Hayes, Acting Program Manager, Housing Policy and Planning, Regional Planning and Housing Services
Heather McNell, Deputy Chief Administrative Officer, Policy and Planning
Edward Nichol, Senior Planner, Regional Planning and Housing Services
Sinisa Vukicevic, Program Manager, Planning Analytics, Regional Planning and Housing Services

*denotes electronic meeting participation as authorized by the *Procedure Bylaw*

A. ADOPTION OF THE AGENDA

1. March 8, 2024 Meeting Agenda

<u>It was MOVED and SECONDED</u>
That the Regional Planning Committee adopt the agenda for its meeting scheduled for March 8, 2024 as circulated.

<u>CARRIED</u>

B. ADOPTION OF THE MINUTES

1. February 9, 2024 Meeting Minutes

<u>It was MOVED and SECONDED</u>
That the Regional Planning Committee adopt the minutes of its meeting held February 9, 2024 as circulated.

<u>CARRIED</u>

C. DELEGATIONS

No items presented.

D. INVITED PRESENTATIONS

1:02 pm Mayor Knight arrived at the meeting.
1:03 pm Councillor Bligh arrived at the meeting.

1. Don Iveson, Co-Chair, Task Force for Housing & Climate

Don Iveson, Principal, Civic Good, Co-Chair, Task Force for Housing & Climate provided a presentation titled "Blueprint for More and Better Housing" that provided an advanced briefing on the *"Blueprint for More and Better Housing*" for how federal, provincial, and municipal governments can enable creation of affordable, low-carbon, resilient homes. Don Iveson highlighted four gamechanging principles and the need for government intervention to advance the Blueprint's goals.

In response to questions, Don Iveson noted the single biggest impact is for the Federal government to enter back into the affordable housing market through preservation through acquisition of the existing older housing stock.

E. REPORTS FROM COMMITTEE OR CHIEF ADMINISTRATIVE OFFICER

1. Regional Multi-Hazard Mapping Project

Report dated February 12, 2024, from Edward Nichol, Senior Planner, Regional Planning and Housing Services providing the Regional Planning Committee with the results of the Regional Multi-Hazard Mapping project, which includes the completion of regional single-hazard maps, data quality rating maps, and multi-hazard maps for coastal flooding, riverine flooding, earthquake, and wildfire.

Edward Nichol provided a presentation titled "Regional Multi-Hazard Mapping Project" with an overview of the regional multi-hazard maps which are a collation of natural hazard data.

It was MOVED and SECONDED
That the MVRD Board receive for information the report dated February 12, 2024, titled "Regional Multi-Hazard Mapping Project".

CARRIED
Mayors Lahti and West absent at the vote.

2. Metro 2050 Implementation Guideline – Sewerage Area Amendment Applications

Report dated January 15, 2024, from Victor Cheung, Regional Planner, Regional Planning and Housing Services, providing the MVRD Board with the proposed updates to *Metro 2050* Implementation Guideline – Sewerage Area Amendment Applications. The main changes include the description of common sewerage area amendment scenarios and corresponding board procedures, updates to the sewerage area amendment application process diagram, and formatting for better readability.

It was MOVED and SECONDED
That the MVRD Board endorse the Metro 2050 Implementation Guideline – Sewerage Area Amendment Applications as presented in the report dated January 15, 2024, titled "Metro 2050 Implementation Guideline – Sewerage Area Amendment Applications".

CARRIED
Mayors Lahti and West absent at the vote.

3. Request for Sanitary Service Connection at 4276 – 248 Street, Township of Langley

Report dated February 12, 2024, from Victor Cheung, Regional Planner, Regional Planning and Housing Services, seeking MVRD Board concurrence that the regional sewerage service for 4276 – 248 Street, in the Township of Langley, is consistent with *Metro 2050.*

It was MOVED and SECONDED
That the MVRD Board:

a) resolve that sewer service for the property at 4276 – 248 Street, Township of Langley is generally consistent with the provisions of Metro 2050; and

b) forward the requested Fraser Sewerage Area amendment application for the property at 4276 – 248 Street in the Township of Langley to the GVS&DD Board for consideration.

CARRIED
Mayors Lahti and West absent at the vote.

4. Acceptance of the Fraser Valley Regional District Regional Growth Strategy - Bylaw No. 1706, 2023

Report dated February 12, 2024, Victor Cheung, Regional Planner, Regional Planning and Housing, providing the MVRD Board with the *Fraser Valley Regional District Fraser Valley Future 2050 Regional Growth Strategy Bylaw No. 1706, 2023* for review. Per section 436 of the *Local Government Act,* before the bylaw can be adopted, the MVRD Board and other affected local governments must pass a resolution formally accepting the regional growth strategy.

It was MOVED and SECONDED

That the MVRD Board:

a) accept the Fraser Valley Regional District Fraser Valley Future 2050 Regional Growth Strategy (Bylaw No. 1706, 2023) pursuant to section 436 of the Local Government Act; and
b) send a letter forwarding the Board resolution to the Fraser Valley Regional District Board.

CARRIED
Mayors Lahti and West absent at the vote.

5. Inclusionary Housing Policy Review – Final Report and Regional Model Policy Framework

Report dated February 20, 2024, from Jessica Hayes, Acting Program Manager, Housing Policy and Planning, Regional Planning and Housing Services, providing the MVRD Board recommendations of the Inclusionary Housing Policy Review. The report seeks to assist member jurisdictions seeking to adopt or update inclusionary housing policies and encourage policy consistency across the region.

Jessica Hayes provided a presentation titled "Inclusionary Housing Policy Review", with an overview of the key recommendations from the Regional Model Policy Framework for creating inclusionary housing policies.

It was MOVED and SECONDED

That the MVRD Board:

a) receive for information the report dated February 20, 2024, titled "Inclusionary Housing Policy Review – Final Report and Regional Model Policy Framework"; and
b) send correspondence to member jurisdictions, requesting that the regional model policy framework be considered when adopting or updating inclusionary housing policies.

CARRIED

6. **Population Projections Update**
Sinisa Vukicevic, Program Manager, Planning Analytics, Regional Planning and Housing Services provided a presentation titled “Regional Population Projections”, discussing variations between Metro Vancouver and BC Statistics modeling data.

In response to questions, Heather McNell, Deputy Chief Administrative Officer, Policy and Planning, informed the committee that staff are working with BC Statistics to align municipal and provincial growth projections.

7. **Regional Food System Strategy Update – Scope of Work and Engagement (Phase 2)**
Report dated February 8, 2024, from Carla Stewart, Senior Planner, Regional Planning and Housing Services, providing the Regional Planning Committee with the scope of work and engagement plan for the update to the *Regional Food System Strategy.*

It was MOVED and SECONDED
That the Regional Planning Committee receive for information the report dated February 8, 2024, titled “Regional Food System Strategy Update – Scope of Work and Engagement (Phase 2)”.

CARRIED

8. **Manager’s Report**
Report dated February 21, 2024, from Jonathan Cote, Deputy General Manager, Regional Planning and Housing Development, Regional Planning and Housing Services, providing the Regional Planning Committee with an update on: the Regional Planning Committee 2024 Work Plan, 2024 Canada Mortgage and Housing Corporation Rental Market report, Streamlining of the Delivery of Rental Housing Initiative, Agricultural Viability Strategy, and an overview of the presentation at the 2024 Small Housing Gentle Density Leaders’ Summit.

It was MOVED and SECONDED
That the Regional Planning Committee receive for information the report dated February 21, 2024, titled “Manager’s Report”.

CARRIED

F. INFORMATION ITEMS
No items presented.

G. OTHER BUSINESS
No items presented.

H. RESOLUTION TO CLOSE MEETING
No items presented.

I. ADJOURNMENT

It was MOVED and SECONDED
That the Regional Planning Committee adjourn its meeting of March 8, 2024.

CARRIED
(Time: 3:00 pm)

Rapinder Khaira,
Legislative Services Coordinator

Eric Woodward,
Chair

66366316 FINAL

To: Regional Planning Committee

From: James Stiver, Division Manager, Regional Land Use Policy, Regional Planning and Housing Services

Date: March 13, 2024 Meeting Date: April 5, 2024

Subject: **Where Matters II – Final Report**

RECOMMENDATION

That the MVRD Board:

a) receive for information the report dated March 13, 2024, titled "Where Matters II – Final Report"; and
b) forward the "Where Matters II – Final Report: Walkability and Greenspace Relationships with Health and Climate Change" report to member jurisdictions for information with an offer of presenting the report findings to councils.

EXECUTIVE SUMMARY

Transportation investment and land use decisions can have considerable public health consequences. The physical environment where we live, work, and play shapes our activity and travel patterns which in turn directly impacts vehicle emissions and our health and wellness. Since 2016, Metro Vancouver has been part of a research partnership led by Dr. Lawrence Frank, formerly at UBC's Health and Community Design Lab (School of Population and Public Health), to study and quantify the health and economic benefits of walkable communities and access to parks. Phase 2 of the Where Matters project is now complete and is being presented to the Regional Planning Committee and MVRD Board for information. It documents the direct and indirect health-related impacts and costs of transportation and land development decisions.

The findings confirm that living in more walkable rather than car-dependent neighbourhoods is associated with:

- increased walking (from 5 to 35 percent), transit use (from 3 to 17 percent), and fewer motor vehicle trips (declining from 92 to 44 percent);
- significantly lower travel-based greenhouse gas emissions (from 17 to 6 kilograms per person / day);
- higher rates of residents achieving the recommended amount of moderate to vigorous physical activity per week, resulting in reduced levels of obesity (51 percent lower odds) and diabetes (39 percent lower odds);
- time spent in cars declining from 37 to 19 minutes per day, while walk and bike time rising from 2 to 14 minutes per day; and
- residents reporting a 47 percent higher sense of community belonging.

PURPOSE
To provide the Regional Planning Committee and MVRD Board with the final *Where Matters II – Final Report: Walkability and Greenspace Relationships with Health and Climate Change* project report and a summary of findings for information.

BACKGROUND
Metro Vancouver has been participating and financially contributing to the "Where Matters" study with other partners including TransLink, Vancouver Coastal Health, the Real Estate Foundation of BC, and UBC's Health and Community Design Lab, to better understand the relationship between health outcomes and built environment. Phase 2 of the Where Matters Study also included the City of North Vancouver as a partner.

While there is a general recognition of the association between walkability and park access and better health outcomes, the first phase of the Where Matters Study, completed in 2019, explored the extent of that relationship for the first time in the Metro Vancouver region. The Study explored and quantified the relationships between the multiple health-related impacts of two of the determinants of health, the built and natural environments, as well as their collective influence on healthy behaviours. Phase 2 of the Where Matters Study is now complete. It leverages the findings of the first phase of the Study, and further explores the relationships between the built environment, health, and travel data to also assess the impacts of transportation and land use decisions on the prevalence of chronic diseases, travel patterns, and greenhouse gas (GHG) emissions.

WHERE MATTERS STUDY
The promotion of public health and well-being is an important component in building complete, healthy communities and an important objective of community and regional planning in this region. While there are other determinants of health, the Where Matters Study looked at multiple health-related impacts of the built and natural environments, as well as their collective influence on health outcomes and healthy behaviours, separated by age and income.

The promotion of public health and walkability is fundamental to many of the strategies and policy actions in *Metro 2050*, including:

- focusing growth in Urban Centres and Frequent Transit Development Areas (Strategy 1.2);
- developing resilient, healthy, connected, and complete communities with access to a range of services and amenities (Strategy 1.3); and
- coordinating land use and transportation to encourage transit, multiple-occupancy vehicles, cycling, and walking (Strategy 5.1).

At its July 5, 2019 meeting, the Regional Planning Committee received a staff report dated June 11, 2019 titled, "Where Matters: Health and Economic Impacts of Where We Live Final Report" on the research findings of the first phase of the Where Matters Study (Reference 1). Phase I of the Where Matters Study developed a Built Environment Database for the region (Reference 2) that considered how the region's built environment is related to the prevalence of chronic disease and physical activity behaviours by considering: walkability, access to park space, and neighbourhood type (ranging from 'car dependent' to 'walkable'). The results of the Study confirmed that higher levels of walkability and access to parks are associated with increased physical activity and lower incidents of chronic disease, hypertension, and stress. When comparing the results from people living in walkable areas to car dependent areas:

- People are 45 percent more likely to walk for transportation;
- People are 17 percent more likely to meet the weekly recommended level of physical activity;
- People are 42 percent less likely to be obese;
- People are 39 percent less likely to have diabetes;
- People are 14 percent less likely to have heart disease;
- People are 23 percent less likely to experience stressful days; and
- People are 47 percent more likely to have a strong sense of community belonging.

WHERE MATTERS STUDY - PHASE II

Phase 2 of the Where Matters Study tracks how Metro Vancouver's communities are changing over time, and how these changes impact public health and climate change. It builds on the previous work and connects the same measures of walkability and place types with climate impacts, and provides the ability to evaluate if health relationships with the built environment are connected (i.e., does a change in neighbourhood results in a change in health?).

The Phase 2 Study utilizes the Vancouver Walkability Index, TransLink's 2017 Travel Diary Survey data, the BC Generations Health Survey, Metro Vancouver's Greenspace data, and air quality data from the Canadian Urban Environmental Health Research Consortium. This data can be used to determine measurable biological responses such as body weight, inflammation, and stress which, over time, can impact the prevalence of chronic disease.

Findings

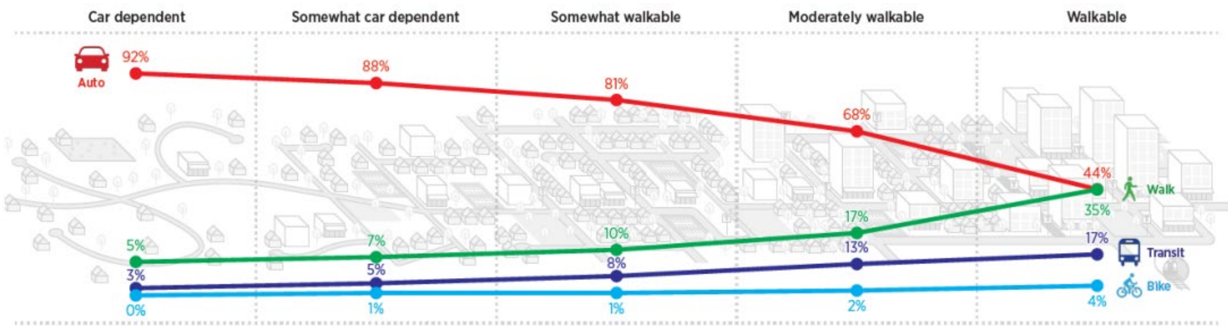
Travel and Climate Change

The Study concludes that higher levels of neighbourhood walkability are associated with increased walking and transit use, and fewer motor vehicle trips. Using travel data from TransLink's 2017 Trip Diary Survey, the region's travel habits were compared with travel-related emissions, walkability and other factors. In particular, when comparing the most car dependent to the most walkable areas of the region:

- the proportion of trips by car declined from 92 to 44 percent;
- walking increased from 5 to 35 percent; and
- transit use rose from 3 to 17 percent.

The Study also demonstrates a strong connection between walkability and travel mode choice. When comparing the most car dependent to the most walkable areas of the region, the average per person vehicle kilometres travelled declined from 11.92 to 5.83 per day (Figure 1).

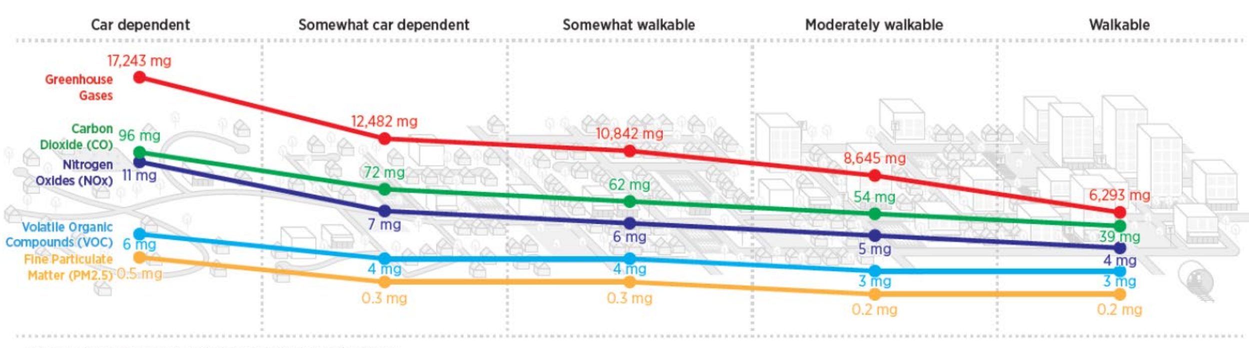
Figure 1. Proportion of Daily Trips by Mode of Transportation and Place Type



These results provide clear support for encouraging increased development densities and walkability as a GHG emissions reduction measure.

Greenhouse Gas Emissions
Private vehicle trips are responsible for roughly 32 percent of regional GHG emissions, and travel-related vehicle emissions have well-documented adverse human health impacts. Comprehensive lifecycle emissions estimates were generated for each reported trip, and a model was developed of daily GHG emissions on the same variables. The Study's model results show that emissions were significantly lower in more walkable neighbourhoods when adjusting for regional accessibility, vehicle ownership, income, and other factors. Travel-related GHG emissions declined nearly threefold, from 17 to 6 kilograms per person / day from the least to most walkable Place Type. Overall, those living in the region's more walkable areas generated between half to a third as many GHG emissions as those in the most car-dependent areas (Figure 2).

Figure 2. Amount of Typical Daily Transportation-Related Emissions by Place Type



Walkability
Walkability is one of the key community variables analyzed by Where Matters II. Walkability is a measure of the physical characteristics of the urban environment at the neighbourhood level that support walking. The results of the Study show that higher levels of walkability are associated with higher rates of walking as a transportation mode, and higher rates of residents achieving the recommended amount of moderate to vigorous physical activity per week (i.e., 150 minutes). The most walkable places in the region have a mix of housing types ranging from moderate to denser

residential development, easy access to retail stores, amenities and services, and highly connected streets; these are referred to as 'complete communities' in *Metro 2050.* In general, when neighbourhood walkability is improved, the culmination of these changes has been shown to be a significant factor in living healthier, more environmentally-friendly lifestyles.

The Study summarizes the component indicators by providing regional scale mapping and a summary of the average Metro Vancouver regional values for each of the 5 core components of walkability for 2006, 2011 and 2016. Each of the components show an increasing trend at subsequent time points (noting a slight reduction in land use mix), increasing trends in intersection density and net residential density, and commercial floor area ratio (FAR). Table 1 shows a summary of average walkability component values for Metro Vancouver in 2006, 2011, and 2016.

Table 1. Average Walkability Component Values for Metro Vancouver by Year

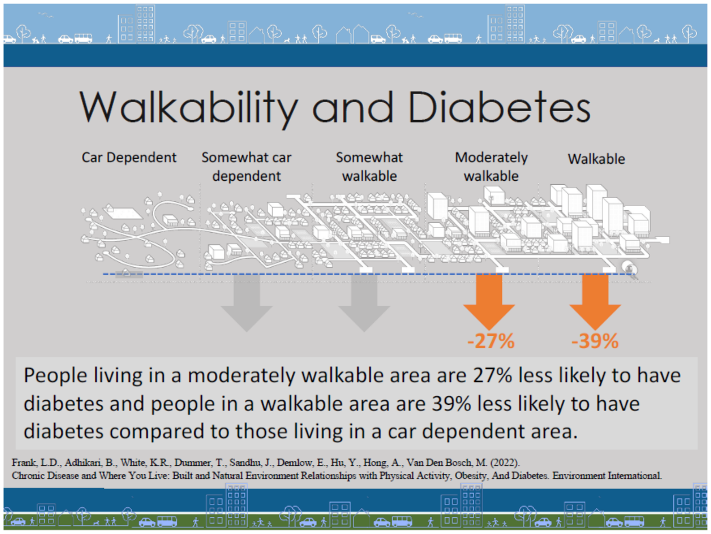
Community Design Characteristic	Year		
	2006	2011	2016
Intersection Density (intersections/km^2)	45	63	65
Net Residential Density (units/acre)	10	16	18
Commercial FAR	0.345	0.348	0.350
Land Use Mix	0.275	0.375	0.325

The region's walkability mapping is currently being updated by Dr. Frank and his team as a separate project supported by the 2024 Board-approved Regional Planning budget. Later this year we will be able to see these changes between 2006 and 2021.

Community Health Impacts
The relationship between chronic disease and impacts of the built and natural environment were estimated using the BC Generations Project, a database of 30,000 British Columbians aged 35-69. This dataset was established over the past decade as a research platform for evaluating the genetic, behavioural, and environmental causes of chronic disease.

- Obesity – Living in walkable neighbourhoods has been linked to significantly higher levels of physical activity. Among the Metro Vancouver sample, obesity showed a 16 percent prevalence rate, with 12 percent being treated for hypertension, and 2 percent being treated for type 2 diabetes. The Where Matters II study found that a 1-unit increase in the walkability score was associated with a 9 percent reduction in the odds of becoming obese. When compared to the least walkable areas, those participants living in the most walkable areas have 51 percent lower odds of becoming obese.
- Diabetes – Related to obesity as an indicator, residents in the most walkable areas of the region have a 39 percent lower odds of having diabetes compared with those in the most car-dependent areas (Figure 3).

Figure 3. Relationship Between Walkability and Diabetes



- <u>Mental Health and Sense of Community</u> – Sense of community belonging and concern over social isolation has become a major mental health issue in North American cities in recent years. The Where Matters II study found that participants living in the most walkable areas of the region were 47 percent more likely to report having a strong sense of community compared with those in the most car-dependent areas. However, participants in the most walkable areas were also shown to be 1.74 times more likely to report experiencing anxiety and stress compared to those living in the least walkability areas, which could appear to be a counter indicator; more consideration of this data is needed to better understand that relationship.

Summary
The physical environment where we live, work, and play shapes our activity and travel patterns which in turn impacts our wellness and vehicle emissions. Time spent in cars is a sedentary activity while walking and biking are forms of physical activity. When comparing the least to the most walkable areas of the region the time spent in cars declined from 37 to 19 minutes per day, while walk and bike time rose from 2 to 14 minutes per day respectively.

NEXT STEPS
It is recommended that copies of this staff report with the attached “Where Matters II – Final Report: Walkability and Greenspace Relationships with Health and Climate Change” be shared with all member jurisdictions for information with an offer of a staff presentation to councils. The final report will also be posted on the Metro Vancouver website for download and will be promoted broadly in other ways. Joint presentations and webinars with the other project partners that highlight the Study’s results will be explored.

ALTERNATIVES
1. That the MVRD Board:

a) receive for information the report dated March 13, 2024, titled "Where Matters II – Final Report"; and
b) forward the "Where Matters II – Final Report: Walkability and Greenspace Relationships with Health and Climate Change" report to member jurisdictions for information with an offer of presenting the report findings to councils.

2. That the Regional Planning Committee receive for information the report dated March 13, 2024, titled "Where Matters II – Final Report and provide alternative direction to staff.

FINANCIAL IMPLICATIONS
Metro Vancouver was a partner in the Where Matters Study, and contributed $20,000 towards Phase 2 of the Where Matters project. These funds were included in the 2020 MVRD Board-approved budget for Regional Planning. The project leveraged a $170,000 grant from the Canadian Institute of Health Research, and the overall budget totaled $542,000.

CONCLUSION
Transportation investment and land use decisions can have considerable public health consequences. The physical environment where we live, work, and play shapes our activity and travel patterns which in turn impacts our wellness and vehicle emissions. Since 2016, Metro Vancouver has been part of a research partnership led by Dr. Lawrence Frank, formerly at UBC's Health and Community Design Lab (School of Population and Public Health), to study and quantify the health and economic benefits of walkable communities and access to parks. While there is a general recognition of the association between walkability and park access and better health outcomes, the first phase of the Where Matters Study, completed in 2019, explored the extent of that relationship for the first time in the Metro Vancouver region. Phase 2 of the Where Matters project documents the direct and indirect health-related impacts and costs of transportation and land development decisions as well as the impacts on GHG emissions. The findings confirm that living in more walkable neighbourhoods can be associated with lower emissions, higher rates of physical activity and sense of community belonging, and lower rates of obesity, diabetes, and cardiovascular disease.

The promotion of public health and walkability is fundamental to many of the strategies and policy actions in *Metro 2050*. The connection between walkability and improved health outcomes demonstrates that local governments have a key role to play in supporting health and wellness by:

- building compact residential areas;
- increasing intersection density;
- supporting compact, mixed-use neighbourhoods; and
- improving access to parks.

However, the most walkable parts of the Metro Vancouver region also tend to be the least affordable. More work is needed by Metro Vancouver, member jurisdictions, other levels of government, and other agencies and organizations in this region to ensure that social equity continues to be a consideration of land use and development decision making, and that lower income households are not priced out of the places with the best health outcomes.

ATTACHMENT

1. Where Matters II – Final Report: Walkability and Greenspace Relationships with Health and Climate Change.

REFERENCES

1. Regional Planning Committee staff report dated June 11, 2019, titled "Where Matters: Health and Economic Impacts of Where We Live Final Report".
2. Where Matters: Health and Economic Impacts of Where We Live Policy Brief, May 6, 2019.

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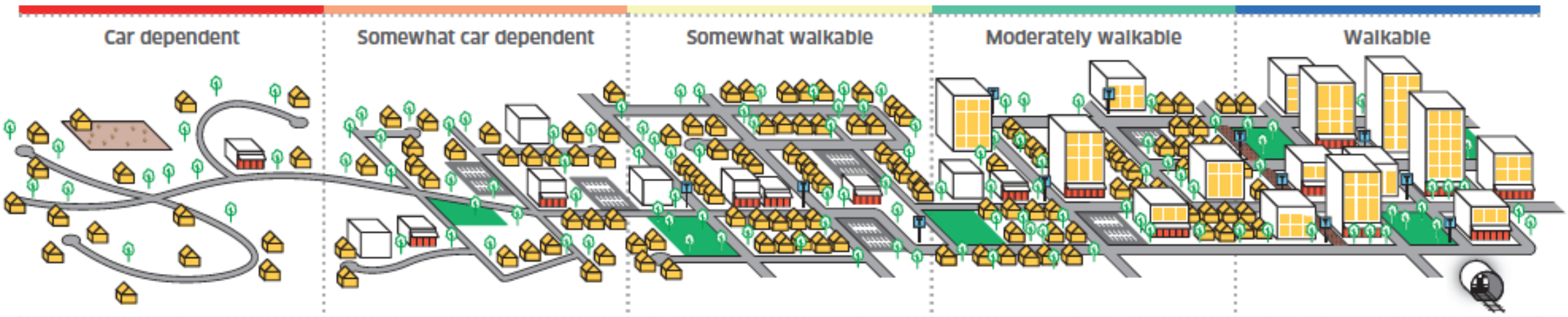
Attachment 1



Where Matters II – Final Report
Walkability and Greenspace Relationships with Health and Climate Change

Prepared For:

TransLink | metrovancouver SERVICES AND SOLUTIONS FOR A LIVABLE REGION | The University of British Columbia School of Population and Public Health Faculty of Medicine | British Columbia Ministry of Transportation | real estate foundation British Columbia | city of north vancouver | UBC Health and Community Design Lab

Prepared By:

Dr. Lawrence D. Frank, UC San Diego, Lead | Dr. Alex Bigazzi, UBC, Co-Lead | Dr. Trevor Dummer, UBC, Co-Lead | Ms. Katherine White, UBC | Dr. Katie Crist, UC San Diego | Dr. Atul Aravindakshan, UBC | Ms. Adriana Berjisian, UBC |Mr. Connor Wolff, UBC | Ms. Nasim Niknej, UBC | Mr. Eric Fox, Urban Design 4 Health, Ltd | Ms. Maureen Prentice & Mr. Victor Ngo, Consultants

February 29, 2024

Suggested Citation

Frank, LD, Bigazzi, A., Dummer, T., White, K., Crist, K., Aravindakshan, A., Berjisian, Wolff, C., Niknej, N., Fox, EH. & Prentice, M. (2024). Final Report – Where Matters II: Walkability and Greenspace Relationships with Health and Climate Change. Prepared by the Health & Community Design Lab, School of Population & Public Health, University of British Columbia. Support provided by the Real Estate Foundation of British Columbia, the British Columbia Ministry of Transportation & Infrastructure, Metro Vancouver, TransLink, and the City of North Vancouver.

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WHERE MATTERS…

WHEREVER

YOU

GO…

THERE

YOU

ARE

Executive Summary

Where Matters II documents public health and climate change win – win "co-benefits" from creating walkable communities with access to greenspace. Where Matters II investigated relationships between the built and natural environment where people live and the prevalence of physical and mental chronic diseases and sense of community. The physical environment where we live, work, and play shapes our activity and travel patterns which in turn impacts our wellness and vehicle emissions. Health and climate change are both impacted by the location and design of transportation and land use decisions. Demand for evidence linking built and natural environment features with our individual health and the health of the planet (e.g. climate change) is featuring more prominently within local, regional, provincial, and federal decision-making contexts to help shape investment priorities.

Where Matters II is a multi-sectoral (government, academia, industry) inter-disciplinary (public health, urban planning, transportation) collaboration. Primary funders are the Ministry of Transportation and Infrastructure, and the Real Estate Foundation of BC; who along with Metro Vancouver, TransLink, and the City of North Vancouver sponsored this project. WMII leverages and spatially integrates physical environment data with health outcome and travel data to assess causal impacts of transportation and land use actions on chronic disease, and associations with travel patterns and GHG emissions.

Walkability was measured consistently in 2006, 2011, and 2016 creating the ability to document how lower mainland communities have changed over time. This data along with greenspace and other social environment predictors was spatially joined with health outcome and travel data (see Figure 0-1).

Figure 0-1: Health and Climate Impacts of the Built and Natural Environment

Where Matters II provides a blueprint to track how communities are changing over time; and tracking how these changes impact public health and climate change. Tracking physical changes to the built environment over time and linking it with travel and health outcome data provides planners and decision-makers with a tool that links the health of a population and the environment with community design. WMII utilizes the Vancouver Walkability Index[1], TransLink's 2017 travel survey data, the BC Generations Health Survey, Metro Vancouver's Greenspace data, and air quality

[1] Developed by Dr. Lawrence Frank and researchers at the Health & Community Design Lab (HCDL). Dr. Frank led this work as the Bombardier Chair in Sustainable Transportation over a 17 year period at the University of British Columbia.

data from the Canadian Urban Environmental Health Research Consortium (CANUE). The conceptual study design shown in Figure 0-2 captures how transportation, land use, pedestrian design, and greenspace investments through travel and activity patterns affect our behaviours and exposures. These factors result in biological responses such as weight, inflammation, and stress which through time impact physical and chronic disease and downstream costs.

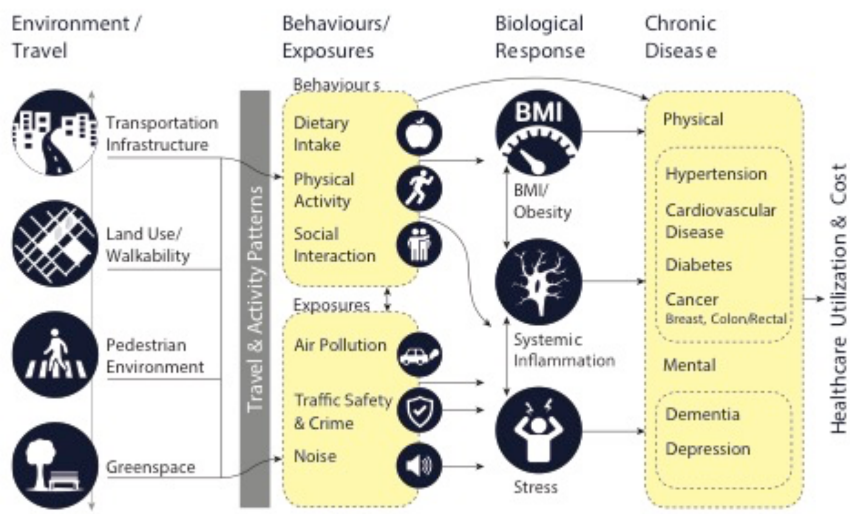


Figure 0-2: Conceptual Framework [2]

Where Matters found significant reductions in diabetes, and cardiovascular disease rates and increases in sense of community for those living in more walkable areas of the Vancouver region. Where matters II builds on this work and connects the same measures of walkability and community design with climate impacts. It also provides the ability to evaluate if health relationships with the built environment are causal. We can connect health outcomes more accurately to a person's neighbourhood and assess if a change in neighbourhood results in a change in health.

Tracking Walkability Changes

Figure 0-3 shows changes in the four main components of walkability between 2011 and 2016 across Metro Vancouver. Increases in residential density were largely concentrated in the urban centres and frequent transit development areas in the region. Changes in commercial floor area ratio (FAR) were widespread for areas with existing commercial and retail land uses with concentrated pockets of high change in some outlying areas in Richmond, Surrey, and Langley.[3] Land use mix shows relatively stable patterns across existing established mixed-use areas in Vancouver, Burnaby, and New Westminster, with larger changes in outlying and suburban areas. This is due to the fact that these previously single-use areas (e.g., residential subdivisions) are becoming more mixed with floor area from different land uses. Lastly, relatively limited change in intersection density was detected for the region with the exception of those outlying areas with greenfield development and significant new updates to the road network, especially in areas like Burke Mountain in Coquitlam and South Surrey.

[2] Frank, L. D., Iroz-Elardo, N., MacLeod, K. E., Hong, A. The pathways from built environment to health: Connecting behavior and exposure-based impacts. 2016. Journal of Transport and Health.
[3] Note that these areas may not exhibit high levels of commercial Floor Space Ratio (FSR); but have become more neighbourhood retail oriented.

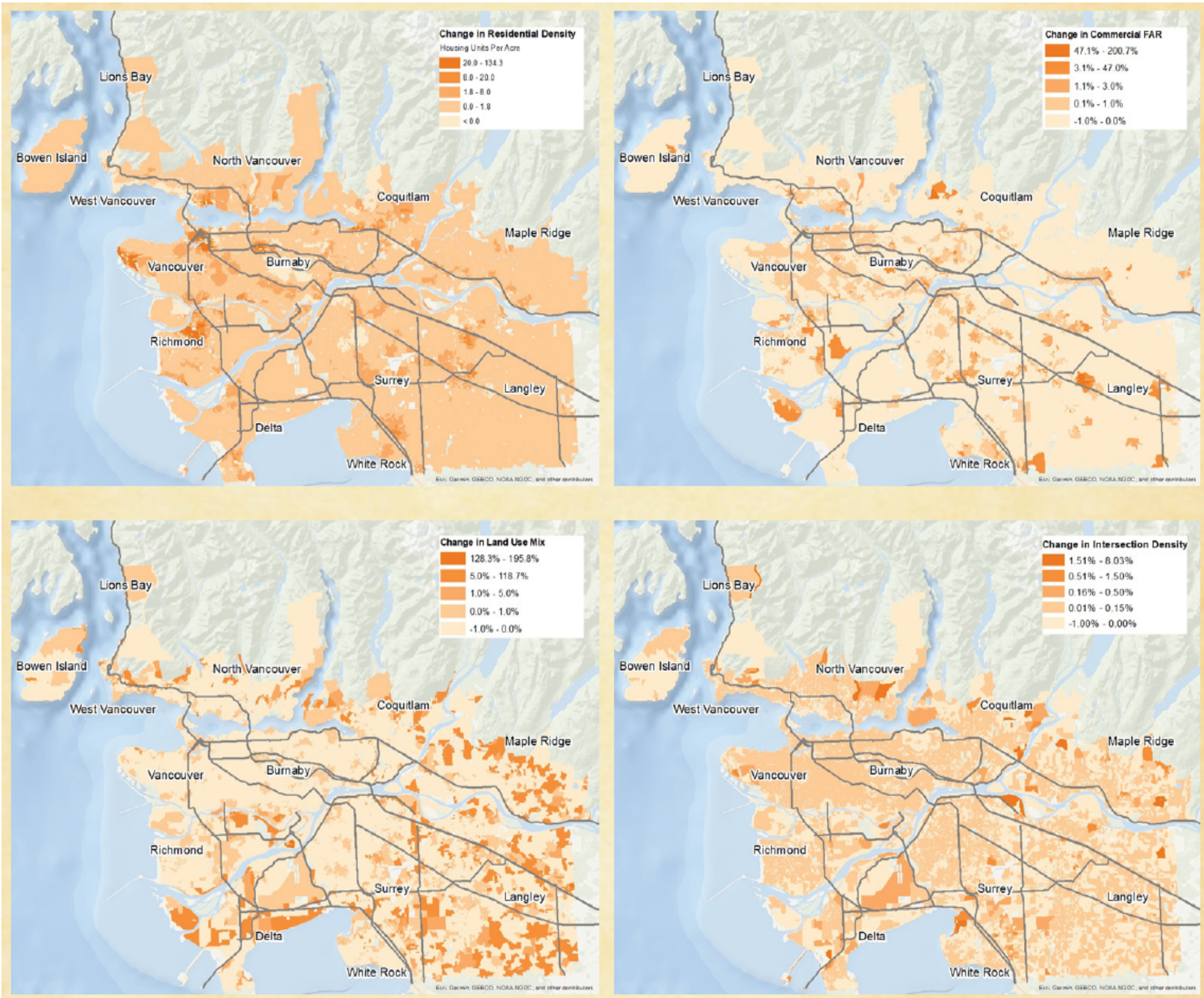


Figure 0-3: Longitudinal changes (2011-2016) by each component of walkability in Metro Vancouver.

Changes in residential density for four key areas experiencing the most population between 2011 and 2016 are shown in Figure 0-4 and include Downtown Richmond, Lonsdale in North Vancouver, False Creek/Olympic Village in Vancouver, and UBC. Similar findings can be mapped and quantified for the other metrics where changes were the greatest.

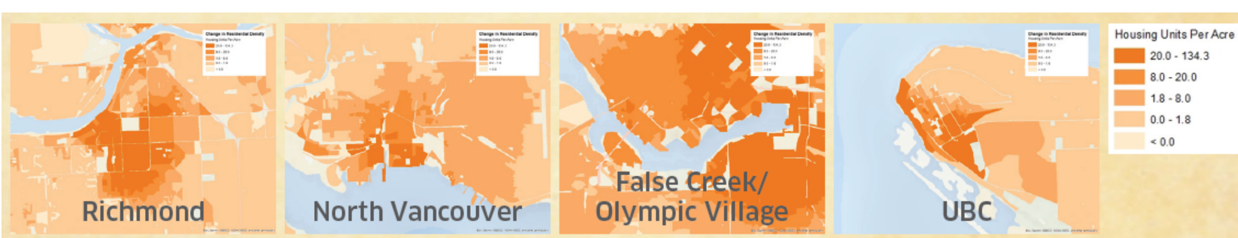


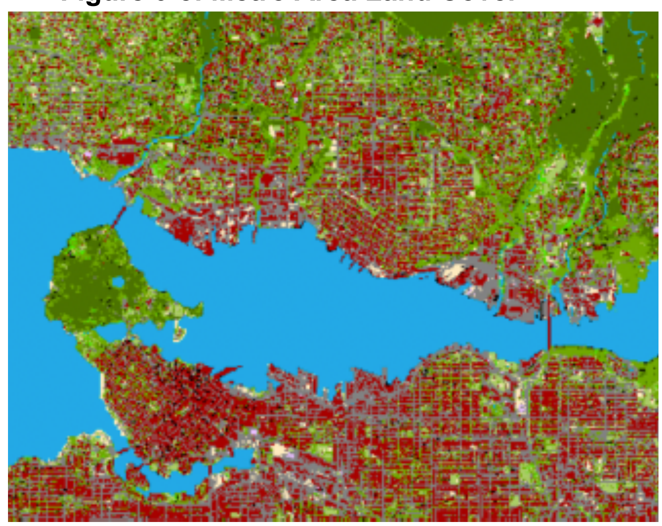
Figure 0-4: Longitudinal changes (2011-2016) in residential density for four key areas in the region.

The Where Matters II conceptual framework (Figure 0-2) and subsequent analyses show that changes in walkability metrics (e.g. residential density) result in changes in travel and related downstream health and GHG outcomes. Increased density creates demand for and proximity to shops and services which increases land use mix. Density and mix along with connected street networks and retail built up to the sidewalk without large surface parking lots (higher retail FAR) supports walking and physical activity, less driving and sedentary time, and reduced vehicle emissions.

A 2021 walkability surface is now being created for Metro Vancouver providing measurement of these same walkability metrics at a 4th time points spanning a 15-year period. Tracking how communities are changing around these key walkability metrics supports the potential for piloting a performance-based approach to transportation funding and once again making the Lower Mainland a global leader in progressive land use and transportation planning. This would explore the prioritization of active transportation and transit funding based on local government achievement of performance-based goals to meet health and GHG reduction objectives. This is a form of performance-based funding that has been used in education and public health and can fuse a stronger link between regionally and provincially led transportation funding with local government-controlled land use planning.

Greenspace Access & Exposure

Figure 0-5: Metro Area Land Cover



Road-based network buffers were developed to analyze Metro Vancouver's Land Cover data layer which allowed us to more accurately measure the proportion of different types of natural and developed land uses accessible to an individual. Three greenspace indicators were utilized for this study: 1) tree canopy coverage, 2) Normalized Difference Vegetation Index (NDVI), and 3) access to developed parks. Metro Vancouver had a median proportion of about 25% tree canopy coverage varying from <1% to 96% coverage[4] at the postal code level. Nearly all postal codes evaluated (98.5%) were within 1 kilometre of a park 1-hectare in size or larger. Seventy-four percent of postal codes had a park at least 1-hectare in size within 400 metres. Greenspace was used to predict physical and mental health outcomes.

Travel & Climate Change

Travel data from TransLink's 2017 travel survey on over 28,000 households containing 200,000 trips reported over a 2-day period was used to evaluate how travel habits and travel-related emissions relate with walkability and other factors. Higher levels of walkability are associated with increased walking and transit use, and fewer motor vehicle

[4] Median tree canopy coverage for the region was 24% for 400 metre buffer neighbourhoods and 26% for 1-kiolmetre buffer neighbourhoods.

trips (Figure 0-6). The proportion of trips by car declined from 92 to 44 percent and walking increased from 5 to 35 percent and transit rose from 3 to 17 percent from the least to the most walkable areas of the region. Chapter 4 results convey that overall relationships between travel patterns and walkability remain significant after controlling for regional accessibility, vehicle ownership, income, and other factors. Results also show that mean per capita vehicle kilometers traveled declined from 11.92 to 5.83 per day from the least to the most walkable areas of the region.

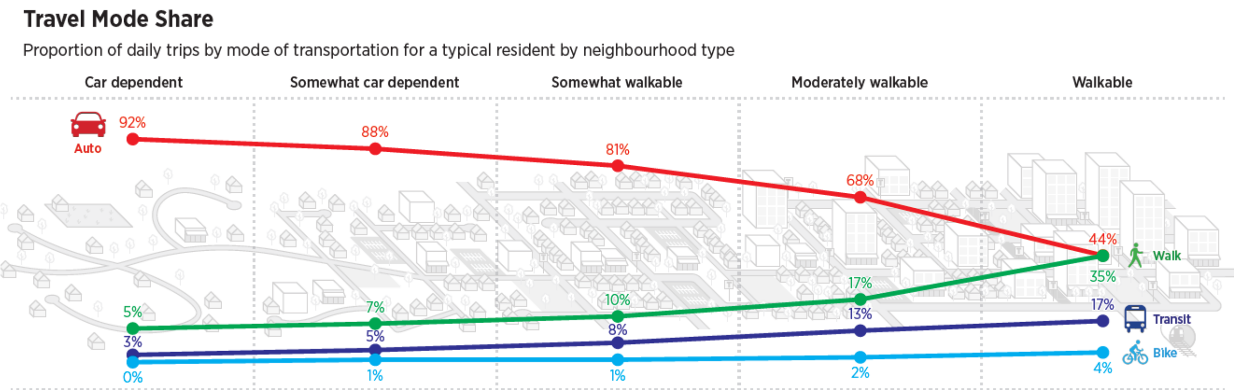


Figure 0-6: Travel mode share by walkability

Time in cars is a sedentary activity while walking and biking are forms of physical activity. Figure 0-7 shows a decline from 37 to 19 minutes of time in cars and a reduction from 23 to 9 kilometres traveled from the least to the most walkable areas. Conversely, walk and bike time rose from 2 to 14 minutes per day from the least to the most walkable areas.

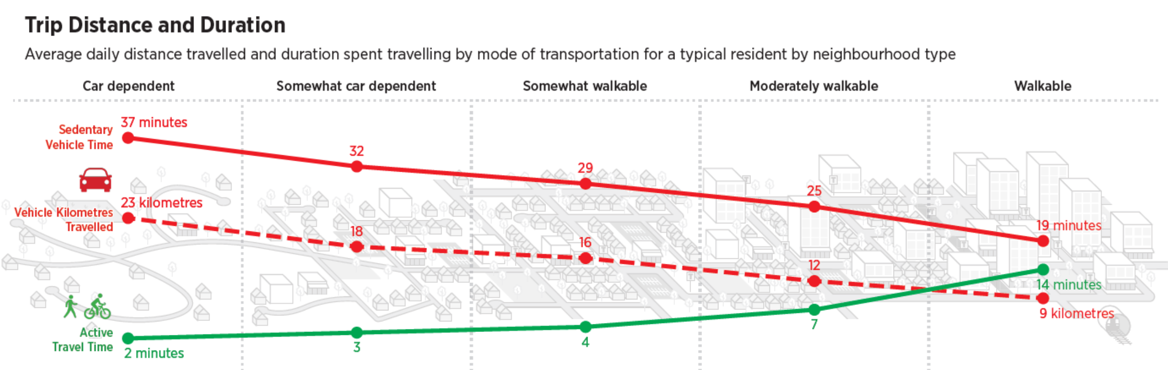


Figure 0-7: Distance and Duration

Comprehensive lifecycle emissions estimates were generated for each reported trip, and models were developed of daily greenhouse gas and local air pollutant emissions, dependent on the same explanatory variables. Model results in Chapter 5 show that emissions were significantly lower in more walkable neighbourhoods when adjusting for regional accessibility, vehicle ownership, income, and other factors. Travel-related GHG emissions declined nearly threefold from 17 to 6 kilograms per person / day (Figure 0-8).

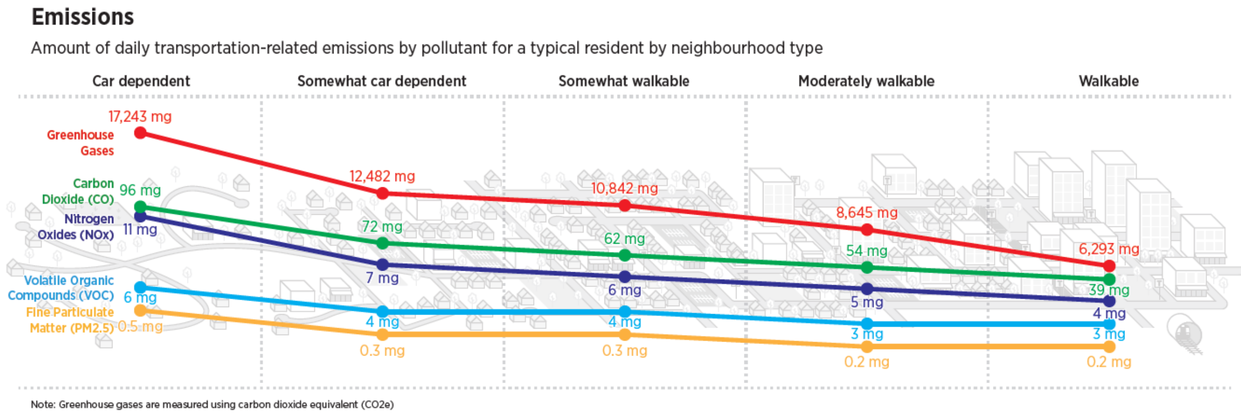


Figure 0-8: Average daily emissions from travel by quintile of walkability

Travel-related vehicle emissions have well-documented adverse health impacts. Where Matters estimated per capita daily travel-related amounts of Volatile Organic Compounds (VOCs), Oxides of Nitrogen (NOx), Small Particulate Matter (PM2.5), and Carbon Monoxide (CO). Overall, those living in walkable areas generated between half to a third as much of these pollutants as those in the most car-dependent areas of the region (see Figure 0-8). CO declined from 96 to 39, NOx declined from 11 to 4, VOC declined from 6 to 3, and PM 2.5 declined from 5 to 2 milligrams per day. Detailed emissions estimates that account for vehicle type and fuel, congestion level, vehicle occupancy, and other key factors.

Community Health Impacts

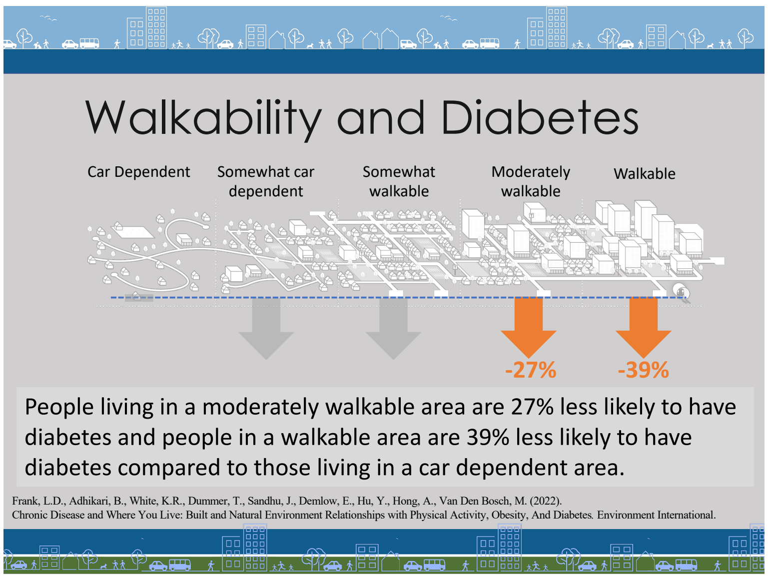
Chronic disease relationships with and impacts of the built and natural environment were estimated using the BC Generations Project (BCGP), a database of 30,000 British Columbians aged 35-69 years which represents. BCGP is a component of the Canadian Partnership for Tomorrow's Health (CanPath) Pan-Canadian prospective health cohort. This dataset was established over the past decade as a research platform for evaluating the genetic, behavioural and environmental causes of cancer and other chronic diseases. BCGP collects health, lifestyle, occupation, residential history, diet and physical activity, socio-demographic, behavioural and health-related data. Walkability datasets were linked with BCGP participants allowing us to investigate the causal impact of exposure to walkable versus car-dependent environments over time and how changes in walkability impact chronic disease and health behaviours.

Obesity, Hypertension & Diabetes

Obesity and obesity-related diseases continue to adversely impact health and economic indicators across low, middle and high income countries. Overweight and obesity are linked to increased risk of numerous chronic conditions including type 2 diabetes mellitus (T2DM) and high blood pressure (HBP), which are leading causes of cardiovascular disease and premature mortality globally. Living in walkable environments has been linked to significantly higher levels of physical activity via active travel. Among the Metro

Vancouver sample, obesity showed a 16% prevalence rate, with 12% being treated for hypertension, and only 2% being treated for type 2 diabetes.

We evaluated how changes in walkability over time impacted obesity. A reduction in the prevalence rate of obesity was observed with increased levels of walkability. **A 1-unit increase in the walkability change score was associated with a 9% reduction in odds of becoming obese.** When compared to the least walkable areas, those participants living in the most walkable areas had a 51% lower odds of becoming obese. This association was further reinforced by now-published evidence from Where Matters I. Figure 0-9 shows residents in the most walkable areas of the region have a 39 percent lower odds of having diabetes compared with those in the most car-dependent areas.



This relationship was tested longitudinally in the current study where change in walkability over a short time frame (5.5 years) was found to be an insufficient duration of exposure to cause downstream chronic health impacts such as type 2 diabetes or hypertension (at the 95% confidence level). However, other studies have begun to document causal relationships.

Figure 0-9: Walkability & Diabetes Risk[5]

Cancer Risk

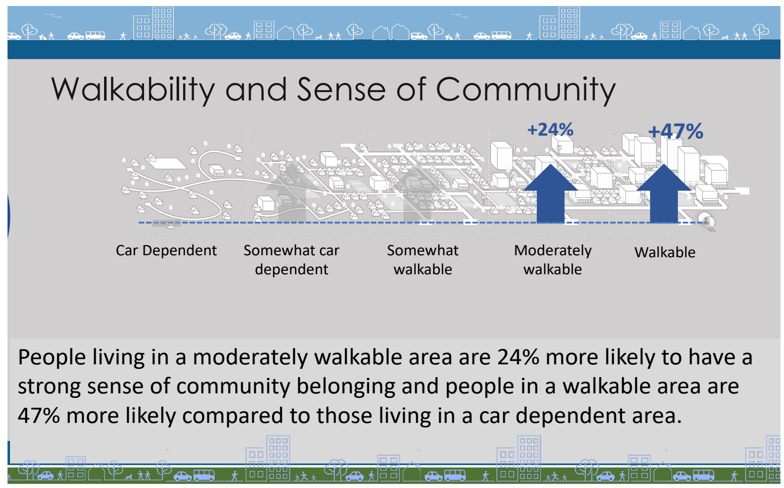
Cancer is the leading cause of death in Canada with lung, breast, colorectal, and prostate cancer accounting for approximately half of the cancer cases diagnosed. Two out of five Canadians are expected to receive a diagnosis of cancer in their lifetime resulting in one in four cancer-related deaths after diagnosis. Despite advances in detection and treatment, lung cancer is the leading cause of death in Canada with a 5-year survival of 19%. Little research has effectively linked built or natural environment features with Cancer outcomes. We found that increases in walkability were linked with decreasing trends for lung cancer hazards while a decreasing trend in risk for colorectal cancer was observed for participants with higher NDVI exposures but neither result was significant at the 95 percent confidence level. Potential protective trends for greenness and walkability were identified for certain cancer types but more research is needed on a larger sample.

[5] Frank, L.D., Adhikari, B., White, K.R., Dummer, T., Sandhu, J., Demlow, E., Hu, Y., Hong, A., Van Den Bosch, M. (2022). Chronic Disease and Where You Live: Built and Natural Environment Relationships with Physical Activity, Obesity, And Diabetes. Environment International. Http://Doi.Org/10.1016/J.Envint.2021.106959

Mental Health and Sense of Community

Mental disorders have a significant impact on the global burden of disease, affecting communities and people of all ages in both high and low-income countries. Sense of community and concern over social isolation has become a major mental issue in recent years.

Figure 0-10: Walkability & Sense of Community



In 2023, the US Surgeon General released a major report on social isolation and similar policy discussions are underway in Canada. Where Matters I found participants living in the most walkable areas of the Vancouver region were 47% more likely to report having a strong sense of community compared with those in the most car-dependent areas. Figure 0-10 reports these statistically significant results.[6] Depression stands as a significant public health issue affecting 344 million individuals globally in 2019, and 4.7% of Canadians aged 15 and older exhibited it in 2012. Anxiety disorders stand as the second most common mental disorder globally, affecting approximately 301 million individuals in 2019, and 14% of Canadians aged 12 in the same year. We did not observe any significant association between walkability and depression.

However, participants in the most walkability areas were 1.74 times more likely to report experiencing anxiety compared to those living in the least walkability areas. Participants living in areas with very high walkability had statistically significant increased odds of experiencing anxiety, even after adjusting for demographic, lifestyle, and health-related variables. These results are counter to results suggesting a higher sense of community and social capital in more walkable areas. More work is needed to understand the underlying mechanisms of this potential relationship and its generalizability.

[6] Results are based on My Health My Community Survey Data Collected by Vancouver Coastal Health Authority. Where Matters I: Health & Economic Impacts of Where We Live, University of British Columbia, 2019.

Summary and Conclusions

Findings presented in this report support GHG reduction and health promotion policies at the Provincial and Regional levels. Transportation and public health constitute two of the biggest Provincial responsibilities and perhaps the largest expenditures. These two issues are interrelated; yet institutionally separated. Both benefit from walkability and are adversely impacted by car dependence. Transportation investment decisions have considerable public health consequences. Results support Metro Vancouver's Regional Growth Strategy and TransLink's Transport 2050: Regional Transportation Strategy. Results further underpin the Ministry of Transportation and Infrastructure's CleanBC Roadmap to 2030. Findings support recently enacted Provincial bills 44, 46 & 47 which include a wide range of actions to increase density across most of BC municipalities primarily in association with transit. Bill 44 requires local governments to amend zoning bylaws to increase permitted density in areas currently zoned single-family or duplexes.

Residents within the more walkable areas of the lower mainland generated a third to half as much emissions as those in the most car-dependent areas and are at lower risk of several obesity-related chronic diseases. However, the most walkable parts of the lower mainland are also the least affordable and the less fortunate are priced out of the places with the best health outcomes. The promotion of walkability as a population health and GHG reduction solution requires mechanisms to make it more affordable to the less fortunate. Chronic disease is concentrated in the most underserved and constitutes a massive economic burden in BC and across Canada.

In 2015, the estimated cost of chronic disease was $7.8 billion and significant portion of the overall provincial budget (BCCDC). Where Matters I documented higher rates of chronic disease in the most car-dependent areas of the lower mainland. The estimated costs of chronic disease are massive. One study by the Chronic Disease Alliance of Canada in 2017 found that the direct cost of Chronic Disease accounts for about 58% of the annual health spending in Canada (CDPAC / APMCC 2017). Transportation and health care constitute two of the biggest Provincial expenditures. Findings from Where Matters I and II studies documents currently externalized direct and indirect health-related impacts and costs of transportation and land development decisions. It presents a dynamic 5-year surveillance approach to quantify and internalize impacts into future decision-making processes.

A broad range of findings presented confirm these relationships built around a dynamic model where changes to walkability over time are captured and related to health and travel-related climate change outcomes. Living in a more walkable environment is associated with generating less harmful emissions, more physical activity, and lower obesity, diabetes, and cardiovascular disease rates. Where Matters provides a model for tracking key features of the physical environment that impact health and climate change – two of the most pressing societal / provincial mandates. Where Matters has measured walkability at the postal code level using parcel-level land use data at what will soon be 4 time points and linked with the census in a consistent manner. This project shows how changes in walkability impact obesity and is presented as a test case. Tracking changes in access to greenspace can also be done consistently over time and along with walkability can be linked with a broader array of travel, emissions, and health outcomes.

Tracking changes in those features of the built and natural environment that logically impact health and climate change is arguably a necessary form of surveillance given the broad array of population-level consequences of these actions. A dynamic change detection framework is presented that can further be used as a decision support tool to guide infrastructure investments and land use actions. A performance-based approach to transportation funding could be introduced whereby at least some portion of investments in transportation infrastructure is awarded based on the achievement of positive changes to the built and natural environment. This concept is presented as one method to further strengthen the link between local government-led land use decisions and regional and provincially-led transportation investment processes.

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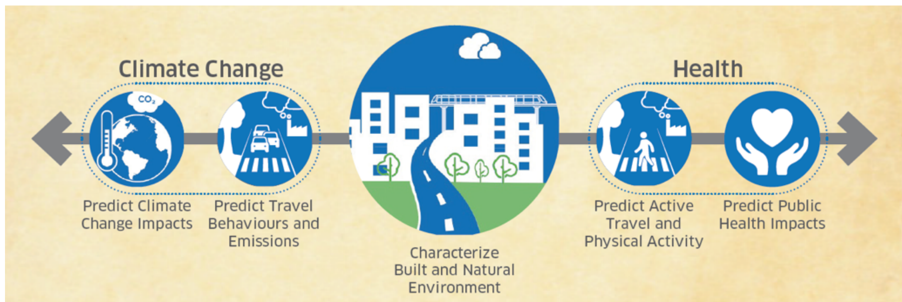
1. Project Purpose & Report Overview

Phase I of the Where Matters study evaluated associations between built and natural environment features and health outcomes from the My Health, My Community (MHMC) survey and the data from the BC Generations project. Phase II aims to connect health with climate change impacts of built and natural environment features and where possible, document causal impacts on chronic disease outcomes. The overall goal is to provide evidence to inform local and regional policy actions by examining the pathways shown in Figure 1-1 linking the built environment, activity patterns, chronic diseases, and mental health. This second phase builds on this work by incorporating more extensive environmental exposure data and additional health outcomes (e.g., cancer incidence). The current study uses spatially linked existing detailed built environment data and integrates a wide range of health-related data from the BC Generations Project.

Figure 1-1: The key goal of the project is to link built and natural environment characteristics with health and climate impacts.



Data linkages were also established with the most recent TransLink Travel Survey to provide detailed information on travel behaviour and emissions. Where Matters II also leverages consistently measured environmental conditions at multiple time points to allow for longitudinal health impact analyses. Results from this study informs and supports policies and strategies mentioned above designed to reduce car dependence by further quantifying reductions in chronic disease and generation of GHG emissions in the Metro Vancouver region. Five different analyses were conducted linking environmental data with travel and vehicle emissions and health outcome data.[7]

[7] Ethics approval from the Behavioral Research Ethics Board of the University of British Columbia was granted to all researchers accessing these unique health and travel behaviour datasets required for this study.

Table 1-1 provides an overview of the organization of the analysis sections included in this report including key outcomes examined and study design characteristics. Additional information on each individual study design and the data sources utilized is reviewed in the research analysis sections of this report. For each study, an accompanying full-length manuscript has been developed in draft form, in process towards publication in leading scientific journals. These manuscripts are included as appendices focused on travel patterns, vehicle emissions, obesity and chronic conditions, cancer, and mental health.

Table 1-1: Summary of organization of analysis sections.

Analyses	Theme	Travel Activity		Health Outcomes		
	Impacts	Impacts on Human Behaviour & Air Quality		Impacts on Human Health		
	Sector	**Travel Behaviour**	**Travel & Emissions**	**Obesity & Chronic Disease**	**Mental Health**	**Cancer**
	Title	The Association Between Built Environment Factors with Active and Sedentary Travel Behaviour	Transportation Emissions Estimates for Integrated Environment-Health Modelling	Longitudinal Adult Associations Between Walkability and Incident Obesity, Hypertension, and Type 2 Diabetes	Multifaceted Impacts of Green Space and Walkability on Mental Health: Depression and Anxiety in Focus	The Effect of Residential Greenness and Walkability on Cancer Risk in the Greater Vancouver Region
	Key Outcomes	Physical Activity, Sedentary Time	Emissions by Mode	Obesity, Hypertension, Type 2 Diabetes	Depression, Anxiety	Cancers: Lung, Breast, Colorectal, Prostate
	Study Design	Cross-Sectional	Cross-Sectional	Longitudinal	Cross-Sectional	Longitudinal
	Report Section	4	5	6	7	8

1.1. Background

Where Matters is a collaboration of researchers and practitioners from health, transportation, and urban planning evaluating potential public health and climate change “co-benefits” from creating walkable communities with access to greenspace. Relationships between the built and natural environment where people live, travel and related vehicle emissions, and the prevalence of physical and mental chronic diseases were evaluated. Health and economic benefits of transit and active transportation strategies and walkable community design are not captured in cost-benefit processes that shape transportation investments.[8]

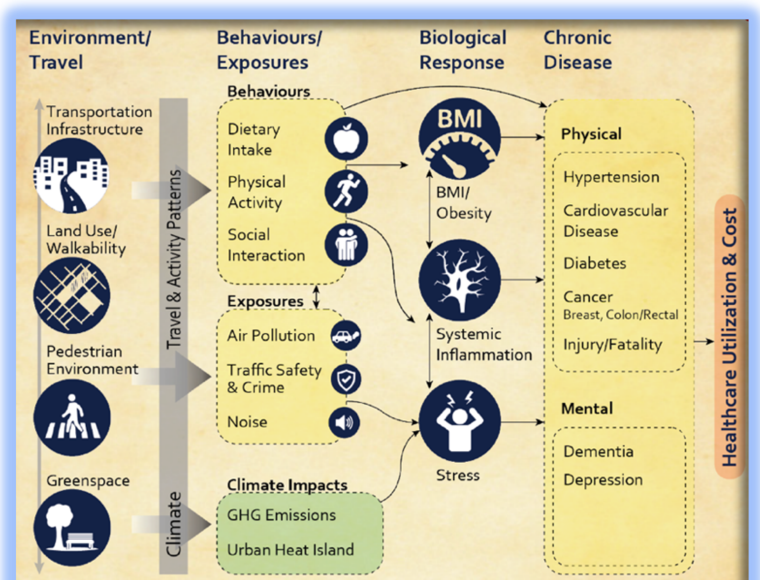


Figure 1-2: provides a conceptual framework used to link built and natural environmental features with behaviours and exposures and climate impacts and their biological responses, chronic disease outcomes, and associated costs.

[8] Adapted From: Frank, L. D., Iroz-Elardo, N., MacLeod, K. E., Hong, A. The pathways from built environment to health: Connecting behavior and exposure-based impacts. 2016. *Journal of Transport and Health.*

1.2. Measuring & Achieving Regional Strategy Goals

Where Matters II is based on a high-resolution, geospatial database of environmental metrics. These environmental metrics are categorized into two broad domains: 1) Built Environment including land use, transportation, and walkability-related measures, and 2) Natural Environment containing a series of measures focusing on access to greenspace including park access and regional vegetative cover. The environmental metrics, developed as part of Where Matters II, provide the opportunity to directly inform the strategic goals and objectives of Metro 2050, Transport 2050, and the CleanBC Strategy.

These data are a resource to Metro Vancouver, TransLink, the Province of British Columbia, and local municipalities. It provides objective measurement to track the success of policies and strategies over time. These data provide detailed information about the distribution of housing, employment, amenities, and services within the region. These data can help planners assess whether communities are 'complete' and identify areas for improvement. Walkability metrics can be enhanced to include measurement of the pedestrian-friendliness of neighbourhoods, including the availability and quality of sidewalks, lighting, street furniture, proximity to amenities, and safety. This can help measure progress toward Metro 2050's goal of creating vibrant neighbourhoods. Metro 2050 and Transport 2050 emphasize importance of sustainable transportation choices, regional accessibility, and effectiveness of transit-oriented development strategies.

The database resource included as part of Where Matters II can be used to directly measure the impact of Metro 2050 by comparing the current state of the region with the goals outlined in the strategy. For example, Metro 2050 includes regional targets such as protecting over half of the land base for nature, expanding tree canopy cover in urbanized areas, and ensuring minimum standards for new and redeveloped housing units in urban centres and frequent transit development areas are affordable, and prioritizing rental housing. These geospatial data can provide a quantitative measure of progress towards these targets and can consistently track changes in environmental conditions over time. These data were added to the Performance Monitoring Dashboard[9] used by Metro Vancouver to track changes in key metrics over time.

Study results from Where Matters I were used to support Metro Vancouver's 30-year plan: Regional Greenways 2050.[10] The plan maps out 830 kilometres of greenways, connecting with other multi-use corridors, such as TransLink's major bike network and municipal greenways. The results from Where Matters I showed that proximity to green space or parks is associated with less chronic disease and lower health care costs. In summary, accurate, high-resolution geospatial data is a powerful tool for measuring the success of Metro 2050. It provides a wealth of information that can be used to assess progress toward the strategy's goals and objectives and to guide future planning decisions. By providing a clear picture of the current state of the region, this data can ensure that Metro Vancouver continues to move towards a more sustainable, equitable, and livable future.

[9] Performance Monitoring Dashboard, Metro Vancouver, 2023.
[10] Regional Greenways 2050, Metro Vancouver, 2020.

1.3. Policy Framework: Regional & Provincial Strategies

1.3.1. Metro Vancouver Regional Growth Strategy

As the main governing body in the region responsible for land use, Metro Vancouver is mandated with developing, maintaining, and updating the Regional Growth Strategy. The Metro Vancouver Regional Growth Strategy, known as Metro 2050[11], is a long-range, strategic land use plan aimed at advancing the region's livability and sustainability goals and preparing for anticipated future growth. Led by Metro Vancouver, a collaborative development process was used to craft the Regional Growth Strategy (RGS) which includes extensive engagement and interaction with all member municipalities, TransLink, Provincial ministries, First Nations, and other regional organizations.

Metro 2050 provides a framework for concentrating growth into compact, walkable, complete communities, that rely on transit-oriented development, and a range of accessible housing choices that are close to jobs, amenities, and services. The strategy aligns projected long-term growth with transportation and infrastructure planning while protecting agricultural, rural, ecologically sensitive, and industrial lands. The strategy has five regional goals which are supported by corresponding strategies and policy actions: 1) Create a Compact Urban Area, 2) Support a Sustainable Economy, 3) Protect the Environment, 4) Respond to Climate Change Impacts, and 5) Enhance Community Well-being. The RGS aims to shape long-term growth and development in the region in a way that protects the natural environment, fuels economic prosperity, provides diverse and affordable housing choices, ensures the efficient provision of utilities and transit, reduces greenhouse gas emissions, improves resilience to climate change and natural hazards.

1.3.2. Metro Vancouver Regional Transportation Strategy

As the main governing body in the region responsible for transportation, TransLink has led the development of the Regional Transportation Strategy. The Metro Vancouver Transportation Strategy, known as Transport 2050 is a comprehensive plan that outlines the region's vision for sustainable transportation over the next 30 years. The strategy closely integrates with Metro 2050 while maintaining a focus on the transportation sector. As with Metro 2050, Transport 2050, was developed in direct collaboration with member municipalities in the region, Metro Vancouver, provincial ministries, First Nations, and other regional organizations. The vision for Transport 2050 is to create a future where every person in the region can easily access the people, places, and opportunities they need to prosper. Transport 2050 aims to provide transportation choices that are reliable, affordable, safe, comfortable, and carbon-free. The key goals of Transport 2050 include: 1) Expansion of the Rapid Transit Network, 2) Completing a Major Bikeway Network, 3) Promoting the Use of Electric and Shared Vehicles, and 4) Goods Movement that Supports Sustainable Economic Growth. The main initiatives in the strategy aim to bolster the current bike network and support the development of traffic-calmed streets for walking, biking, rolling, and transit.

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[11] Metro 2050: The Regional Growth Strategy, Metro Vancouver, 2023.

1.3.3. Province of British Columbia CleanBC Strategy

The Ministry of Transportation & Infrastructure plays an important role in guiding strategic province-wide goals and providing support tools and investment for municipalities to help reach these goals. One of the key guiding strategies developed by the province is the CleanBC Strategy[12]. The CleanBC Strategy is a comprehensive approach by the province of British Columbia to reduce greenhouse gas emissions and build a sustainable, low-carbon economy.

The Ministry of Transportation has emphasized the importance of supporting active transportation uptake in BC as a key component in reducing greenhouse gas emissions.[13] The Ministry is working towards making active transportation an accessible and safe option for more people, thereby reducing carbon pollution, and building healthier communities. Some of the key initiatives include: 1) investing over $60 million over the next three years to help communities build over 400 active transportation projects, including new paths, bike lanes and crosswalks across the province, 2) working with communities to create policies and plans that enable and support complete active transportation networks, and 3) developing the Clean Transportation Action Plan for 2023[14] focusing on five pillars: reducing distance traveled, increasing mode shift, improving vehicle efficiency, adopting zero-emission vehicles, and using clean fuels.

In summary, the CleanBC Strategy, with its focus on active transportation, represents a significant step towards achieving a sustainable, low-carbon future for British Columbia. The Ministry of Transportation and Infrastructure's commitment to investing in active transportation infrastructure is a testament to the province's dedication to achieving the strategic goals and objectives of CleanBC.

1.3.4. Changes in Regulatory Approaches

Over the past couple of years, the regulatory landscape regarding land-use planning in BC has undergone significant and far-reaching changes. The provincial government, with the enactment of Bills 44, 46, and 47 and other measures, now has the power to override municipal authority in land-use planning and promote densification across municipalities. The new legislation, which applies to municipalities with a population over 5,000, mandates amendments to zoning bylaws to increase densification, introduces new development financing tools, and designates transit-oriented development areas. These initiatives align with the Homes for People action plan, aiming to streamline housing delivery and eliminate restrictive zoning policies. Additionally, the province emphasizes active transportation and public transit infrastructure investments to meet emission reduction targets, collaborating with municipalities and federal programs such as the Active Transportation Fund. However, there is a need to balance densification efforts with the preservation of greenspaces and urban tree canopy cover, which may require regulatory mandates, incentives, and coordination between government levels to ensure

[12] CleanBC: Roadmap to 2030, Province of British Columbia, 2021.
[13] Active Transportation, Ministry of Transportation & Infrastructure, Province of BC, 2023.
[14] Clean Transportation Action Plan, Province of British Columbia, 2023.

sustainable development. The remaining report is organized in the following sections and then followed by several appendices:

- Community Design Characteristics
  - Built Environment (Walkability)
  - Natural Environment (Greenspace)

- Travel & Climate Impacts
  - Travel Behaviour with Walkability
  - Greenhouse Gas Emissions with Walkability

- Health Impacts
  - Obesity, Diabetes & Hypertension with Walkability
  - Mental Health with Walkability & Greenspace
  - Cancer Risks with Walkability & Greenspace

- Regulatory & Fiscal Approaches

2. Tracking Change in Walkability and Regional Accessibility[15]

2.1. The Walkability Index

Walkability is one of the key independent variables in communities by which we are analyzing health outcomes in *Where Matters II.* Walkability is a measure of the physical characteristics of the urban environment at the neighbourhood level that support walking. The Walkability Index is a composite measure of neighbourhood walkability capturing proximity to and connectivity between destinations and their composition and is comprised of four equality-weighted main component measures[16]: 1) net residential density, 2) commercial floor space ratio (FSR) or floor area ratio (FAR), 3) land use mix, and 4) intersection density.

Net Residential Density: The concentration of dwelling units. Higher values indicate a greater number of dwelling units relative to residential land area.

Commercial Floor Area Ratio (FAR): The ratio between the total commercial floor area of a building to the land area of the property it is built on. Higher values indicate less surface parking and buildings set close to sidewalks and the street.

Land Use Mix: The balance between building floor areas of six land uses (retail, entertainment/recreation, civic/educational, office, single family and multi-family residential), providing more opportunities for different activities in the same neighbourhood.

Intersection Density: Measures route directness. Higher values indicate smaller block lengths and a greater number of intersections and shorter distances.

Sidewalk Coverage: Measures the proportion of local street network within a walkable distance (1 km) with sidewalks on one or both sides of the street.

These measures were calculated for every postal code (appx 60,000) in Metro Vancouver at 3 time points thus far. The calculations were conducted within a 1-kilometre road network buffer from postal code centroids, following a walkable road network. Measures were created for each postal code in Metro Vancouver as shown in Figure 2.1.

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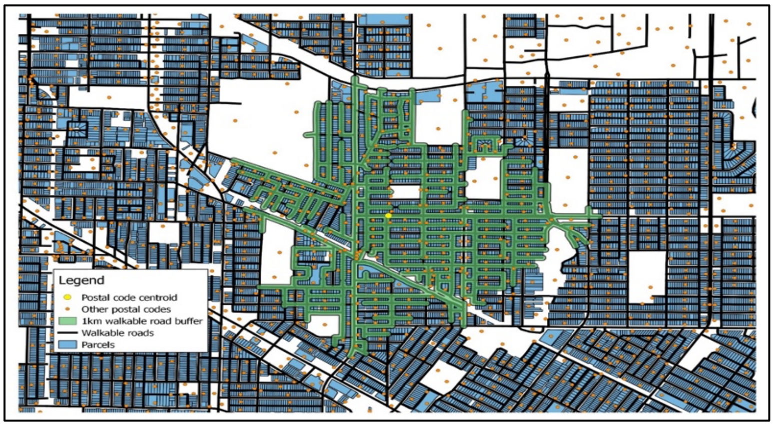
[15] For more details on the development of the walkability surface, please see Appendix B.

[16] Different combinations of component measures may comprise the walkability index. For instance, Where Matters II also utilized a secondary walkability index that also included the percentage of sidewalk coverage. Several iterations of the land use mix may be used that typically include between four and six land use types. In some instances, some component measures may also be weighted over others.

Figure 2-1: Network-based buffer area used to calculate the walkability index.



The network buffers are then used to capture each component measure, which are then converted to standardized value (z-scores) which allows them to be summed into a composite walkability index. Figure 2-2 shows a map of the change in walkability from 2006-2016. The final walkability index is the amalgam of a normalized z-score value for each component measure. Each of these walkability metrics are highly correlated with each other making the effect of each component on travel, health, and emissions difficult to isolate from another. This creates the need to roll them into an index to enable statistical analyses to proceed. Arguably, each of these features align with other factors and work as a system to shape travel and activity pattern.

The most walkable places in the region have a mix of housing types ranging from moderate to denser residential development, retail stores, and highly connected streets; also known as complete communities within a 15-minute travel time on foot via compact mixed-use development.

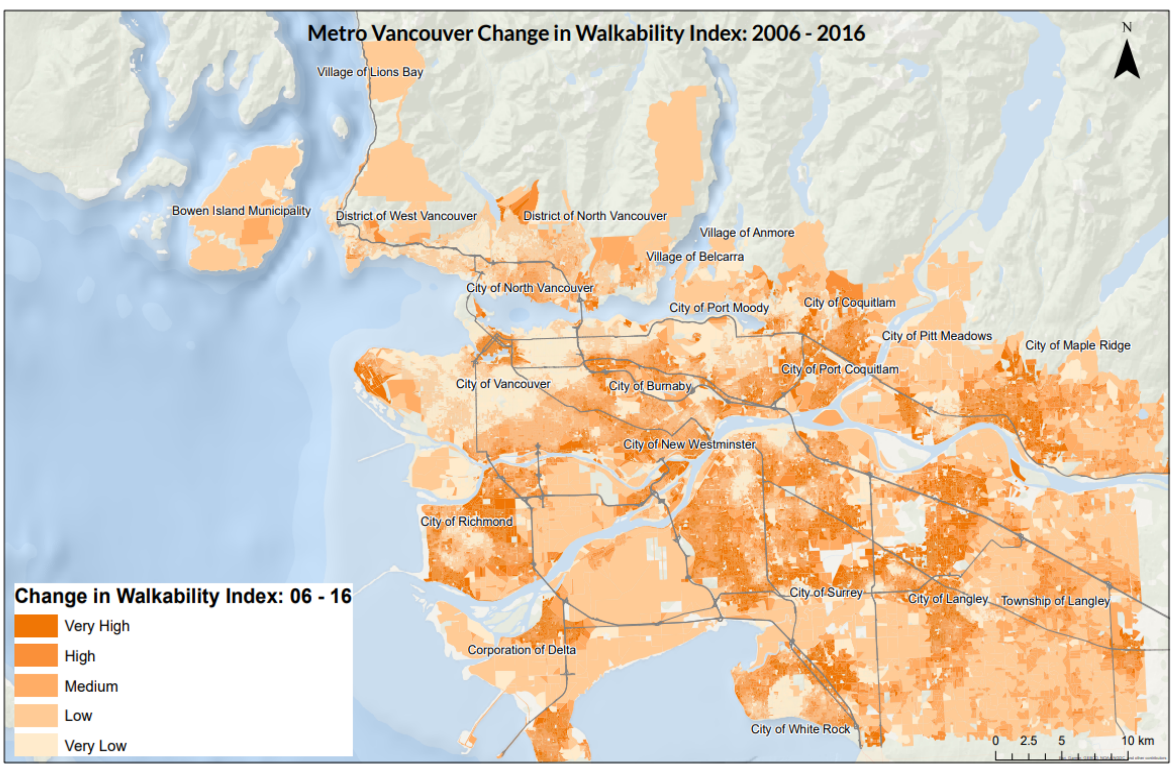


Figure 2-2: Change in the walkability index (2006-2016) in Metro Vancouver.

Figure 2-3 lays out a continuum from the most car dependent to the most walkable areas of the region along with aerial and street level images.

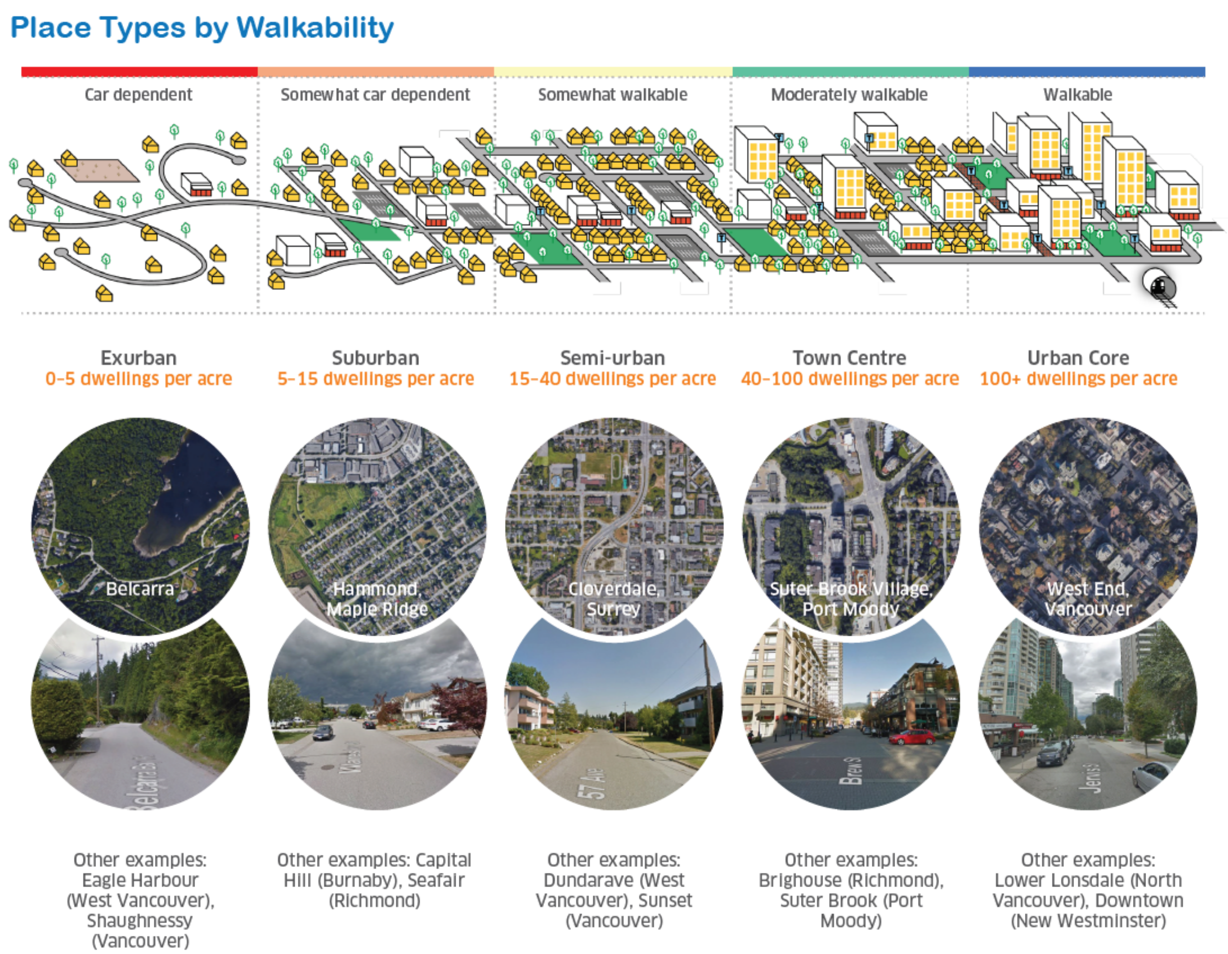


Figure 2-3: Continuum of walkability across five place types in Metro Vancouver.

2.2. Defining the Neighbourhood

Conceptualization and consistent definition of a neighbourhood boundary are important when creating a built environment metric using spatial data. This is primarily because of the Modifiable Area Unit Problem (MAUP). The MAUP arises when there is variation in the results of a spatial analysis based on the spatial unit used to collect the data. In the creation of each walkability index, this is explicitly addressed using spatial units derived from a walkable road network and consistent buffering techniques. Each postal code is given a 1-kilometre neighbourhood or walkshed using a network buffer, which corresponds to 10 to 15 minutes of walking time (Colabianchi et al., 2007). This boundary is defined by a network buffer that travels along a closely matched and updated walkable road network for each study year.

The figure below shows the approach used to define neighbourhood boundaries for 2006, 2011 and 2016 walkability indices using the 1km distance. In all three indices, street network buffers were used instead of a crow-fly (also called straight line) distance buffer. Street network buffers represent the actual built environment experienced by the pedestrian as they follow a road network that is known to be accessible by walking.

2.3. Longitudinal Walkability Data

With three waves (2006, 2011, 2016) of the walkability index completed using the methods outlined above, the longitudinal analysis of changes in the built environment in the Metro Vancouver region has become possible. This begins with the construction of a walkable road network. All roads that are not walkable by a pedestrian are removed from the road network to accurately reflect the pedestrian environment. Data from BC Assessment reflecting development across the region is then cleaned and analyzed to facilitate the calculation of the land-use mix, commercial floor area, and net residential density variables. The walkable neighbourhood for each postal code is then defined by a network buffer that travels along the walkable road network and measures intersection density, land-use mix, commercial floor area, and net residential density. Using these methods has allowed the comparison of neighbourhoods in the Metro Vancouver Region at the postal code level through the linkage of each postal code through a unique identifier.

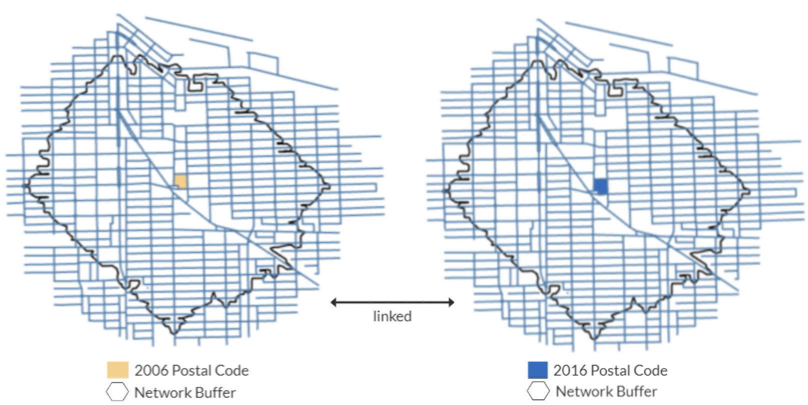


Figure 2-4 Linkage of Postal Code Level Walkability Measures

Assessing the longitudinal changes in walkability in Metro Vancouver is done using two methods. The first looks at the difference in each component measure from 2006 to 2016. Using this method, the change in each built environment variable of land use mix, commercial floor area ratio, net residential density, and intersection density is shown in absolute terms. The second method uses the changes in each component measure and normalizes each across 2006, 2011, and 2016, to create a walkability index using the grand mean and standard deviation of the entire dataset. The combined z-scores of each component measure are added together to create a normalized distribution of walkability from 2006, 2011, and 2016 that can be compared (See Appendix B for more details on the methodological development of the Metro Vancouver walkability surface). For each section below, changes between 2011-2016 are highlighted (for more detailed maps and descriptions of changes between 2006-2011 and 2006-2016 see Appendix B).

Table 2-1 provides a summary of the average Metro Vancouver regional values for each core component of walkability for 2006, 2011 and 2016. Each of the components show an increasing trend at subsequent time points with the section of a slight reduction in land use mix in 2016. In general, larger increasing trends in some components of walkability, such as intersection density and net residential density, were exhibited between 2006 and 2011, while others such as commercial FAR showed more consistent growth trends between both 2006-2011 and 2011-2016.

Table 2-1: Summary of average walkability component values for Metro Vancouver in 2006, 2011 and 2016.

Community Design Characteristic	Year		
	2006	2011	2016
Intersection Density (intersections/sq. km.)	45	63	65
Net Residential Density (units/acre)	10	16	18
Commercial FAR	0.345	0.348	0.350
Land Use Mix	0.275	0.375	0.325

The section that follows provides more detail on the changes in each component of walkability over time.

2.3.1. Intersection Density

The road network defines how we navigate the GVRD, what is accessible, and where development is happening. The road network in many areas of Metro Vancouver is well-established, gridded and many decades old. However, changes in land use patterns, especially in outlying suburban areas, have spurred changes reducing connectivity in the network structure. Major developments can require new roads to access housing, amenities, and the rest of the region. This is reflected in the changes in intersection density over the 10 years between 2006 and 2016 which have gone from a regional average of 45 intersections per kilometre in 2006 to 65 in 2016.

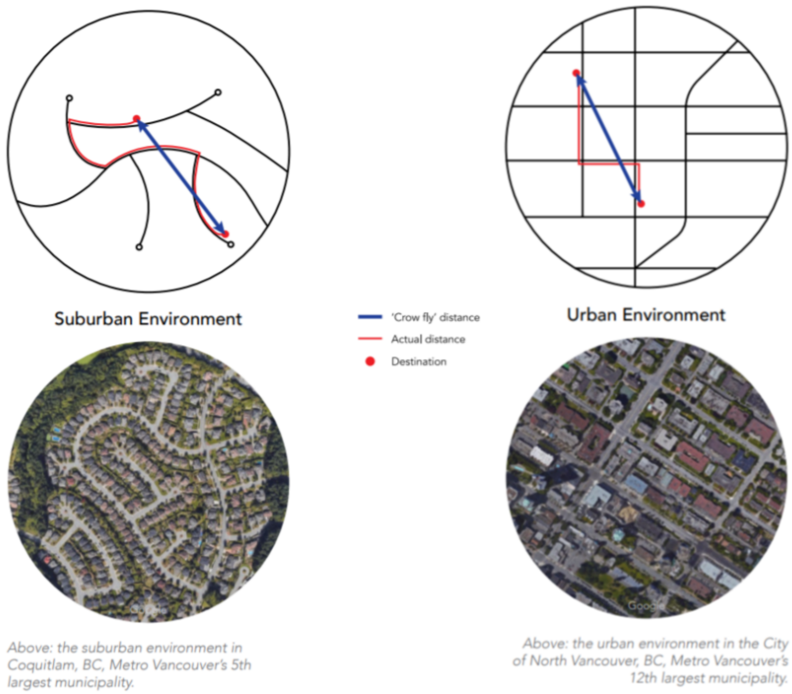


Figure 2-5 Description of Intersection Density

Intersection density is beginning to show a plateauing trend which may be attributed to stagnating greenfield development and new road building in the region. Many of the areas experiencing major development across the region such as Olympic Village and the Cambie corridor are infill or densification projects that require relatively limited changes to the road network. These areas already have a high road connectivity.

Many of the significant changes in intersection density across Metro Vancouver between 2006 to 2011 were in suburban areas of the region. Then from 2011-2016 the map shows that there is far less change across the region, especially in the suburban areas (Figure 2-6). Looking at the differing rates of intersection density change across the member jurisdictions, we can see that the suburban areas have experienced higher increases. Improved intersection density in rural areas may indicate suburban subdivisions which may have low connectivity even if increasing over time. It is also important to remember that some areas of the region, especially those designated for agricultural lands, are not intended for urban development.

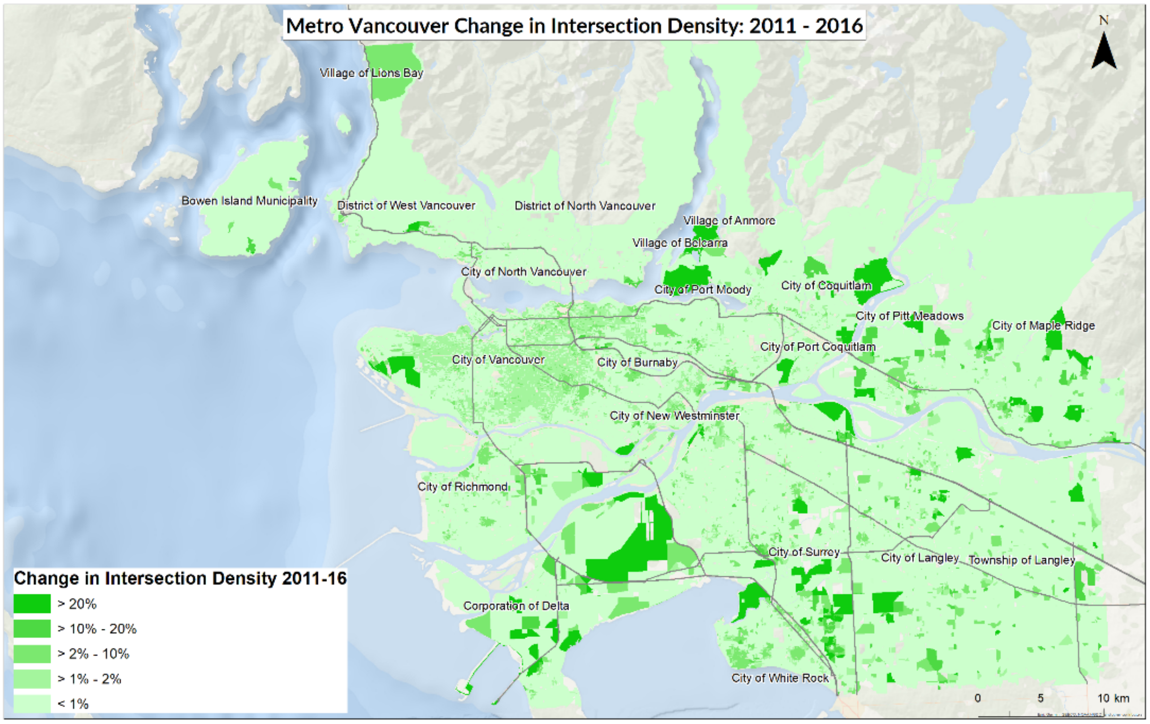
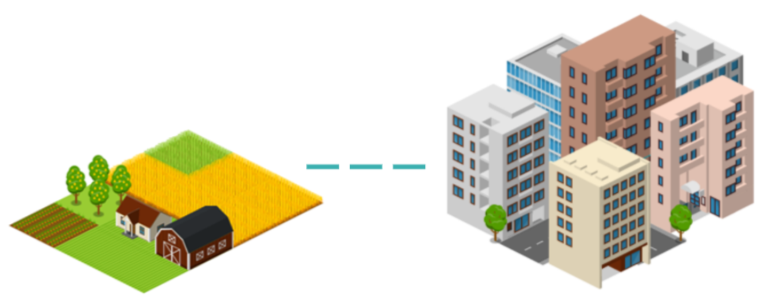


Figure 2-6: Change in Intersection Density 2011-2016

2.4. Net Residential Density

Residential compactness is one of the hallmarks of urban areas. Dense urban forms allow for more agglomeration of goods and services while facilitating social interaction and well-connected transportation networks.



Net residential density has continued on an upward trajectory from 2006-2016 (Figure 2-7). This can be attributed to increasing density in the urban areas of Metro Vancouver and residential development in the suburbs. Places such as the City of North Vancouver, Port Moody, the UBC Main Campus, Richmond, and Vancouver show some of the highest increases in net residential density from 2011 – 2016.

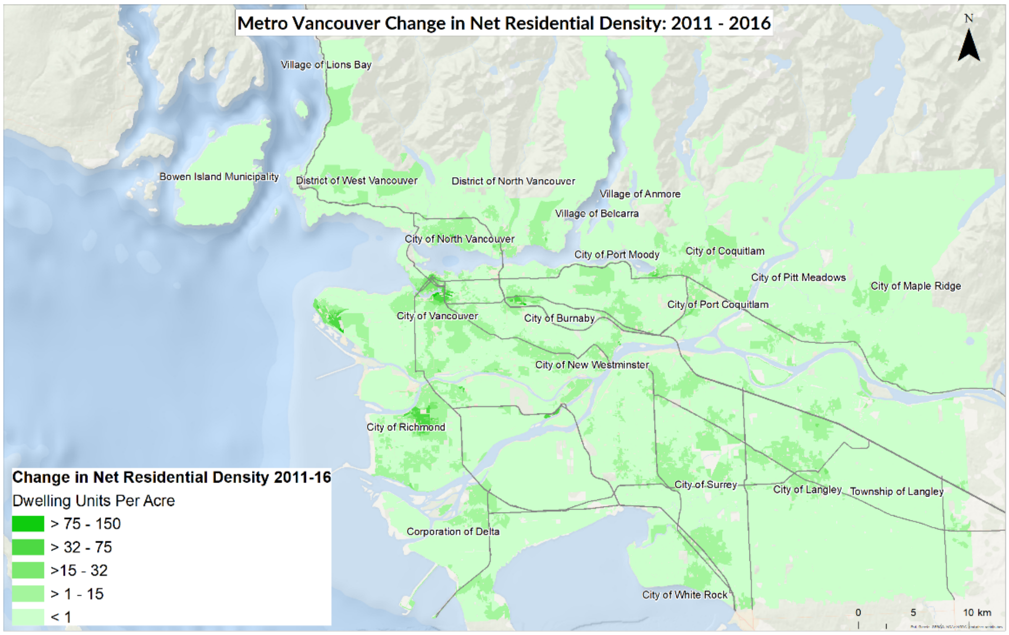
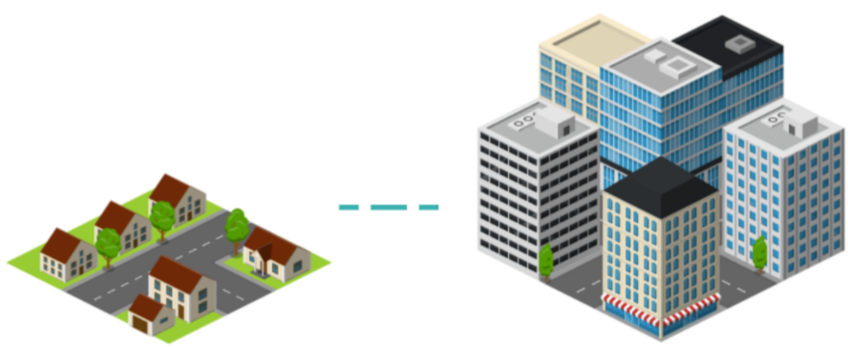


Figure 2-7: Change in Net Residential Density 2011-2016

2.4.1. Commercial Floor Area (FAR)

Commercial floor rea ratio (FAR) of a neighbourhood describes the intensity of commercial development. Neighbourhoods with high commercial FAR are generally more urban, have reduced parking and are typically orientated towards more neighbourhood retail allowing residents to easily access goods and amenities.



Regionally, commercial FAR has stayed at a consistent level on average. From 2006 to 2016 it is showing a levelling off trend which could be attributed to widespread increases across the metro region from before 2006 and through to 2011. This indicates that much of the land use that is commercial in the region had been zoned to this use early in the development of the region. From 2006 – 2011 the region experienced the highest rates of change for each component measure, in many of the same areas, which could indicate a period of development in which commercial, residential, and road network development were completed in tandem.

From 2011-2016, the highest rates of changes in commercial FAR were no longer in the most urban areas of Metro Vancouver (Figure 2-8). Many of the largest changes were experienced in concentrated areas in Surrey, the City of Langley, Tsawwassen, and the City of North Vancouver. This is reflected when looking at the differing levels of change in the Member Jurisdictions of Metro Vancouver.

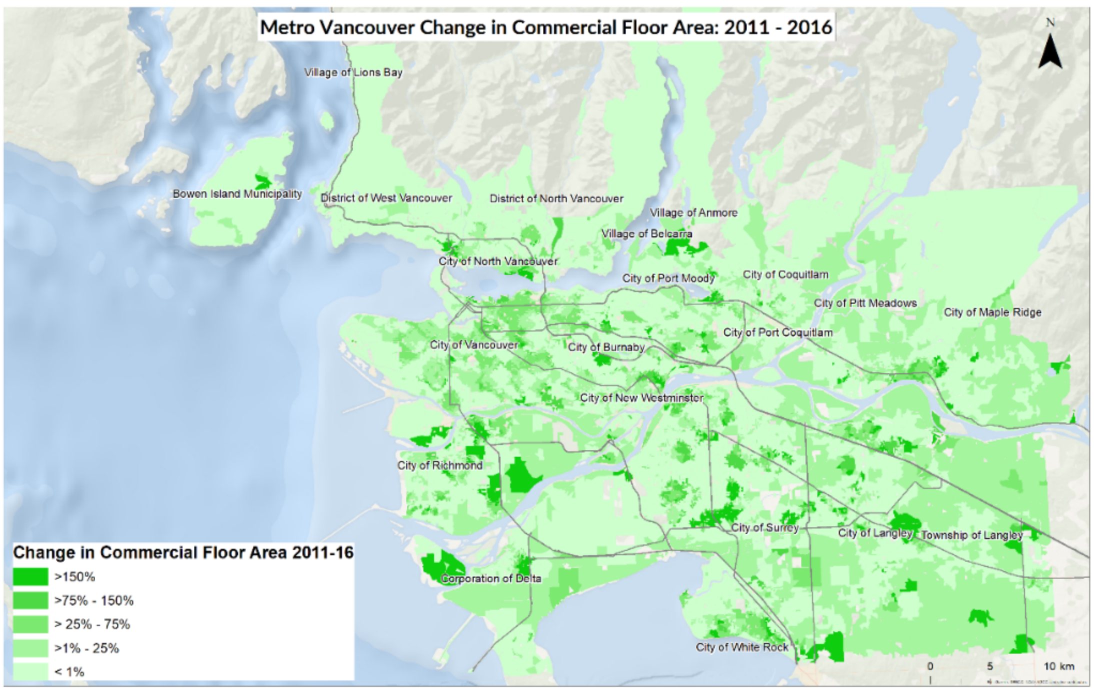


Figure 2-8: Change in Commercial FAR 2011-2016

2.4.2. Land Use Mix

Think of some of your favorite places to visit and walk around. Many of the neighbourhoods you thought of probably have a variety of businesses, amenities, and residences. This is what land use mix measures. Land Use Mix shows the evenness of square footage distribution across residential, commercial (including retail and services), entertainment, and office development within a neighbourhood buffer.

From 2006 to 2011 the changes in land use mix show that development across the region in these land use types became more balanced (Figure 2-9). This indicates that within a neighbourhood, new development included retail, residential, office, and entertainment land uses more equally. This can be seen in the trajectory of change in the land use mix measure as well as the consistent upward trend of commercial FAR and net residential density from 2006-2011.

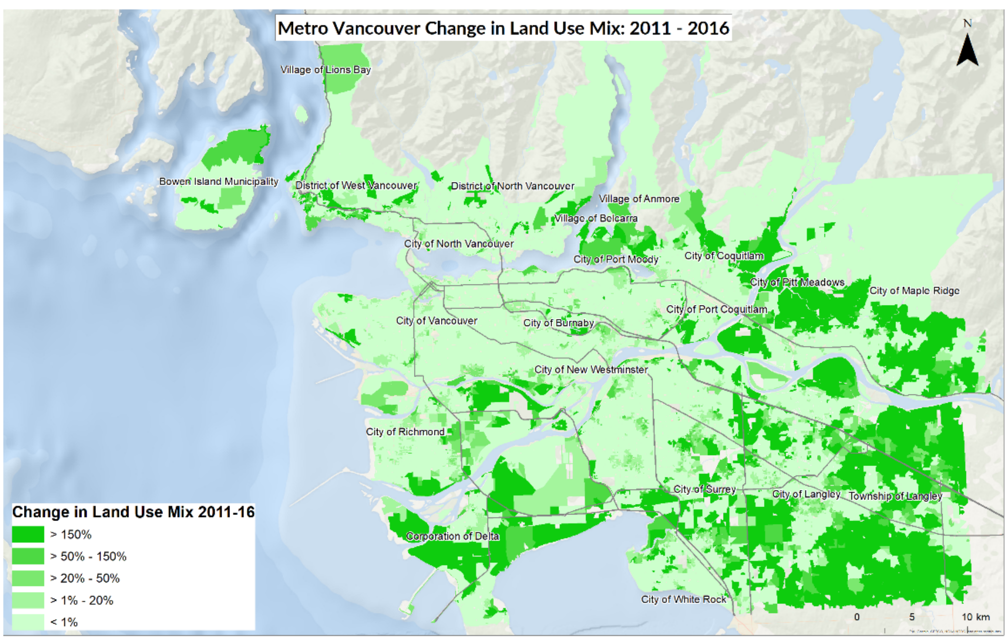


Figure 2-9: Change in Land Use Mix 2011-2016

Figure 2-9 shows that changes in land use mix from 2011 – 2016 have shifted into the southern and easternmost suburban areas where greenfield development of communities is still possible. Elsewhere in the region, changes in net residential density have kept a modest pace while commercial FAR has begun to plateau. This explains the downward trajectory of land use mix from 2011-2016 as the intensification of one land use type over another result in a less even distribution within a neighbourhood buffer. Further, denser urban forms such as apartment buildings with ground-level retail and residences above can result in lower land use mix scores due to the increases in residential density.

2.5. Regional Accessibility

The Walkability Index describes neighbourhood level local accessibility but does not address accessing destinations beyond a 15–20-minute walk. A definition of describing Regional Accessibility is required to analyze how disparate areas of the region are connected. Both local and regional accessibility impact travel and activity patterns. Using Generalized Transit Feed Specification (GTFS) data from TransLink average travel times for auto and transit at peak AM and mid-day times were determined for the region for 2011 and 2016. These travel times are based on a variety of regional destinations and include Metro Vancouver Regional Growth Strategy destinations (Figure 2-10), those determined by the Health and Community Design Lab (HCDL), and Metro Vancouver and UBC destinations combined. Additional destinations (Figure 2-11) were added by the HCDL based on their importance to regional transportation using criteria such as volume and proximity to regional centers. An example of this is the Commercial Drive Station transportation hub which is one of the most heavily used transit corridors in the region[17]. The destinations are outlined in the tables below.

[17] TransLink. (n.d.). 2019 TSPR - Rail Summaries [Interactive]. Tableau Public. Retrieved August 12, 2021, from https://public.tableau.com/app/profile/translink/viz/2019TSPR-RailSummaries/TableofContents

#	Destination Name	Municipality	Type
1	Downtown Vancouver	Vancouver	Metropolitan Core
2	Surrey Centre	Surrey	Suburban Metro Core
3	Oakridge	Vancouver	Municipal Town Centre
4	Metrotown	Burnaby	Regional City Centre
5	Columbia Skytrain	New Westminster	Regional City Centre
6	Richmond Brighouse	Richmond	Regional City Centre
7	Lonsdale Quay	North Vancouver	Regional City Centre
8	Brentwood Town Centre	Burnaby	Municipal Town Centre
9	Lougheed Town Centre	Burnaby	Municipal Town Centre
10	Coquitlam Town Centre	Coquitlam	Regional City Centre
11	Edmonds	Burnaby	Municipal Town Centre
12	Newton	Surrey	Municipal Town Centre
13	Guildford Town Centre	Surrey	Municipal Town Centre
14	Willowbrook Centre	Langley City	Regional City Centre
15	Downtown Port Moody	Port Moody	Municipal Town Centre
16	Downtown Port Coquitlam	Port Coquitlam	Municipal Town Centre
17	Downtown Maple Ridge	Maple Ridge	Regional City Centre
18	Fleetwood	Surrey	Municipal Town Centre
19	Downtown Pitt Meadows	Pitt Meadows	Municipal Town Centre
20	Ambleside	West Vancouver	Municipal Town Centre
21	Lynn Valley Centre	DNV	Municipal Town Centre
22	Semiahmoo Centre	White Rock	Municipal Town Centre
23	Cloverdale	Surrey	Municipal Town Centre
24	Aldergrove Centre Mall	Township of Langley	Municipal Town Centre
25	Ladner	Delta	Municipal Town Centre
26	Willoughby	Township of Langley	Municipal Town Centre

Figure 2-10: Metro Vancouver Regional Growth Strategy Destinations

#	Destination Name	Municipality	Type
1	Commercial Dr. Station	Vancouver	Transportation Hub
2	Central Broadway	Vancouver	Transportation Hub
3	UBC	UEL	Educational
4	YVR	Richmond	Transportation Hub
5	Clearbrook	Abbotsford	Regional City Centre
6	Cottonwood Centre	Chilliwack	Municipal Town Centre
7	Mission City	Mission	Municipal Town Centre

Figure 2-11: Health & Community Design Lab Regional Growth Strategy Destinations

To calculate the travel times for each postal code, travel times acquired from the GTFS data were linked to each postal code based on the traffic analysis zone it falls within. The travel times for each destination were then aggregated and divided by the total number of destinations to arrive at mean AM and mid-day travel times for auto and transit. The resulting travel times for all Metro Vancouver and Health and Community Design Lab destinations are visualized in maps below (Figure 2-12 and Figure 2-13).

2016 Regional Accessibility: Mean AM Transit Travel Time to All Destinations

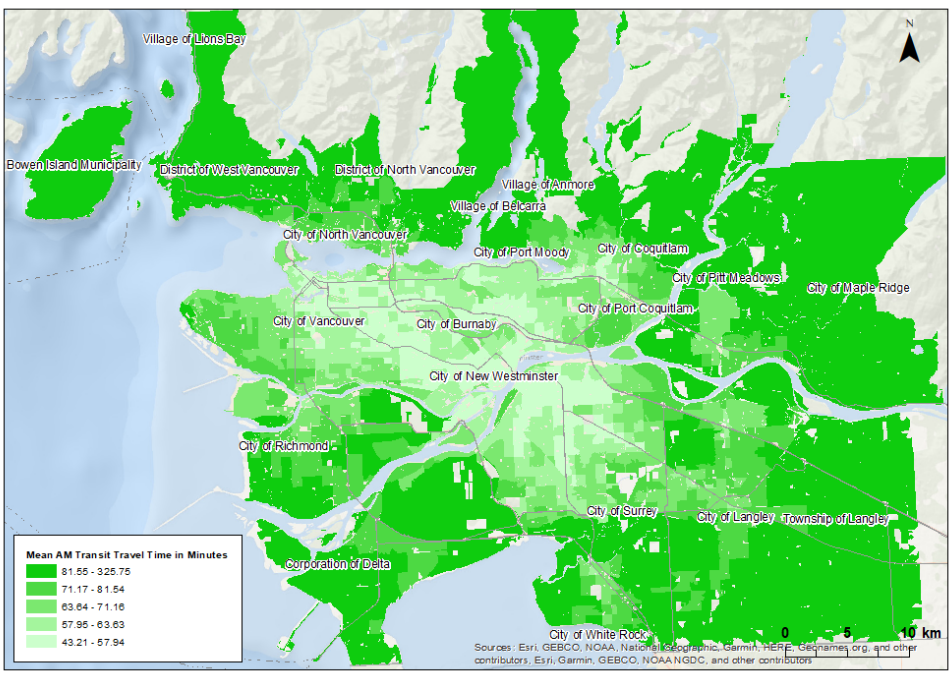


Figure 2-12: Map of 2016 Mean AM Transit Travel Time

2016 Regional Accessibility: Mean Mid Day Auto Travel Time to All Destinations

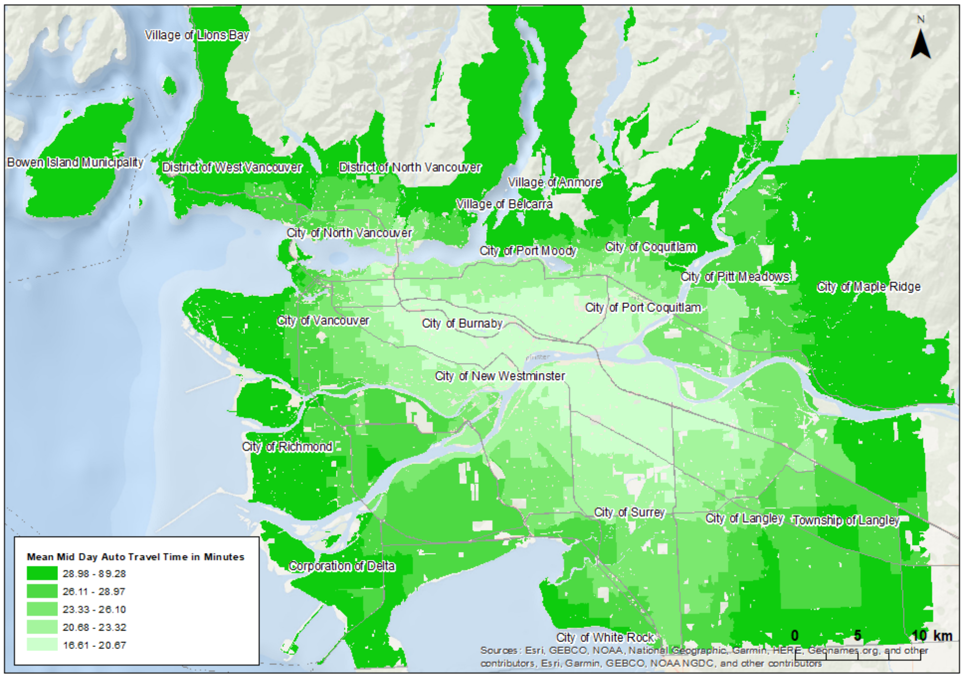


Figure 2-13: Map of 2016 Mean Mid-Day Auto Transit Travel Time

The transit travel time maps consistently show the lowest travel times for transit where transportation is easily accessible. This is apparent on the downtown peninsula of Vancouver, East Vancouver at Commercial Dr. Station, in New Westminster, and areas of Port Moody and Coquitlam where transit is concentrated. Transit travel time increases in car dependent areas with poor transportation connection. This is shown in suburban areas such as Anmore, Belcarra, Maple Ridge, and Lions Bay where transportation investment has historically been low. Auto travel times exhibit similar patterns regionally due to most destinations being closer to the downtown core of Vancouver. Some suburban areas exhibit travel times like those found closer to the downtown core of Vancouver due to transportation design differences. Many suburban areas were built as car dependent enclaves with well-connected highways, while areas within the City of Vancouver have transitioned to more transit and active transportation friendly modes of travel. As transportation policies evolve in the region, we would expect to see transit travel times decrease allowing greener more equitable travel across Metro Vancouver.

2.6. Summary

The analysis of changes in the component variables which comprise the walkability index allows policy decision makers to examine how changes in the built environment over time shape each neighbourhood and the collective region. These changes show, at the postal code level, the development trajectory of Metro Vancouver with policy relevant measures. When neighbourhood walkability is improved, the culmination of these changes has been shown to be a factor in living healthier more environmentally friendly lifestyles.

3. Greenspace Access & Exposure[18]

3.1. Health Impacts of Greenspace Access and Exposure

Related to walking-supportive features of the built environment, the proximity to greenspace within neighbourhoods is a core component of access to the natural environment. The role of access and exposure to greenspaces and the resulting human health impacts has been the topic of many studies, reviews, and systematic analyses. There is an abundance of literature that has established a relationship between greenspaces and various health behaviours and health outcomes. Increased exposure to greenness has been associated with health-promoting behaviours, such as increased physical activity and social interaction (Peters et al., 2010; Sugiyama et al., 2008). Studies have shown a positive relationship between greenspace proximity and specific health outcomes, such as lower prevalence of diabetes (Bodicoat et al., 2014; Mazumdar et al., 2021; Yang et al., 2019), reduced hypertension and CVD (Dzhambov et al., 2018; Jia et al., 2018), and lessened symptoms of depression, anxiety, and stress (Beyer et al., 2014). In addition, greenspaces have been shown to promote general health (Brindley et al., 2019) and reduce overall mortality (Rojas-Rueda et al., 2019). However, not all studies have found access or exposure to greenspace to benefit health. Some studies find no relationship (when controlling for other variables) or find greenspace exposure associated with adverse health outcomes (for example, increased asthma hospitalization) (Amato et al., 2011; Dales et al., 2004, 2008). It has been suggested that the use of diverse greenspace metrics, the varied quality of these metrics, and the specific methods used to quantify exposure or access, may contribute to these inconsistent findings (James et al., 2015; Lachowycz & Jones, 2011).

Despite the considerable existing literature examining the role of greenspace (in addition to other built and natural environmental exposures), there is no standardized definition of greenspace. Although there are some commonly used metrics to quantify greenspace, this overarching term may be used to refer to the ability to access any greenspace, the number of accessible park spaces, the percentage of local tree canopy cover, the proportion of natural land cover types, or the amount of healthy vegetation within a specified pixel size (e.g., Normalized Difference Vegetation Index (NDVI)). To further complicate this situation, a recent review of 125 greenspace articles, reported that less than 50% of these publications satisfactorily explained how "greenspace" was defined in their study (Taylor & Hochuli, 2017). This makes it difficult to compare across studies using greenspace as an exposure.

When greenspace exposure is sufficiently operationalized, the use of different metrics may yield diverse results in terms of health outcomes. Thus, the choice of greenspace metric could therefore unintentionally influence the result on health outcomes. This

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[18] For more details on the development of greenspace access and exposure surface, please see

Appendix C.

happens when a statistically significant relationship between greenspace access or exposure and the health behaviour or outcome of interest is found. For example, one study examined Dutch adults to determine the relationship between various greenspace metrics and both the odds of being overweight and the odds of engaging in at least 150 minutes of outdoor activity. It found that the choice of how access or exposure to greenspace was measured (e.g., NDVI, land-use database, or distance to nearest park space) determined whether greenspace was significantly associated with the odds of a participant being overweight (BMI 30 or higher) or engaging in at least 150 minutes of weekly outdoor activity (Klompmaker et al., 2018). In this study, the use of NDVI as the exposure metric resulted in the strongest and most consistent associations with reduced odds of being overweight and increased odds of engaging in the recommended amount of outdoor activity. Another study found inconsistency in the correlations between different greenspace metrics when using various criteria and buffer sizes. This study in New South Wales, Australia reported correlations (Kendall's Tau) of between 0.09-0.38 when comparing both 100m and 10-minute walking buffers using NDVI, park land use, and tree canopy (Mazumdar et al., 2020). In addition to the inconsistency between these various quantitative measures of greenspace, there also tends to be a mismatch between these measures and perceptions by residents. Many objective measures of greenspace do not correspond to individual perceptions of greenspace (Larkin & Hystad, 2019; Li et al., 2015; Mazumdar et al., 2020). However, expert ratings of neighbourhood greenness (in this case Environmental Psychologists) tended to be highly correlated with NDVI (Rhew et al., 2011).

There are also various methods to determine the appropriate scale and location of greenspaces one could reasonably be exposed to or have access to. The selection of the area from which to measure exposure may have a significant influence on the "amount" of exposure that is ascribed to an area or individual. In large ecological studies, an entire city or census geographical areas may be used to determine the amount of exposure, such as in some early works on air pollution and mortality (Dockery et al., 1993) or extreme heat-related deaths (Medina-Ramón et al., 2006). However, for many environmental exposures, a smaller geographical area, encompassing the area that an individual would regularly engage with during their daily activities is desirable or necessary. In these cases, buffers are commonly used to define the area an individual may encounter from their place of residence or work. Previous studies have used several different buffering methods and a wide range of buffering distances to determine relative access or exposure to greenspace associated with a specific location or individual (Mazumdar et al., 2021; Rugel et al., 2019). The most used buffering methods are circular buffers (also called Euclidean or crow-fly) which require no additional data to calculate and rely on simple distance calculations, and network buffers, which utilize roadway or sidewalk infrastructure data to determine the area that is accessible from a specific location. Circular buffers use a simple process to measure a specified radius from a central point of interest, or centroid, to create a circular buffer area. Due to simplicity, and not requiring any additional data (such as the roadway or sidewalk infrastructure necessary to calculate network buffers), this method is commonly used in research and by other planning authorities (Coutts et al., 2010, 2013; Moseley et al., 2013). As circular buffering does not include roadway or sidewalk connectivity, or the possibility of other impassable obstacles (e.g., highways, or private property), this method may over-estimate the distance an individual is able to travel under real-world conditions.

Buffer distances commonly range from 100-3000 metres and may be selected *a priori* to examine a specific hypothesis or multiple distances may be utilized in the analysis to determine the most predictive or strongest association with the health outcome of interest. Similar to the discrepancies that arise from comparing different greenspace metrics, using different buffering methods and distances may also result in different conclusions when examining the association between these exposures and health outcomes. While there is much existing work that has applied these various greenspace metrics within environmental epidemiological analysis, there has been far less emphasis on how these various metrics compare to one another. Even less attention has been focused on the potential discrepancies in exposure calculation when utilizing circular rather the network buffer methods.

Previous work has directly compared various buffering techniques, both circular and network, as well as the various methods to create network buffers, in relation to physical activity and walkability (Frank et al., 2017; Oliver et al., 2007). A study that compared 1 km circular buffers and line-based road network buffers found that the use of the network buffer method resulted in a stronger association between land use type and leisure and transport walking for respondents. (Oliver et al., 2007). To date, less work has focused on examining the impact of buffer method choice on the resulting association between greenspace and health outcomes.

3.2. Built and Natural Environment Exposures

In order to consider the effect of greenspace on health outcomes, we must create a spatial measure. The greenspace metrics were calculated from the centroid of each 6-digit postal code in the study area. The 6-digit postal code represents a spatially precise unit and is commonly used in Canadian environmental epidemiology studies (Labib et al., 2020b; Rugel et al., 2019). In urban neighbourhoods a postal code typically corresponds to one side of a city-block or a single high-rise building. Across urban and rural postal code areas studied, there was a median population of 19 and a mean of 41 residents, rural postal code areas tended to be larger, and the average corresponding population was higher in rural areas (el Emam et al., 2011). The use of postal code centroid as a proxy measure for full residential street address was found to be most accurate for high-rise or multi-unit residential buildings, with less accuracy in more rural areas (Healy & Gilliland, 2012; Khan et al., 2018). Each environmental exposure metric outlined below was calculated from the centroid of each unique postal code, using both 400m and 1000m circular and network buffers.

3.2.1. Land Cover

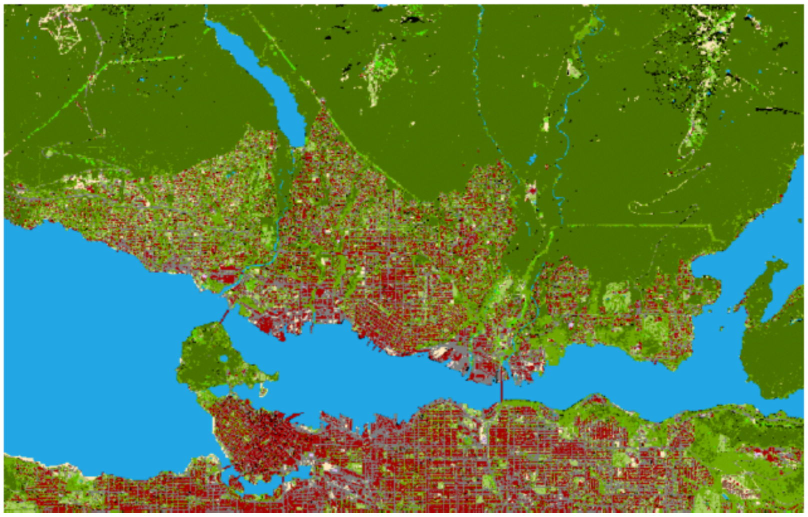

Figure 3-1: Example of Land Cover in Metro Vancouver.

The study area was classified into 13 urban land cover types using a geographic object-based image analysis which combined airborne laser scanning and RapidEye high-spatial-resolution imagery collected in 2016 (Metro Vancouver, 2020) (Figure 3-1). This method had a reported overall accuracy of 88% (kappa 0.87). These land cover types were mapped at a 2m spatial resolution, with some areas mapped at a 5m spatial resolution. The full methods are described elsewhere (Williams et al., 2018). The land cover types included 5 types of green land cover: coniferous (containing >75% coniferous tree species); deciduous (containing >75% deciduous tree species); shrub (vegetation taller than grass but shorter than tree, approximately < 3-4m tall); modified grass-herb (e.g., agricultural crops, golf course greens, park space, lawns); and natural grass-herb (e.g., meadows, grassland, or wetlands). These 5 green land cover types were analyzed individually and as a composite "total green" exposure variable (Jarvis, 2020). This data also contains 8 categories that were not included in the aggregate total green land cover: buildings; paved; other built (e.g., sport surfaces or transit and rail areas); barren; soil; non-photosynthetic vegetation (e.g., dead grass); water; shadow (e.g., an artifact of the method).

3.2.2. Tree Canopy

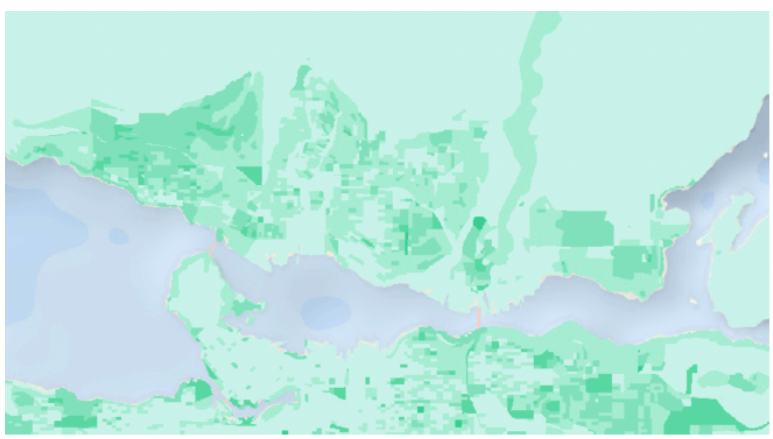

Figure 3-2: Example of Tree Canopy Coverage in Metro Vancouver.

Tree canopy values were calculated from the Metro Vancouver Open Data "EcoHealth Indicators – Canopy and Imperviousness" data layer (Figure 3-2). This data was summarized by census dissemination block throughout the study area and was generated from the Land Cover Classification (5m, hybrid) data collected in 2016. Tree canopy was calculated as a proportion of the buffer area, including the ground area covered by leaves and branches as visible from the air (Metro

Vancouver, 2020). Tree canopy cover is distinct from land cover data, due to this metric quantifying the proportion of buffer area covered by tree canopy, rather than the specific land cover types which may be predominant underneath the canopy (which may contain other types of vegetative and impervious land cover).

3.2.3. Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) was calculated using NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data (Figure 3-3). This data was obtained through the Application for Exacting and Exploring Analysis Ready Samples (AppEEARS) portal, and utilized 16-day averages data, at 250m resolution, collected in 2016 (U.S. Geological Survey, 2021). These resulting NDVI values were calculated using the following formula:

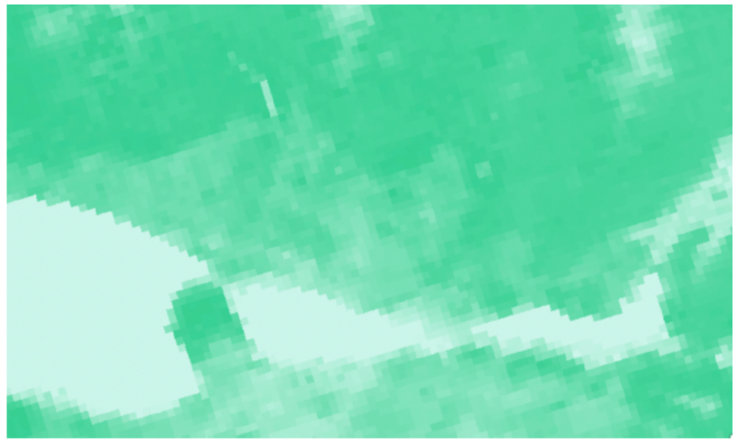

Figure 3-3: Example of NDVI in Metro Vancouver.

$$NDVI = \frac{\rho NIR - \rho Red}{\rho NIR + \rho Red}$$

This formula is intended to assess the proportion of healthy live vegetation within a specified pixel of land area. The resulting values range from -1 to +1, with low positive values indicative of barren areas, moderate positive values (0.2-0.3) indicating areas with shrub and grass, and high positive values indicating healthy dense forested areas. Negative values typically indicate areas covered with water. The buffer average NDVI value was used for subsequent analysis.

3.2.4. Park Access

Park access was calculated using the Metro Vancouver 2016 Land Use Classification data layer (Figure 3-4). Each parcel in this data layer is classified by the official land use

(Metro Vancouver, 2020). Parcels coded as "Recreation, Open Space and Protected Natural Areas" were identified as potential park areas. Only parks with at least 1 hectare of total area were considered in this analysis to ensure that these areas would be appropriate for active recreation and physical activity, which is consistent with the exclusion of smaller park spaces in previous work (Annerstedt Van Den Bosch et al., 2016). The inclusion of only 1 hectare and larger park spaces prevents the inadvertent inclusion of greenspaces where recreation would be unlikely such as roadway or sidewalk medians with vegetation, but as a result also excludes intentionally designed parklets and small urban open spaces less than 1 hectare, where residents may recreate and engage in social interaction.

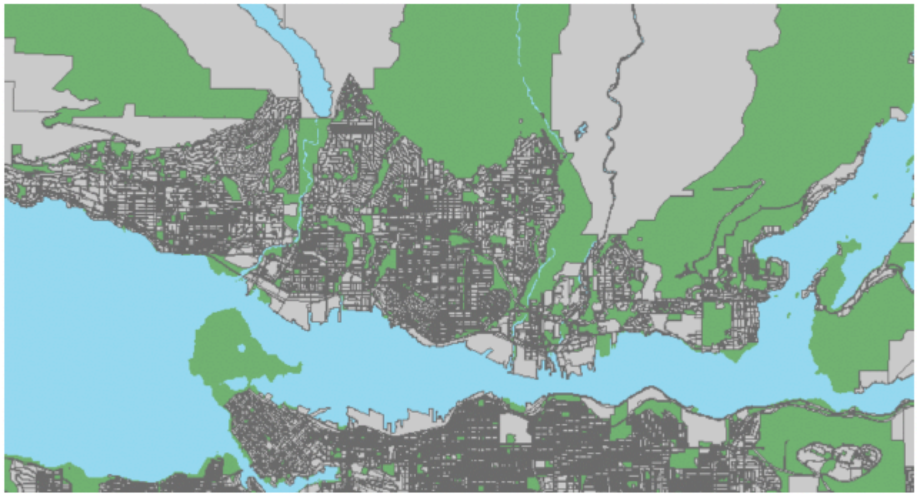

Figure 3-4: Example of Park Access in Metro Vancouver.

3.3. Exposure Buffers[19]

Two sizes of buffers were created surrounding each postal code in the study area (n = 57,430) using both circular and network buffers (with methods described below). 400m corresponds to an approximately 5-minute walk and is used by many local and regional planning authorities as a benchmark for access to greenspaces in the region (e.g., City of Vancouver, 2015). 1000m buffers, corresponding to approximately 10-15 minutes of walking, are also commonly used within walkability and environmental exposure literature (Labib et al., 2020). Distances between 400-1000m are often referenced as a distance that individuals are willing and able to walk to access neighbourhood amenities or services. The discrepancies between the same distance of circular and network buffer are reduced in areas with a more developed and connected walkable roadway network.

The centroid or center most point of each 6-digit postal code area was used as the starting point for the creation of each buffer, this is a common method in environmental epidemiology as it allows for greater de-identification of respondent/research participant's specific location. In urban areas of Canada, postal code centroids are within 200m of the corresponding residential location in nearly 90% of addresses, and therefore make for a reasonable location proxy while increasing the protection of confidentiality for

[19] Portions of this study on greenspace access and exposure in Metro Vancouver derived from an excerpt from: White, K.R. (2021). A comparison of greenspace metrics and measurement methods, walkability, and social and material deprivation in Metro Vancouver. [MSc Thesis, University of British Columbia]. UBC Theses and Dissertations Open Collections: https://dx.doi.org/10.14288/1.0402572

respondents (Bow et al., 2004). Circular buffers were created using a straight-line radius of 400m and 1000m centered on each postal code centroid.

Network buffers were also applied to the centroid of each 6-digit postal code. These buffers incorporate the existing pedestrian road network developed in the Health and Community Design Lab. The pedestrian road network dataset includes all pedestrian-accessible road segments, including roadways with existing sidewalk infrastructure (including pathways or walkable road shoulders). All controlled access roads, divided highways/dual lane roads, and on/off-ramps were excluded. The resulting pedestrian road network was then applied to identify a comprehensive set of all possible “walking” routes from the 6-digit postal code centroid to the specified distance (400m and 1000m). The resulting buffer polygon vector layers were then applied to each greenspace exposure layer to determine the exposure estimates for each greenspace metric. All spatial data preparation was completed in ArcMap 10.8.1 (Esri, 2020) and QGIS 3.18 (QGIS Development Team, 2021).

3.4. Statistical Analysis

To measure the correlation of each greenspace metric all variables outlined above were joined by a unique 6-digit postal code. The postal-code level values were then compared for the 400m and 1000m distances for both the circular and network buffers. Correlation matrices were created, for the 400m and 1000m circular and network buffers, using the “Hmisc” package (Harrell Jr, 2021). To display the series of relationships heatmap visualizations were created using the “corrplot” package (Wei & Simko, 2021). All analyses were performed using R version 3.6.1 (R Core Team, 2019).

3.5. Results

3.5.1. Natural Land Cover

The aggregate or “total green” land cover type was calculated by combining the coniferous, deciduous, modified-grass herb, natural-grass herb, and shrub land cover types, these composite measures ranged from a mean of 0.33-0.41 of buffer areas. Throughout the region, the most prevalent category of green land cover was deciduous trees, with mean proportions from 0.157 (400m network buffer) to 0.187 (1000m circular buffer) of buffer area depending on size and type. The least prominent category of green land cover was natural grass-herb, a category that includes meadows, grasses and bogs/wetlands that have not been modified by human activity. The mean proportion and standard deviation of each land cover type are shown in Table 3-1.

Table 3-1: Mean residential postal code proportion and standard deviation of land cover types

	Circular Buffers		**Network Buffers**	
	400m	**1000m**	**400m**	**1000m**
Coniferous	0.070 (0.088)	0.075 (0.091)	0.059 (0.078)	0.059 (0.069)

Deciduous	0.186 (0.096)	0.187 (0.080)	0.157 (0.093)	0.162 (0.073)
Shrub	0.006 (0.011)	0.007 (0.009)	0.004 (0.009)	0.004 (0.006)
Modified grass-herb	0.129 (0.083)	0.136 (0.082)	0.108 (0.076)	0.114 (0.062)
Natural grass-herb	0.001 (0.007)	0.002 (0.007)	0.001 (0.008)	0.001 (0.005)
Aggregated green	0.393 (0.169)	0.408 (0.160)	0.330 (0.159)	0.340 (0.133)

3.5.2. Tree Canopy

The proportion of tree canopy cover within each postal code buffer was very diverse, from a minimum of <1% to a maximum of 96% in most tree-covered postal code buffers (see Table 3-2). The median proportion of tree canopy cover was 24% for 400m buffers, and 26% for 1000m buffers.

Table 3-2: Descriptive statistics of each greenspace metric by buffer type and size

	Buffer Type	Min	Max	Median	Mean	SD	*r*	*p*-value
Park Count								
1000m	**Circular**	0	23	8	8.37	3.56	0.66	< .01
	Network	0	21	4	4.54	2.15		
400m	**Circular**	0	13	2	2.09	1.41	0.66	< .01
	Network	0	16	1	1.17	1.00		
Proportion of Tree Canopy Cover								
1000m	**Circular**	<0.01	0.96	0.26	0.31	0.19	0.92	< .01
	Network	<0.01	0.96	0.26	0.30	0.17		
400m	**Circular**	<0.01	0.98	0.24	0.29	0.18	0.86	< .01
	Network	<0.01	0.96	0.24	0.29	0.17		
Proportion of Aggregate Green Land Cover Type								
1000m	**Circular**	0.01	0.99	0.39	0.41	0.16	0.81	< .01
	Network	<0.01	0.99	0.31	0.34	0.13		
400m	**Circular**	0.00	1.00	0.37	0.39	0.17	0.78	< .01
	Network	<0.01	0.99	0.30	0.33	0.16		
NDVI								
1000m	**Circular**	-0.08	0.92	0.55	0.55	0.12	0.80	< .01
	Network	-0.10	0.97	0.54	0.55	0.11		
400m	**Circular**	-0.10	0.95	0.55	0.55	0.12	0.54	< .01
	Network	-0.10	0.97	0.54	0.51	0.18		
Note: *r* and *p*-values for the correlation coefficient of the relationship between circular and network buffer for the same distance								

3.5.3. Normalized Difference Vegetation Index

Similar to tree canopy, there was a vast range of mean NDVI values across the region. Maximum NDVI values ranged from 0.92 (1000m circular buffer) to 0.97 (400m and 1000m network buffer), which indicates a buffer almost entirely covered with healthy dense vegetation. This greenspace metric had the greatest difference (between buffer sizes) in correlation coefficients when comparing circular and network buffer methods at the 400m (r = 0.54, p < .01) and 1000m (r = 0.80, p < .01) buffer sizes.

3.5.4. Park Access

The majority (99.6%, n = 57,222 circular buffer; 98.5%, n = 56,580 network buffer) of postal code centroids were within 1000m of at least one park of 1-hectare or larger, with (90.1%, n = 51,720 circular buffer; 73.8%, n = 42,397 network buffer) within 400m of at least one park. There was a moderate correlation when circular and network buffer methods were compared (r = 0.66, p < .01).

3.5.5. Comparison of Buffer Types

For all greenspace metrics, the correlation coefficients for the relationship between the results when using circular or network buffers were positive; however, these results ranged from moderate to strong (see Table 3-2). The circular and network buffer results were most highly correlated for the tree canopy metric (1000m r = 0.92; 400m r = 0.86, p < .01), while park count had the weakest correlation between methods overall (1000m r = 0.66; 400m r = 0.66, p < .01).

3.5.6. Comparison of Greenspace Metrics

Total green land cover type (the composite measure of all vegetative land cover), proportion of tree canopy cover, and average NDVI were all moderately to strongly positively correlated. Park count was weakly correlated to the other greenspace metrics (with this relationship weakly positive when using the circular buffer method, and weakly negative when using the network buffer method).

3.6. Discussion

These findings show that using a measure of total green land cover, average NDVI, or tree canopy, results is moderate to strong association between these greenspace exposure estimates, in the MVRD. However, quantifying postal code level greenspace exposure through the number of accessible parks (e.g., park count) was only weakly positively correlated with the other three greenspace metrics when 1000m circular buffers (NDVI r = 0.12; total green land cover r = 0.07; tree canopy r = 0.14, p < .01) were used, when 1000m network buffers (NDVI r = -0.34; total green land cover r = -0.12; tree canopy r = 0.05, p < .01) were used two of the correlations became weakly to moderately negative.

When comparing the results for the circular and network buffer methods applied to estimating greenspace exposure and access, the results range from moderately to highly correlated. The greenspace metric for which these buffering methods are most highly correlated is tree canopy cover (1000m r = 0.92; 400m r = 0.86, p < .01). This indicates that the choice of buffering method may have less of an impact when tree canopy is the exposure metric of choice utilized in studies of health behaviours or outcomes. For tree canopy, NDVI and total green land cover, the choice of buffering methods seems to be more influential at smaller distances, as the results for these metrics became more correlated at the 1000m compared to 400m distance. Overall, the results for park count were the least strongly correlated when the circular and network buffering methods were compared, suggesting that future work should be intentional about which buffering method is used when access to parks is the chosen greenspace exposure.

When the circular and network methods are only moderately correlated (such as in the case of park count, $r = 0.66$, $p < .01$), the use of circular buffers may tend to overestimate the real-world access to park spaces as this method does not take into consideration the walkable roadway network or physical barriers which may prevent convenient access to these spaces. The MVRD contains a diverse mix of urban, suburban, and rural areas, so these results may not be consistent in areas with a different mix of land uses. As circular and network buffers are less consistent in “less walkable”, typically more suburban and rural areas, it may be more important to be intentional about the choice of buffering method used in these types of neighbourhoods. For example, in a neighbourhood with a limited walkable roadway network, or with obstacles (e.g., highway or watercourse), a park within a 500m circular buffer may require a much longer walking route distance to access. This would not be taken into consideration when using a circular buffer and therefore both access and estimated exposure may be overestimated.

Previous work has typically shown a lack of a strong relationship between green land cover type and park access in the Metro Vancouver region (Jarvis et al., 2020), as well as in other cities (Cusack et al., 2017). These current findings are consistent, with park access not being highly correlated to other greenspace metrics. This report contributes to the existing knowledge regarding the lack of a strong association between various greenspace metrics commonly used to quantify exposure to predict health outcomes in environmental epidemiology studies.

Previous work has compared circular and network buffering methods (Mazumdar et al., 2021; Oliver et al., 2007), however, no studies to date have compared these methods across several greenspace metrics. These findings may provide evidence for researchers when determining which buffer method is most appropriate for their specific research questions, and which types of greenspace metrics may be most influenced by buffering method.

Due to the scope of this report, and the focus on quantitative metrics of greenspace access and exposure, no measures of perceived greenspace were included. Given that some studies have found that individual perception of greenspace is more predictive of health behaviours, additional examination of how quantitative metrics of greenspace exposure relates to individual perceptions of their own access and exposure to residential greenness is warranted (Bai et al., 2013). This future work may provide evidence that perception of greenness can be adequately measured through a proxy quantitative metric.

This study also did not include measures of biodiversity or species richness within each park or greenspace. Previous work has found that increased species richness (measured through in person sampling of plant, butterfly, and bird species) was associated with an increase in psychological well-being of greenspace visitors, over and above the benefits associated with the size of the greenspace (Fuller et al., 2007). Methods have been developed to estimate biodiversity using remote sensing data; however, this type of analysis is more common in environmental and natural resources research and is less often included when examining environmental exposure and health outcomes (Madonsela et al., 2018).

3.7. Implications

Future work using greenspace as an environmental exposure should be intentional about which greenspace metric and buffering method most accurately estimate the potential pathway by which greenspace is hypothesized to impact human health. The selection of buffering method may be particularly influential when park count (rather than tree canopy, NDVI or land cover) data is utilized to quantify greenspace access and exposure. This is important, as the use of circular buffers may overestimate the accessibility of greenspace or the likely exposure during local outings, as this method does not consider potential obstacles (such as highways or watercourses). Future work should examine the differences in greenspace metric results when using circular and network buffers in other diverse geographic areas to determine if these same relationships are found.

Travel & Climate Impacts

A key focus of Where Matters II was to expand on the work completed in Where Matters I by providing further advancements into the new research avenues using local data for Metro Vancouver. Applying the wide range of the built and natural environmental measures discussed in the sections above, a series of research applications were performed. Figure 3-5 conceptualizes the organization of five research analyses conducted as part of this project. Each research study is broadly categorized into two types: 1) analyses that examine impacts on human health using health outcomes, or 2) analyses on travel activity that examines human behaviour and pollution and air quality impacts. Three main health sectors were examined: 1) obesity and chronic diseases, such as hypertension and type 2 diabetes, 2) mental health including depression and anxiety and 3) four types of risks of cancer: a) lung, b) breast, c) colorectal, and d) prostate. Leveraging regional trip diary data, studies related to travel activity examined 1) travel emissions from automobiles and transit vehicles, and 2) travel behaviour related to types of household trips by mode and associated physical activity and sedentary time. While all five research studies evaluate built environment impacts on the dependent variables, two of the studies on mental health and cancer risk also integrate measures of green space related to the natural environment.

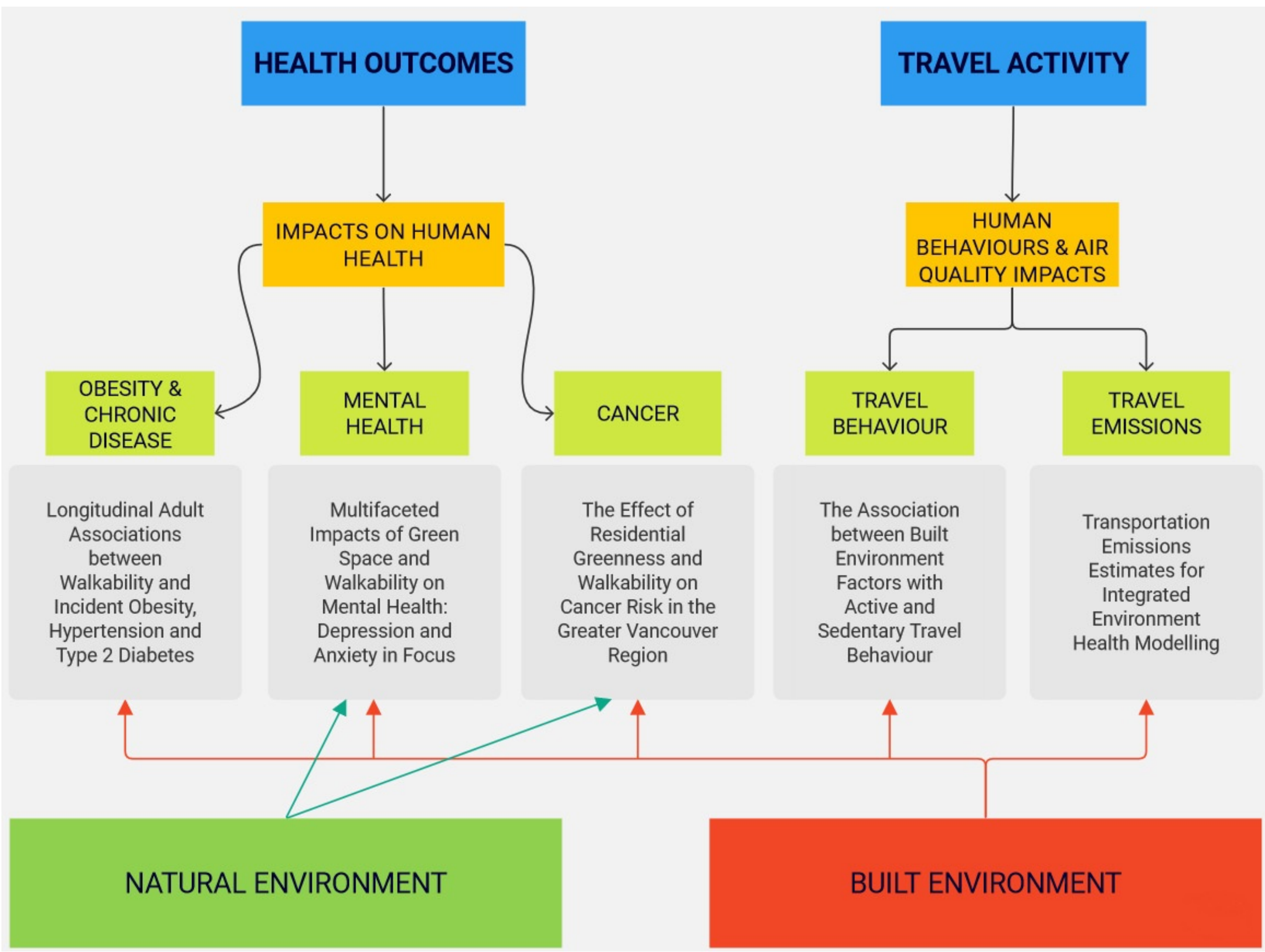

Figure 3-5 Conceptual model showing the organization of each of the five analyses conducted.

Where Matters II expands on the work done previously by evaluating the impact of the built environment on chronic disease and health behaviours. A central resource for our work is the BC Generations Project (BCGP), a database comprising 30,000 British Columbians aged 35-69 years which represents BC's largest-ever population health longitudinal cohort study. BCGP is a regional component of the Canadian Partnership for Tomorrow's Health (CanPath), the Pan-Canadian prospective health cohort, established over the past decade as a research platform for evaluating the genetic, behavioural and environmental causes of cancer and other chronic diseases.

BCGP collected baseline data (health, lifestyle, occupation, residential history, diet and physical activity) from participants using questionnaires. This included a wide range of socio-demographic, behavioural and health- related questions, such as: age, marital status, ethnicity, education, employment, income, personal and family health history. Health- related behavioural questions included tobacco use and exposure to second-hand smoke, sun exposure, daily servings of fruits and vegetables, alcohol consumption and physical activity. Physical measures (height, weight, waist and hip circumference, percentage body fat) and biological samples (venous blood) were obtained from 90% of participants.

Participant follow-up in BCGP is through active recontact for additional survey information (three follow-up questionnaires have been completed to-date), and passive follow-up via linkage to administrative health datasets, for which all participants have consented. Through this administrative linkage 1,678 incident cancer diagnoses since recruitment have been identified, including the following top five cancer types: 411 breast, 235 prostate, 135 colorectal, 111 lung and 105 melanoma skin.

Environmental data has been linked to BCGP participants through a collaboration with the Canadian Urban Environmental Health Research Consortium (CANUE). This includes traffic-related air pollution and greenspace. Walkability datasets generated by the Where Matters team for three timepoints is being linked to historical address information through a CANUE/ Statistics Canada collaboration, allowing us to investigate the impact of changing walkability over time on chronic disease and health behaviours.

Table 3-3 provides an overview summary of each of these research analyses and their components. Two of the analyses present longitudinal studies that systematically compare both health outcomes and environmental conditions at multiple time points to examine causation. The remaining three research studies examine the dependent variables cross-sectionally using the most recently available health and travel survey data combined with current environmental conditions.

Table 3-3: Summary of organization of analysis sections.

	Theme	Travel Activity		Health Outcomes		
Analyses	**Impacts**	Impacts on Human Behaviour & Air Quality		Impacts on Human Health		
	Sector	**Travel Behaviour**	**Travel & Emissions**	**Obesity & Chronic Disease**	**Mental Health**	**Cancer**
	Title	The Association Between Built Environment Factors with Active and Sedentary Travel Behaviour	Transportation Emissions Estimates for Integrated Environment-Health Modelling	Longitudinal Adult Associations Between Walkability and Incident Obesity, Hypertension, and Type 2 Diabetes	Multifaceted Impacts of Green Space and Walkability on Mental Health: Depression and Anxiety in Focus	The Effect of Residential Greenness and Walkability on Cancer Risk in the Greater Vancouver Region
	Key Outcomes	Physical Activity, Sedentary Time	Emissions by Mode	Obesity, Hypertension, Type 2 Diabetes	Depression, Anxiety	Cancers: Lung, Breast, Colorectal, Prostate
	Study Design	Cross-Sectional	Cross-Sectional	Longitudinal	Cross-Sectional	Longitudinal
	Report Section	4	5	6	7	8
Outcomes/ Activity	**Data Source Organization**	TransLink		BC Cancer Agency, BC Cancer Foundation, Canadian Partnership Against Cancer		
	Source Database	Regional Trip Diary		BC Generations Project		
	Database Year	2017		2009-2016; 2016-2019	2016-2019	2009-2016; 2016-2019
Environment	**Environmental Variables**	Built Environment	Built Environment	Built Environment	Built Environment; Natural Environment	Built Environment; Natural Environment
	Source Database	UBC SPPH Metro Vancouver Environmental Surface				
	Database Year	2016	2016	2006, 2011, 2016	2016	2006, 2011, 2016
	Source Database	-	-	-	Canadian Urban Environmental Health Research Consortium (CANUE)	
	Database Year	-	-	-	2016	2006, 2011, 2016

The sections that follow review the linkages of built and natural environmental conditions on health and travel activity outcomes in Metro Vancouver. These provide abbreviated summaries for each of the individual studies with supplementary information included for the full manuscript analysis in their respective appendix sections.

4. Travel Behaviour Relationships with Walkability – The Association of Built Environment Factors on Active and Sedentary Travel Behaviour: A Cross-Sectional Travel Diary Study[20]

4.1. Background

In North American we are currently facing both an epidemic of sedentary behaviour as well as a need to reduce greenhouse gas (GHG) emissions to mitigate further climate change. Initiatives to reduce the reliance on private vehicle travel, and instead promote the use of active travel modes (walking and cycling) and public transportation, may serve as a strategy to promote public health, and mitigate GHG emissions. Previous work has found a number of built environment factors to be associated with the amount of active travel (E. J. Kim et al., 2020; Koohsari et al., 2017; Liao et al., 2020; Thielman et al., 2015). This current study builds upon these previous works by utilizing detailed trips diary data from a regionally representative sample of households as well as more robustly attributing neighbourhood walkability through the use of the previous described walkability index.

The aim of this study is to examine the association between neighbourhood walkability and travel behaviour across mode (walking, biking, transit, and vehicle). We hypothesize that living in a more walkable neighbourhood would be associated with more trips made by an active mode (walking, biking, and/or transit) whereas living in a less walkable neighbourhood would be associated with more trips made by a sedentary mode (vehicle).

4.2. Methods

4.2.1. Data source, survey design, and ethics

This cross-sectional analysis utilized regionally representative data collected through TransLink's 2017 Trip Diary Data (TDD)[21]. Households through the Metro Vancouver Regional District (MVRD) and Fraser Valley Regional District (FVRD) were recruited through a random sample with approximately 2.5% of households in the region completing the survey (83% via web survey and 17% using smartphone app). The TDD collected data on weekday travel patterns for all individuals living in the recruited households between September 15 and December 12, 2017. In addition to information about the origins and destination, travel mode, and trip purposes, household and individual demographic data was collected.

[20] For the full article associated with this study, please see Appendix G.
[21] https://public.tableau.com/app/profile/translink/viz/Trip_Diary_2017/TripDiary2017

4.2.2. Study sample and study variables

The Walkability Index is a composite measure of neighbourhood walkability, comprised of four component measures (net residential density, commercial floor area, intersection density, and land use mix). Within this current analysis, the walkability value for each household was defined as the composite index value within a 1-kilometre network buffer, which follow a walkable road network, surrounding the location of the home (as defined by home 6-digit postal code). The values for each component measure were calculated beginning at the home postal code location and were then converted to z-scores to calculate the overall walkability index. The 1-km network buffer size was selected to represent the distance individuals could reasonably travel in a 10–15-minute walking trip and has been previous used to define the home “neighbourhood” area. (Colabianchi et al., 2007).

Individual and household demographic data were obtained from the TDD. For this current analysis the following variables were utilized and categorized as follows: gender (dichotomized as female or male), age (categorized as child/youth [age 5-18], adult [age 19-64], and older adult [65+]), driver’s license status (dichotomous yes/no), car share status (continuous 0-4, the number of car share membership participants reporting having), employment status (categorized as ‘full time employed’, ‘full time student’, ‘part time worker or student, or self-employed’ or ‘non-worker/non-student’), household income (categorized as <$50,000, $50,000-100,000, and >$100,000), household size (continuous 1-10), number of household bicycles (continuous 0-10), number of vehicles per adult in the home (dichotomized as less vehicles than adults [vehicles < adults] and 1 or more vehicle per adult in the home [vehicles > = adults]).

In addition to neighbourhood walkability, regional accessibility and sidewalk connectivity were calculated at the 6-digit postal code level and linked to the residential location. Regional accessibility was calculated by the mean number of minutes to travel to regional locations from the home location in morning peak traffic. These values were calculated for both vehicle travel, which provides an estimation of peak travel time from the home location if traveling by vehicle, as well as for transit travel, which conversely provides as estimation of peak travel time from the home if traveling by transit. Additionally, sidewalk connectivity, a measure of the completeness of the pedestrian infrastructure, was calculated using methods similar to the walkability index in the 1-km network buffer surrounding the home.

4.2.3. Statistical Analysis

All analyses were completed in R version 3.6.1; we used the ‘glmer’ function within the ‘lme4’ package to run generalized linear mixed-effect models. Adjusted odds ratios (OR) and 95% confidence intervals (CI) were calculated using logistic regression and three iterations of adjustment variables. Three adjustment models were developed based on existing literature and conceptual understanding of individual and environmental factors associated with travel behaviour. Multi-level (or mixed effects) models were developed to account for the hierarchical nature of the TDD (e.g., multiple participants living in the same household). A two-level model was used to account for clustering of participants within households. Additionally, survey weights obtained from the TDD were utilized in these analyses.

4.3. Results

4.3.1. Walking

Certain individual and household characteristics increased the odds of reporting walking trips (Table 4-1). Numerous individual variables were significantly associated across each iteration of these analyses including gender, age, employment status, car share status, and driver's licence status. Female participants had 1.22 times the odds of males to make a walking trip in the minimally adjusted model. When accounting for additional variables these results were attenuated, but remained statistically significant. Younger participants reported the most walking trips, with a 15% increase in odds of walking compared to adults (in the fully adjusted model). Participants who reported non-worker/non-student status reported the most walking trips, with 11% increase in odds of walking compared to full time workers. Conversely, participants who reported having a driver's licence had 14% reduced odds of reporting a walking trip compared to those without a driver's licences.

Regional accessibility did not have a significant effect on walking trips; however increased sidewalk connectivity did have a small but significant association with walk trips. There was a graded relationship between walkability and walking. For each increase in walkability there was a corresponding increase in walking trips, with this association being significant across each level of walkability. Participants in the most walkable neighbourhoods reported 13% increased odds in making a walk trip compared to those living in the least walkable neighbourhoods.

Table 4-1: Odds of walking trips across walkability quintiles

	Mod 1		Mod 2		Mod 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Gender						
Male	REF		REF		REF	
Female	**1.22**	**1.15, 1.30**	**1.02**	**1.01, 1.03**	**1.03**	**1.02, 1.03**
Age						
5-18	**2.32**	**1.98, 2.72**	**1.14**	**1.12, 1.17**	**1.15**	**1.12, 1.18**
19-64	REF		REF		REF	
65+	**0.54**	**0.48, 0.62**	**0.97**	**0.95, 0.98**	**0.97**	**0.95, 0.98**
Drivers License						
No	REF		REF		REF	
Yes	**0.30**	**0.27, 0.33**	**0.85**	**0.84, 0.87**	**0.86**	**0.84, 0.87**
Car share						
+1	**2.73**	**2.55, 2.94**	**1.10**	**1.08, 1.12**	**1.09**	**1.08, 1.11**
Status						
Full time employed	REF		REF		REF	
Full time student	**1.23**	**1.07, 1.41**	**1.03**	**1.01, 1.05**	**1.03**	**1.01, 1.05**
Part time or self-employed	**1.43**	**1.29, 1.58**	**1.05**	**1.03, 1.06**	**1.05**	**1.03, 1.06**
Non-worker/non-student	**2.09**	**1.87, 2.35**	**1.11**	**1.09, 1.12**	**1.11**	**1.09, 1.11**
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	**0.78**	**0.70, 0.87**	**0.98**	**0.97, 0.99**	0.98	0.97, 1.00
>$100,000	**0.89**	**0.80, 0.99**	**0.98**	**0.96, 0.99**	0.98	0.99, 1.00
Household size						
+1	**0.75**	**0.73, 0.77**	**0.99**	**0.98, 0.99**	0.99	0.99, 1.00
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		0.95	0.90, 1.00	0.96	0.91, 1.01
Bicycles						
+1	-		**1.02**	**1.01, 1.04**	**1.03**	**1.01, 1.04**
Regional Accessibility						
Vehicle	-		1.00	1.00, 1.00	1.00	1.00, 1.00
Transit	-		0.99	0.99, 0.99	0.99	0.99, 0.99
Sidewalk connectivity					**1.05**	**1.01, 1.09**
Walkability						
1	-		-		REF	
2	-		-		**1.04**	**1.01, 1.06**
3	-		-		**1.07**	**1.04, 1.10**
4	-		-		**1.11**	**1.08, 1.14**
5	-		-		**1.13**	**1.08, 1.19**

Notes: bolded results indicate statistical significance at $p<0.05$
Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

4.3.1. Cycling

The patterns for cycling trips differed considerably compared to the trends for walking trips (Table 4-2). Females had 58% decreased odds of making a bike trip, and full-time students reported lower odds of cycling trips (81% decrease in odds) compared to full time workers. Participants in households with more bicycles reported increased odds in making a cycling trip. There was no significant association between neighbourhood walkability and odds of participants making a cycling trip.

Table 4-2: Odds of cycling trips across walkability quintiles

		Mod 1		Mod 2		Mod 3
	OR	95% CI	OR	95% CI	OR	95% CI
Gender						
Male	REF		REF		REF	
Female	**0.37**	**0.31, 0.45**	**0.41**	**0.41, 0.42**	**0.42**	**0.30, 0.58**
Age						
5-18	**1.46**	**0.88, 2.43**	**4.86**	**4.85, 4.86**	**4.72**	**1.83, 12.2**
19-64	REF		REF		REF	
65+	**0.38**	**0.24, 0.59**	**0.73**	**0.73, 0.73**	0.68	0.32, 1.42
Drivers License						
No	REF		REF		REF	
Yes	**0.67**	**0.47, 0.95**	**0.56**	**0.56, 0.56**	**0.55**	**0.30, 0.99**
Car share						
+1	**3.29**	**2.86, 3.80**	**2.74**	**2.74, 2.74**	**2.71**	**1.94, 3.77**
Status						
Full time employed	REF		REF		REF	
Full time student	**0.42**	**0.28, 0.67**	**0.18**	**0.18, 0.18**	**0.19**	**0.07, 0.48**
Part time or self-employed	0.79	0.58, 1.05	**0.69**	**0.68, 0.69**	0.68	0.39, 1.19
Non-worker/non-student	0.98	0.67, 1.41	**1.37**	**1.37, 1.37**	1.40	0.73, 2.67
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	0.84	0.59, 1.20	**1.39**	**1.39, 1.39**	1.39	0.68, 2.85
>$100,000	1.15	0.82, 1.63	**1.34**	**1.34, 1.34**	1.31	0.64, 2.68
Household size						
+1	0.81	**0.73, 0.88**	**0.97**	**0.96, 0.97**	0.95	0.81, 1.11
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		0.47	0.09, 2.31	0.52	0.08, 3.47
Bicycles						
+1	-		**4.75**	**4.75, 4.76**	**4.75**	**3.56, 6.34**
Regional Accessibility						
Vehicle	-		**1.04**	**1.04, 1.04**	1.02	0.95, 1.01
Transit	-		**0.97**	**0.97, 0.97**	0.98	0.95, 1.01
Sidewalk connectivity	-		-		2.66	0.73, 9.68
Walkability						
1	-		-		REF	
2	-		-		0.83	0.39, 1.73
3	-		-		0.84	0.36, 1.98
4	-		-		0.42	0.12, 1.42
5	-		-		1.76	0.53, 5.85

Notes: bolded results indicate statistical significance at $p<0.05$

Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations
Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

4.3.1. Transit

Female participants reported increased odds (17%) of making a transit trip compared to male participants (Table 4-3). Both child/youth respondents and older adult participants had lower odds of transit trips compared to adult participants. Similar to the effects for both walking and cycling travel mode, participants with a driver's license had lower odds of transit trips (89%), while participants with car share memberships were more likely to make a transit trip (119%). There was a large effect for employment status, with full-time student participants reporting 12.8 times (95% CI 10.6, 15.4) the odds of making a transit trip compared to participants who were employed full time. Unlike walking and cycling, income was associated with odds of participants reporting a transit trip, with higher income associated with lower odds of transit trips (45% decrease in the middle-income category, and 37% decrease in the higher income category compared to the lower income category), with these results remaining significant in the fully adjusted model. Increased neighbourhood walkability was also associated with greater odds of transit use. However, these results were less consistent across the levels of walkability when compared to the trends for walking trips. Participants with neighbourhood walkability in the 4th and 5th levels (e.g., the most walkable and second most walkable), reported greater odds of making a transit trip when compared to participants living in the least walkable neighbourhoods. However, these results do not follow the same graded response as for walking trips.

Table 4-3: Odds of transit trips across walkability quintiles

	Mod 1 OR	Mod 1 95% CI	Mod 2 OR	Mod 2 95% CI	Mod 3 OR	Mod 3 95% CI
Gender						
Male	REF		REF		REF	
Female	**1.18**	**1.11, 1.26**	**1.15**	**1.05, 1.26**	**1.17**	**1.07, 1.28**
Age						
5-18	**0.01**	**0.01, 0.02**	**0.01**	**0.01, 0.02**	**0.02**	**0.01, 0.02**
19-64	REF		REF		REF	REF
65+	**0.73**	**0.64, 0.83**	**0.82**	**0.68, 0.99**	**0.81**	**0.67, 0.98**
Drivers License						
No	REF		REF		REF	
Yes	**0.09**	**0.08, 0.11**	**0.10**	**0.09, 0.12**	**0.11**	**0.10, 0.13**
Car share						
+1	**2.15**	**2.00, 2.30**	**2.30**	**1.98, 2.67**	**2.19**	**1.88, 2.55**
Status						
Full time employed	REF		REF		REF	
Full time student	**12.0**	**10.5, 13.7**	**13.8**	**11.4, 16.6**	**12.8**	**10.6, 15.4**
Part time or self-employed	0.93	0.84, 1.03	1.07	0.93, 1.25	1.08	0.93, 1.25
Non-worker/non-student	**0.60**	**0.53, 0.68**	**0.52**	**0.44, 0.63**	**0.53**	**0.44, 0.63**
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	**0.51**	**0.46, 0.57**	**0.56**	**0.47, 0.66**	**0.57**	**0.48, 0.67**
>$100,000	**0.54**	**0.48, 0.60**	**0.61**	**0.51, 0.73**	**0.63**	**0.53, 0.75**
Household size						
+1	**0.89**	**0.86, 0.92**	**0.93**	**0.89, 0.98**	**0.95**	**0.91, 0.99**
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		**0.18**	**0.08, 0.41**	**0.28**	**0.13, 0.60**
Bicycles						
+1	-		**0.75**	**0.66, 0.85**	**0.74**	**0.65, 0.84**
Regional Accessibility						
Vehicle	-		**1.08**	**1.06, 1.10**	**1.07**	**1.05, 1.09**
Transit	-		**0.94**	**0.93, 0.95**	**0.94**	**0.94, 0.95**
Sidewalk connectivity			-		**2.13**	**1.44, 3.16**
Walkability						
1	-		-		REF	
2	-		-		1.10	0.88, 1.38
3	-		-		1.22	0.95, 1.58
4	-		-		**1.78**	**1.32, 2.42**
5	-		-		**1.58**	**1.02, 2.44**

Notes: bolded results indicate statistical significance at p<0.05

Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

4.3.1. Vehicle

Individual and household characteristics that were associated with participants reporting a vehicle trip (either as the driver or passenger) differed considerably from the other modes of travel. Both child/youth participants and older adult participants reported significantly increased odds of making a vehicle trip compared to participants aged 19-64 years, with children/youth reporting the greatest odds of making a vehicle trip (Table 4-4). Reporting being employed full time was associated with the greatest odds of vehicle travel, with full time students (86% reduced), part time employed/student or self-employed (33% reduced), and non-worker/non-student (51% reduced) categories reporting reduced odds of any vehicle trip. Unlike the other modes of travel, higher income was associated with greater odds of making a vehicle trip (this is opposite to transit travel, where there was no significant association for income and either walking or cycling trips). Additionally, participants with a driver's license had over 15 times the odds of taking a vehicle trip (either as the driver or passenger), compared to participants without a driver's licence. In the fully adjusted model, the ratio of household vehicles to adults in the home was not significantly associated with vehicle trips. Participants in the least walkable neighbourhoods reported the greatest odds of vehicle travel; however, only the 4th walkability level was associated with a significant decrease in odds of vehicle travel.

Table 4-4: Odds of vehicle trips across walkability quintiles

	Mod 1		Mod 2		Mod 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Gender						
Male	REF		REF		REF	
Female	**1.10**	**1.03, 1.18**	1.08	0.98, 1.18	1.07	0.97, 1.17
Age						
5-18	**9.06**	**7.69, 10.7**	**8.37**	**6.68, 10.5**	**7.72**	**6.16, 9.66**
19-64	REF		REF		REF	
65+	**1.34**	**1.17, 1.53**	**1.29**	**1.06, 1.57**	**1.29**	**1.06, 1.58**
Drivers License						
No	REF		REF		REF	
Yes	**14.5**	**13.0, 16.3**	**16.5**	**14.0, 19.4**	**15.7**	**13.3, 18.4**
Car share						
+1	**0.46**	**0.43, 0.50**	**0.60**	**0.51, 0.71**	**0.63**	**0.53, 0.74**
Status						
Full time employed	REF		REF		REF	
Full time student	**0.18**	**0.16, 0.20**	**0.13**	**0.11, 0.16**	**0.14**	**0.11, 0.17**
Part time or self-employed	**0.91**	**0.82, 1.01**	**0.67**	**0.57, 0.79**	**0.67**	**0.57, 0.79**
Non-worker/non-student	**0.71**	**0.62, 0.79**	**0.49**	**0.41, 0.58**	**0.49**	**0.41, 0.59**
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	**2.10**	**1.87, 2.35**	**1.85**	**1.55, 2.21**	**1.82**	**1.52, 2.18**
>$100,000	**2.31**	**2.06, 2.60**	**2.31**	**1.91, 2.80**	**2.24**	**1.85, 2.72**
Household size						
+1	**1.14**	**1.10, 1.17**	0.96	0.91, 1.01	**0.95**	**0.90, 0.99**
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		**2.23**	**1.08, 4.62**	1.93	0.93, 3.98
Bicycles						
+1	-		**1.31**	**1.14, 1.51**	**1.33**	**1.16, 1.53**
Regional Accessibility						
Vehicle	-		**0.93**	**0.91, 0.95**	**0.93**	**0.91, 0.95**
Transit	-		**1.07**	**1.06, 1.08**	**1.06**	**1.05, 1.07**
Sidewalk connectivity			-		**0.41**	**0.26, 0.63**
Walkability						
1	-		-		REF	
2	-		-		0.91	0.71, 1.17
3	-		-		0.76	0.57, 1.02
4	-		-		**0.59**	**0.42, 0.82**
5	-		-		0.69	0.42, 1.14

Notes: bolded results indicate statistical significance at $p<0.05$
Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations
Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

4.4. Discussion

This chapter describes the relationship between individual, household, and neighbourhood factors and trip mode reported in TransLink's 2017 Trip Diary Data. Overall, these analyses found an increase in active travel mode trips completed (in particular walking trips) and a reduction in sedentary modes (vehicle trips) as neighrbouhood walkability increased, when adjusting for other individual, households, and neighbourhood factors. This effect was most apparent for walking trips, with each increase in niehgbourhood walkability associated with a further significant increase in walking trips. These results are consistent with previous work which found an increase in walking trips completed in more walkable neighbourhoods (Kim et al., 2020), additionally, similar individual and household characteristics were found, with women, younger age, and lower household incomes associated with completing more walking trips. This same pattern was also seen when examining utilitarian walking trips across urban areas in Canada, with increased walking trips reported in more walkable neighbourhoods (Wasfi et al., 2016). Additionally, previous work which looked at components of walkability, found that residential density and land use mixed were also independently associated with increased transportation walking (Eriksson et al., 2012).

Similar to previous work (Riggs & Sethi, 2020), there were increased odds of transit trips in more walkable neighbourhoods, however, this effect was only significant and in the two most walkable quintiles. Previous work also tended to find more biking trips complete in more walkable areas, however this was only seen in the most walkable quintile in this current analysis.

There are a number of strengths of this current work, including the generalizability to the population of the MVRD. However, the cross-sectional nature of these data limit the ability to determine cause and effect, and therefore these results represent correlations rather than causal relationships.

4.5. Conclusions

Analysis results showed that individual, household, and neighbourhood characteristics are all associated with trip mode. When controlling for other factors, living in more walkable areas was associated most strongly with reporting walking trips.

4.6. References[22]

[22] The full set of references used for this analysis are provided in the References section in Appendix G.

5. Greenhouse Gas Emissions and Walkability[23]

5.1. Background

Transportation contributes roughly one third of greenhouse gas (GHG) emissions in Canada, with the majority associated with passenger travel (Environment and Climate Change Canada, 2021). Mitigating the climate impacts of transportation is an ethical, existential imperative, and aligns with strategic plans of TransLink, British Columbia, and Canada (B.C. Ministry of Environment and Climate Change Strategy, 2021; TransLink, 2022b). Despite decades of efforts to reduce motor vehicle emissions through efficiency gains, steady increases in the quantity of travel have led to a net increase in GHG

1.1. [23] For the full article associated with this study, please see References

Eriksson, U., Arvidsson, D., Gebel, K., Ohlsson, H., & Sundquist, K. (2012). Walkability parameters, active transportation and objective physical activity: Moderating and mediating effects of motor vehicle ownership in a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 123. https://doi.org/10.1186/1479-5868-9-123

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Riggs, W., & Sethi, S. A. (2020). Multimodal travel behaviour, walkability indices, and social mobility: How neighbourhood walkability, income and household characteristics guide walking, biking & transit decisions. *Local Environment*, *25*(1), 57–68. https://doi.org/10.1080/13549839.2019.1698529

Thielman, J., Rosella, L., Copes, R., Lebenbaum, M., & Manson, H. (2015). Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *Preventive Medicine*, *77*, 174–180. https://doi.org/10.1016/j.ypmed.2015.05.011

Wasfi, R. A., Dasgupta, K., Eluru, N., & Ross, N. A. (2016). Exposure to walkable neighbourhoods in urban areas increases utilitarian walking: Longitudinal study of Canadians. *Journal of Transport & Health*, *3*(4), 440–447. https://doi.org/10.1016/j.jth.2015.08.001

Appendix H.

emissions from the transportation sector. Clearly, new and more effective strategies are needed.

GHG emissions are only one of the critical externalities of motor vehicle travel. Motor vehicles are also a major source of local air pollution, a leading cause of death through crashes, and a contributor to the myriad negative health effects of sedentary lifestyles. The core goal of the project “Where Matters II: Health and Climate Change Impacts of Transportation and Land Use Actions” (WMII) is to integrate the consideration of health and climate impacts of passenger transportation to inform land use planning in Metro Vancouver and beyond.

This chapter contributes to the emissions component of the WMII project by developing detailed emission estimates from travel survey data, and examining their association with neighbourhood walkability features. We generate emissions estimates for trips reported in TransLink’s 2017 travel survey data using state-of the art estimation methods, and then summarize the estimated GHG and CAC emissions at the person and household levels. Subsequently, we use these estimates to investigate how walkability and transit accessibility relate to person- and household-level GHG emissions from travel, moderated by personal and household characteristics. Previous work has found a number of built environment factors to be associated with the amount of active travel (E. J. Kim et al., 2020; Koohsari et al., 2017; Liao et al., 2020; Thielman et al., 2015). We hypothesize that living in a more walkable neighbourhood is associated with lower transport emissions, due to the ability for more trips to be completed through walking, cycling, and transit, with fewer trips/short distance trips completed with private vehicle.

A variety of methods can be used to quantify the emissions impacts of travel. Directly measuring emissions from motor vehicles is currently impractical in a large-scale survey. Even if direct measurement were possible (such as with Portable Emissions Measurement Systems or PEMS attached to every participant’s vehicle), it would only capture the tailpipe emissions during vehicle operation, and only for personally-owned private vehicle trips, which is a small scope of analysis for passenger transportation.

Emissions estimation methods enable more comprehensive analysis by relying, explicitly or implicitly, on a combination of abstractions and assumptions, which we can describe as an emissions model. The utility of the emissions estimates for subsequent analysis or decision-making depends on the relevance and consistency of the modeling method. Emissions modelling is an analysis process involving trade-offs of precision and accuracy, requiring an understanding of the uncertainties and biases associated with each data source, assumption, and modelling tool. For these reasons, we precede the description of our methodology with a brief discussion of the principles and priorities motivating our modelling approach. These principles are informed by both the WMII project objectives and the state-of-the-art in emissions modeling methods represented in the literature (Al-Rijleh et al., 2018; BC Ministry of Environment and Climate Change Strategy, 2022; Bel & Rosell, 2017; A. Bigazzi, 2019; Cerqueira et al., 2020; M. Chester & Horvath, 2009; Lee & Lee, 2020; Saleh & Hatzopoulou, 2020; Shekarrizfard et al., 2020; U.S. Environmental Protection Agency, 2022b; Venigalla et al., 2018; A. Wang et al., 2018, 2023; Xiao et al., 2017).

1. The first priority is **precision**: the estimates should as closely as possible represent the quantity of emissions attributable to observed travel in the survey data. Precision is maximized by using modelling tools that match the specificity of vehicle and travel information provided in the travel survey data. This priority also motivates use of the most temporally (October 2017) and geographically (metro Vancouver) relevant modelling data and assumptions.
2. The second priority is for **consistent accuracy** across trips in the travel survey data, to ensure comparability and avoid biasing subsequent analysis of the factors influencing person- and household-level emissions. This priority motivates the use of consistent modelling tools and assumptions across trips wherever possible, and so may require trade-offs against the first priority of precision. To avoid introducing bias, missing data should be imputed using the best available information, rather than excluded from the estimates.
3. Enabling subsequent analysis also leads to the third priority, which is incorporating **variability in emissions rates over the factors of interest**, to address the emissions implications of travel behaviour and the built environment. Relevant factors in this and the broader WMII analysis include travel mode, vehicle type, and destinations, among others. As above, this priority may require trade-offs with precision or accuracy.
4. Because the project aims to address climate impacts, the emissions estimates should include **lifecycle emissions** of passenger travel, and not be limited to operating or on-road emissions.
5. Furthermore, because the project aims to inform decision-making, the analysis should use a **consequential emissions accounting framework**, so that the GHG estimates represent the additional or marginal climate impacts of changes or differences in the observed passenger travel.

Applied to the travel survey data, the implication of these principles for modelling decisions is to explicitly account for: vehicle type, vehicle occupancy, traffic congestion, upstream and downstream activities in the vehicle and fuel lifecycles, and non-service activity of non-private vehicles. The emission estimates do not include the guideway lifecycle (i.e., road/track construction and maintenance), for which consequential attribution to person-level travel activity is highly uncertain.

To situate our methods in the literature, Table 5-1 summarizes the scope of a sample of past studies using household travel survey data to estimate personal GHG emission from daily travel. It excludes studies that only considered automobile emissions (Choi & Zhang, 2017) or only included a subset of trips such as commuting (Yang et al., 2019). Few studies have accounted for vehicle-cycle emissions, and only three others used large-sample regional travel surveys (including a very large sample from Toronto). Very few studies have employed dynamic emissions rates within modes, either, with most relying on fixed emission rates by mode. We aim to produce emissions estimates more sensitive to trip attributes by using dynamic vehicle occupancy and emission factors, sensitive to vehicle make, congestion, and other factors.

Table 5-1. Summary of past studies investigating personal GHG from travel survey data

Source	Data year	Location	Number of households	Number of persons	Number of trips	Emission scope
This study	2017	Vancouver	27,980	57,431	224,525	Fuel- and vehicle-cycle
(A. Wang et al., 2023)	2016	Toronto	162,708	395,885	798,093	Fuel-cycle
(Wu et al., 2019)	2017	Twin cities	NR	360	NR	Operating
(L. Xu et al., 2018)	2015	Xiamen City	1,125	NR	NR	Operating
(Al-Rijleh et al., 2018)	2012	Philadelphia	9,235	20,216	NR	Fuel- and vehicle-cycle
(Des Rosiers et al., 2017)	2006	Quebec City	33,859	NR	209,849	Operating
(Bel & Rosell, 2017)	2006	Barcelona	NR	24,605	93,864	Operating
(Reichert et al., 2016)	2008	Germany	25,922	60,712	NR	Fuel-cycle
(Kotval-K & Vojnovic, 2015)	2008	Detroit	NR	940	15,392	Operating
(Ma et al., 2014)	2007	Beijing	NR	1,026	NR	Operating
(Wilson et al., 2013)	2007	Halifax	1,920	NR	NR	Operating
(Barla et al., 2011a)	2002-2006	Quebec City	250	400	15,000	Operating
(L. D. Frank, Stone, et al., 2000)	1996	Seattle	~1,700	NR	~30,000	Operating

NR: Not Reported

Data partially drawn from Wang et al. (2023)

All past analyses of household emissions have used an attributional accounting framework that explicitly or implicitly assigns vehicle emissions to vehicle occupants in equal proportions (often with assumed occupancy). This approach is the most appropriate for creating an emissions inventory, because the aggregation of all person-trip emissions is expected to equal the total system emissions. In contrast, a consequential accounting framework represents the impacts of specific actions or agents within a system on total system emissions. These two frameworks produce different results when there are fixed emissions-generating activities in a system, or when vehicle activity does not change proportionally with passenger travel. Consequential accounting is more appropriate for policy analysis and decision-making because it represents how system emissions change in response to an intervention (Brander et al., 2018; Brander & Ascui, 2015; Corradi et al., 2021; Thomassen et al., 2008).

The Where Matters II project aims to quantify how the climate impacts of passenger travel are influenced by the built and natural environment. The research questions are essentially consequential, with an explicit aim to inform decision-making. The emissions estimates are only aggregated to sampled households in the analysis, and although expansion factors could be used to estimate regional emissions, there is no explicit inventory calculation in the study. Therefore, we believe a consequential accounting framework is the most appropriate for this study. However, we also acknowledge that consequential accounting is new in the transportation field (A. Bigazzi, 2019, 2020), and has been the subject of long debate in the climate analysis literature (World Resources Institute (WRI), 2014, 2015). Therefore, we calculate and report emissions estimates using both attributional and consequential accounting frameworks.

5.2. Methods

Key components of our emissions modelling framework are illustrated in Figure 5-1. Three main local data sources from TransLink are used in the emissions estimates: the Regional Travel Model (RTM), 2017 Trip Diary Data (TDD), and transit system operations data. The next section provides further information on these data sources. Auto and transit emission rate look-up tables are generated from MOVES modelling and transit system operations data, respectively. MOVES, the MOtor Vehicle Emissions Simulator, is a detailed modal motor vehicle emissions model developed by the U.S. Environmental Protection Agency from extensive data recorded from on-road and off-road vehicles (U.S. Environmental Protection Agency, 2022b). Although developed for the USA, MOVES is widely used in Canada due to its precision, adaptability using local input data, large volume of vehicle test data, and the harmonized Canada-USA vehicle fleet (Environment and Climate Change Canada, 2022; Ghafghazi & Hatzopoulou, 2014; Le Hong & Zimmerman, 2021; Requia et al., 2018; J. Xu et al., 2019). Operating auto and transit emissions are calculated by applying vehicle-and route-specific emission rates to observed trips in the TDD. Fuel economy data from Natural Resources Canada (2022) are used to adjust for variations by vehicle make and model within the MOVES vehicle type categories. Vehicle operating emissions are augmented with upstream emissions for lifecycle estimates, and then attributed to vehicle occupants and adjusted for marginality. Finally, trip emissions are aggregated up to the person and household for relational analysis. Given the complexity of the modelling and the scope of details needed to provide a replicable description of the methods, we have provided a lengthy appendix to this chapter reporting complete methodological details. The remainder of the Methods section provides a higher-level overview of the emissions estimation methods.

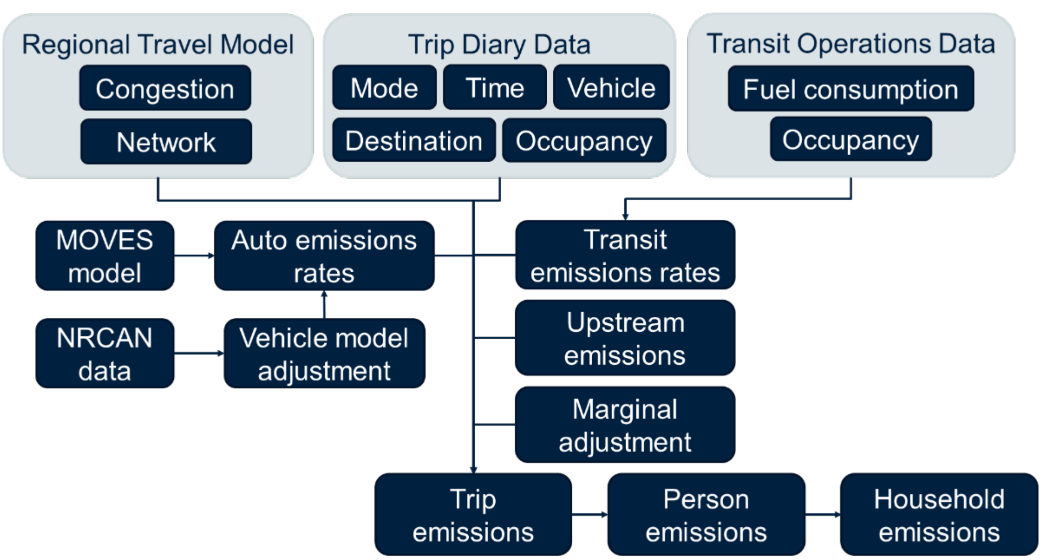

Figure 5-1. Emissions modelling framework

5.2.1. Data Sources

The main source of travel information is TransLink's 2017 Trip Diary Data (TDD) (Ipsos, 2018). Sample households for the TDD were recruited from Grater Vancouver Regional District and Fraser Valley Regional District by a pre-notification letter and followed up by telephone recruitment. Approximately 2.5% of households in the region completed the survey (83% via web survey and 17% using smartphone app). A travel diary instrument was used to record all travel by members of the sampled households over 1 day (or 3 days if they used the smartphone app) between September 15 and December 12, 2017. Person and household sampling weights are included in the TDD to account for representation differences between the sample and the regional population (as indicated by census data).

In total, the TDD consist of 224,525 trips by 57,431 persons in 27,980 households, who collectively own 37,148 motor vehicles and 35,146 bicycles. Based on the geographic study scope (see above), 1333 trips (0.59%) were excluded, leaving 223,192 trips for analysis. The primary mode shares for the analyzed trips were auto driver (55%), auto passenger (14%), walk (15%), transit (13%), and bicycle (2%) – see Table 5-2. Some trips reported in the TDD involved the use of multiple modes of travel. The TDD defines the "primary" mode as the mode that was most likely used for the largest proportion of the trip, with a hierarchy of rail transit, bus transit, then automobile and other modes for multi-modal trips (TransLink, 2013b). For emissions estimation, we disaggregate multi-modal trips into modal "segments", as described below.

Table 5-2. Modal distribution of trips in the TDD

Primary mode	Single mode	Multi-mode	Total	
Auto Driver	122,880	142	123,022	55.1%
Auto Passenger	31,336	68	31,404	14.1%
Taxi	518	3	521	0.2%
Transit Bus	11,867	819	12,686	5.7%
Sky Train	6,919	9,061	15,980	7.2%
Westcoast Express	69	161	230	0.1%
Handy Dart	150	3	153	0.1%
Sea Bus	97	90	187	0.1%
Walk	33,516	0	33,516	15.0%
Bike	4,266	5	4,271	1.9%
School bus	609	21	630	0.3%
Other mode	591	1	592	0.3%
Total	212,818	10,374	223,192	100.0%

TransLink's regional travel model (RTM) is a four-step, trip-based travel model, implemented in EMME software (TransLink, 2018). The current version of the RTM was estimated using data from TransLink's 2011 trip diary data (the predecessor to the TDD) (TransLink, 2013b). The RTM provides link-level information on peak and off-peak period road and transit network congestion levels. The RTM road network consists of 20,043 links with an average length of 61.5 m, and the RTM transit network consists of 16,214 links with an average length of 390 m. The transit network includes all of the regularly serviced transit lines in the region, including bus, Sky Train, Sea Bus, and West Coast Express services (i.e., road, rail, and marine transit). The RTM transit network data were enhanced with TransLink's General Transit Feed Specification (GTFS) data for the period September to December 2017, including transit line attributes (TransLink, 2022a).

TransLink transit system operation data were used to generate regional, fleet-specific vehicle emission factors and vehicle occupancy (i.e., passenger loads) for metro Vancouver. These data were taken from the 2019 Transit Service Performance Review (TransLink, 2019).

5.2.2. Emissions estimates for automobile trips

Emissions for private or shared (car-share and taxi/ride-hail) automobile trips are calculated as the summation of operating (start and running) and non-operating (fuel and vehicle lifecycles) emissions processes. Non-operating emissions are attributed to vehicle-trips based on the amount of fuel and proportion of vehicle-life consumed by the trip. Vehicle-trip emissions are then attributed to person-trips based on vehicle occupancy (excluding working drivers for ride-hail services). All four automobile emission components are vehicle-dependent, and the operating emissions also vary with facility type, congestion level, and temperature.

In the TDD, auto driver and passenger trips were self-reported as made by a household vehicle (96%), another household's vehicle (3.3%), a car-share vehicle (0.4%), or a taxi/ride-hail vehicle (0.3%). For trips made as the driver of a household vehicle, the TDD includes self-reported information on the vehicle's make, model, model-year, and fuel type. The TDD includes trips made by 8,086 unique combinations of vehicle make-model-year-fuel, to which we added supplementary vehicle information from other sources (Insurance Corporation of British Columbia (ICBC), 2020; Natural Resources Canada, 2022; Transport Canada, 2021). See the full report in the appendix for details about assumptions and imputations for missing vehicle data.

Total person-trip emissions are calculated by summing the start and running vehicle emissions (by link), adjusted for deadheading, and then dividing by vehicle occupancy. Vehicle occupancy (excluding the driver for taxi/ride-hail trips) was reported for automobile trips in the TDD. If occupancy was missing, occupancy was assumed to be 1.24 for taxi trips (TransLink, 2013a), and 1.60 for all other automobile trips (the average occupancy in the TDD). For taxi/ride-hail trips, a deadheading adjustment is applied to each reported trip to account for the induced vehicle kilometres travelled (VKT) without the traveller present in the vehicle. The deadheading rate is the percent of operating VKT for taxis without a passenger present. Relevant literature reports deadheading rates of 41% to 61%, with a mean of 55% (Cramer & Krueger, 2016; Li et al., 2020, 2022; San Francisco County Transportation Authority, 2017; Sun & Ertz, 2021). We apply this value to scale up running and upstream (not start) emissions for all taxi trips in the TDD.

MOVES2014, the latest version of the MOVES model at the time of analysis (U.S. Environmental Protection Agency, 2022b), was used to create emission rate lookup tables for application to the TDD. MOVES input data were obtained from Metro Vancouver's Air Quality and Climate Change team (Metro Vancouver, 2018), augmented by data sources on vehicle fleets (Insurance Corporation of British Columbia (ICBC), 2020; Natural Resources Canada, 2022; Statistics Canada, 2010; Transport Canada, 2021), vehicle activity (TransLink, 2013a, 2013b, 2018), and archived weather station data for meteorology (Environment and Climate Change Canada, 2020; Pacific Climate Impacts Consortium, 2020; Weather Underground, 2022).

Because MOVES emission rates are uniform within vehicle type categories (for a given model-year and fuel type), we apply a make/model-specific adjustment factor to the MOVES rates (separately for city and highway road types), based on model-specific fuel economy test data. This approach enables us to leverage both the link-level congestion-sensitive emission rates from the MOVES model (by vehicle type, fuel type, model-year, and road type), and the more detailed vehicle make/model information in the TDD to account for efficiency differences by model within a given vehicle class. Model-specific fuel economy data were taken from NRCAN data (Natural Resources Canada, 2022), averaged across variations in engine size or transmission type within a given make-model-year as necessary.

Automobile trips were routed from origin to destination on the road network data as represented in the RTM. Precise locations (latitude – longitude) for origins and destinations were "snapped" (orthogonal projection) to the nearest centroid connector within their respective TAZ. The network shortest (time) path sequences of links were determined using R software (R Core Team, 2019) with the package igraph (Csárdi et al., 2023).

The non-operating emissions accounted in this analysis include those attributable to 1) upstream activities for fuel provision (i.e., "well-to-tank" (WTT) emissions), and 2) upstream (production), downstream (disposal/scrappage), and non-operating in-use (maintenance) phases of the vehicle lifecycle. Fixed upstream emission rates (in kg CO_2e per unit fuel type) are applied to the operating fuel consumption, taken from GHGenius ((S&T) Squared Consultants Inc., 2022) for petrol fuels and the B.C. Ministry of Environment and Climate Change Strategy (2022) for electricity. Non-operating emissions attributable to the vehicle cycle are calculated using the emission estimation framework applied in Kannangara et al. (2021). This framework is highly parameterized, enabling adaptability with model-specific weight and size parameters, in addition to local energy factors.

5.2.3. Public transit trips

The 29,236 reported transit trips in the TDD (65% uni-modal) were 55% by Sky Train, 43% by transit bus, and the other 2% divided among West Coast Express, Sea Bus, and Handy Dart. Emissions for transit trips are calculated as the summation of operating and non-operating (fuel and vehicle lifecycle) components. Operating and non-operating emissions are attributed to transit vehicle operation (per VKT) based on emission and fuel consumption rates and vehicle lifecycle, and then attributed to person-trips by transit based on the transit vehicle passenger occupancy (excluding working drivers).

Per-VKT emission rates for criteria air contaminants (CAC) from buses are estimated using MOVES, as described above for automobile trips. Fuel consumption and GHG emissions for transit vehicles are based on TransLink reporting of measured transit fleet fuel consumption data for the year 2019. Annual fleet fuel consumption and GHG emissions are attributed equally to annual service km (by mode) using TransLink reported annual operations data (TransLink, 2019, 2020a). The service km exclude deadheading, but the fuel consumption data do not, and so this approach incorporates deadheading emissions into the operations-phase emissions rates. Reported fuel consumption is converted into both operating and upstream GHG emissions using BC guidance on emissions intensity by fuel (B.C. Ministry of Energy, Mines and Petroleum Resources, 2017; BC Ministry of Environment and Climate Change Strategy, 2022, 2022; (S&T) Squared Consultants Inc., 2022; TransLink, 2020b).

Transit trip routing was undertaken using the r5r package in R (Pereira et al., 2021) for all modes except Handy Dart trips (the on-demand paratransit service), which were routed using the same procedure as automobile trips. The link cost function for transit used trip purpose-specific walking, transfer, and waiting time penalties from the Regional Travel Model (RTM) (TransLink, 2018).

For transit vehicle-cycle emissions, we include the same three elements as for automobiles (manufacture, maintenance, and end-of-life), attributing lifecycle emissions equally across a vehicle's operating life VKT. Transit vehicle-cycle emissions rates are based on the literature for bus (Chan et al., 2013; M. V. Chester, 2008; Condon & Dow, 2011; Cooney et al., 2013; Lajunen & Lipman, 2016; Nordelöf et al., 2019; Pourahmadiyan et al., 2021; Spreafico & Russo, 2020; Zhao et al., 2022), rail (M. V. Chester, 2008; Del Pero et al., 2015; Gulcimen et al., 2021; Lederer et al., 2016) and ferry (Istrate et al., 2022; Schmidt & Watson, 2014).

For transit bus and Sea Bus, average peak loads by line-direction are taken from the 2019 TSPR (TransLink, 2019), with missing values imputed from non-missing values for the line. Rail occupancy was extracted from station boarding and alighting data in the TSPR with a higher spatial resolution of station-by-station rather than line-average (still by line, direction, day, and hour).

5.2.4. Other modes

Walking trips (33,516) and trips by wheelchair (41) were assumed to have zero emissions and GHG impact. Lifecycle (all upstream) GHG emissions for the 4,266 bicycle trips were calculated from the trip distance using a factor of 10.5 g CO_2e per km, based on (Sun & Ertz, 2021). There was no way to distinguish electric bicycle trips from non-motorized cycles, but they were probably a small portion (<5%) of the reported trips (Hassanpour & Bigazzi, 2023). Bicycle trips were routed on the OSM network using the r5r package in R (Pereira et al., 2021).

Motorcycle, school bus, shuttle bus, and charter bus emissions rates were generated from MOVES using the same modelling approach described above for automobile trips, supplemented with fuel-cycle and vehicle-cycle rates from the literature. See the appendix for details on the estimates for these trips, as well as the Aqua Bus, boat, and ferry trips.

The primary mode was designated as "Other/unclassified" for 143 uni-modal trips. We developed and applied a Support Vector Machine (SVM) classification algorithm with a 92% success rate to infer a mode for these trips, and then applied the relevant GHG estimation method.

5.2.5. Multimodal trips

The TDD include 10,374 trips (4.6%) reported as multi-modal, but without specific mode-change locations. We use one of two approaches to disaggregate these trips into uni-modal segments for emissions estimation. For trips including fixed-route services (e.g., rail transit, Sea Bus), we use the r5r routing function in R described above, input with the reported mode sequence for the trip. Emissions are then estimated for each of the modal segments of the trip and then summed. For trips without fixed-route services, we assume that trip segment distances for each mode in a multi-modal trip are proportional to their respective typical trip distances for uni-modal trips, and so aggregate multi-modal trip emissions as a weighted average of each constituent mode. For 86 segments of multi-modal trips designated as "Other/unclassified" mode, we use the same SVM algorithm to infer a mode as for uni-modal trips.

5.2.6. Marginal emissions adjustments

The methods up to this point have used an attributional accounting framework, apportioning vehicle emissions equally across vehicle occupants. To our knowledge, consequential emissions accounting has never been applied to household travel data, but we can build on previous work that estimated marginal emissions rates for passenger travel (consequential accounting) from average emissions rates (attributional accounting) using system-level data (A. Bigazzi, 2019). In this approach, the marginal/average emissions ratio, MAER, is calculated from two factors: the elasticity of vehicle to passenger kilometres travel (ε_v^p), and the elasticity of vehicle fuel or emission rates (per VKT) to vehicle occupancy (ε_e^θ). The MAER is estimated from local data and literature values, and then used to scale the attributional (average-rate) estimates. Details of the method are described in the appendix.

We can calculate local values of ε_v^p where dynamic vehicle occupancy data are available. From the TDD and TSPR, we do this for automobile, bus, and rail transit trips. For other modes and for ε_e^θ, we rely on the U.S.-average values reported in Bigazzi (2019, 2020). Local estimates for ε_v^p are generated from a regression model of VKT as a function of passenger kilometres travelled (PKT) and contextual factors. Automobile ε_v^p is estimated using automobile VKT and PKT from the TDD aggregated to the household (N=21,430). , and bus and rail VKT and PKT from the TSPR. Bus ε_v^p is estimated using cross-sectional data from the 2019 TSPR of bus trips and boardings per hour, which are reported by line, direction, day type, season, and time period. A multi-level (mixed effects) model is estimated with random effects by line for 216 unique lines, with a total of 12,315 complete observations. Rail ε_v^p is estimated using cross-sectional data from the 2019 TSPR of train passenger volumes per hour, which are reported by service, station, direction, day type, and hour of the day. The TSPR data are augmented with average train (vehicle) trips per hour over the same segmenting variables, derived from the GTFS data for September through December 2019. A multi-level (mixed effects) model is estimated with random effects by station for 55 unique stations, with a total of 6,268 complete observations. All elasticity models are estimated using the plm package in R (Croissant & Millo, 2008), with heteroscedasticity-consistent standard errors estimated using the lmtest package (Zeileis & Hothorn, 2002).

5.2.7. Contextual Variables for Modelling

The *Walkability Index* is a composite measure of neighbourhood walkability, comprised of four component variables (net residential density, commercial floor area, intersection density, and land use mix). Within this current analysis, the walkability value for each household was defined as the composite index value within a 1-kilometre network buffer, which follow a walkable road network, surrounding the location of the home (as defined by home 6-digit postal code). The values for each component measure were calculated beginning at the home postal code location and were then converted to z-scores to calculate the overall walkability index. The 1-km network buffer size was selected to represent the distance individuals could reasonably travel in a 10–15-minute walking trip and has been previous used to define the home "neighbourhood" area. (Colabianchi et al., 2007).

In addition to neighbourhood walkability, regional accessibility and sidewalk connectivity were calculated at the 6-digit postal code level and linked to the residential location. Regional accessibility was calculated by the mean number of minutes to travel to regional locations from the home location in morning peak traffic. These values were calculated for both vehicle travel, which provides an estimation of peak travel time from the home location if traveling by vehicle, as well as for transit travel, which conversely provides as estimation of peak travel time from the home if traveling by transit. Additionally, sidewalk connectivity, a measure of the completely of the pedestrian infrastructure, was calculated using methods similar to the walkability index in the 1-km network buffer surrounding the home.

Individual and household demographic data were obtained from the TDD. For this current analysis the following variables were utilized and categorized as follows: gender (dichotomized as female or male), age (categorized as child/youth [age 5-18], adult [age 19-64], and older adult [65+]), driver's license status (dichotomous yes/no), car share status (continuous 0-4, the number of car share membership participants reporting having), employment status (categorized as 'full time employed', 'full time student', 'part time worker or student, or self-employed' or 'non-worker/non-student'), household income (categorized as <$50,000, $50,000-100,000, and >$100,000), household size (continuous 1-10), number of household bicycles (continuous 0-10), number of vehicles per adult in the home (dichotomized as less vehicles than adults [vehicles < adults] and 1 or more vehicle per adult in the home [vehicles > = adults]).

5.2.8. Statistical Analysis

We calculated descriptive statistics to characterize the study sample stratified by neighhourhood walkability. Adjusted associations and 95% confidence intervals (CI) were calculated using linear regression and three iterations of adjustment variables. Three adjustment models were developed based on existing literature and conceptual understanding of individual and environmental factors associated with travel behaviour. Multi-level (mixed effects) models were developed to account for the hierarchical nature of the TDD (e.g., multiple participants living in the same household). A two-level model was used to account for clustering of participants within households. Additionally, survey weights obtained from the TDD were utilized in these analyses. All analyses were completed in R version 3.6.1; we used the *glmer()* function within the 'lme4' package to run generalized linear mixed-effect models (Bates et al., 2015).

5.3. Results

This section summarizes the emission estimation results for the observed trips in the TDD. A subsequent chapter investigates relationships between these emissions quantities and household and environmental attributes. The summary values for the TDD emissions are unweighted unless stated otherwise (i.e., without applying sampling or expansion weights), and so are not representative of regional emissions.

5.3.1. Attributional emissions

Table 5-3 summarizes the segment-level occupancy, PKT, and emissions intensity by segment mode. The values are aggregated across segments (not weighted by distance). Start and running emissions are combined to give per-PKT operating emissions. The table shows that emissions intensity varies widely across trips, especially for the automobile and main transit modes (bus and rail), for which dynamic occupancy values were used. Occupancy is a key determinant of per-PKT emissions intensity. Per-VKT emission rates vary as well, depending on vehicle type, fuel, congestion level, and other factors (varying across modes). The varying emissions intensities within modes is a strength of this analysis, which produced emissions estimates more sensitive to trip attributes than the more common approach of applying fixed per-PKT emissions rates by mode.

Table 5-3. Occupancy, PKT, and GHG intensity by segment mode

Segment mode	Occupancy (persons/vehicle)		PKT		Operating (g CO2e/PKT)		Non-operating fuel (g CO2e/PKT)		Non-operating vehicle (g CO2e/PKT)	
	mean	s.d.[1]	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Auto driver	1.38	0.68	10.04	11.52	257.53	216.11	91.83	71.46	69.28	26.09
Auto passenger	2.45	0.85	8.60	10.93	121.97	141.48	43.15	44.07	33.03	10.38
Taxi	1.24	0.00	7.28	8.91	130.03	24.36	37.37	5.70	192.73	0.00
Motorcycle	1.15	0.00	9.81	13.53	243.60	74.84	88.39	25.65	55.68	0.00
Transit bus	35.26	16.29	4.67	5.07	42.38	43.76	13.05	12.27	6.13	5.32
School bus	56.00	0.00	10.37	12.53	18.97	11.28	6.36	3.68	4.52	0.00
Shuttle	21.37	0.00	13.49	22.76	38.80	4.15	13.63	1.45	7.77	0.00
SkyTrain	40.19	31.89	8.54	6.79	0.00	0.00	3.90	4.03	9.70	10.02
Westcoast Express	120.47	71.70	19.95	14.92	19.70	18.34	8.28	6.38	6.96	10.84
SeaBus	124.82	23.39	2.78	1.10	185.46	36.81	58.10	11.53	11.05	2.19
Aqua Bus	4.00	0.00	5.87	7.15	56.34	0.00	36.51	0.00	3.64	0.00
Ferry	366.00	0.00	11.12	8.56	191.08	0.00	59.86	0.00	7.30	0.00
HandyDart	1.31	0.00	7.96	5.60	467.97	60.00	161.40	0.00	126.72	0.00

[1] standard deviation

Table 5-4 gives GHG emissions estimates per trip by primary mode. Figure 5-2 illustrates these values normalized by PKT to illustrate GHG intensity by primary mode. Note that the trip-aggregated values include emissions from other modal segments in the trips. For example, the Sky Train generates no operating emissions, but Sky Train trips that are accessed by automobile or transit bus include those operating emissions.

Table 5-4. Mean GHG emissions per trip by primary mode (g CO2e)

Primary mode	Number of trips	PKT	Operating (running)	Operating (start)	Non-operating (fuel)	Non-operating (vehicle)	Total
Auto Driver	123021	10.1	2079	109	797	714	3699
Auto Passenger	31404	8.6	785	52	304	287	1428
Taxi	521	7.3	790	47	247	1408	2491
Transit bus	12686	7.8	310	7	101	52	471
Sky Train	15980	15.1	300	15	145	176	635
West Coast Express	230	36.1	1668	77	605	456	2806
Sea Bus	187	8.6	996	30	338	197	1560
Handy Dart	153	8.1	3579	95	1296	1019	5988
School bus	630	10.6	206	5	70	54	335
Bike	4271	4.5	1	0	0	48	49
Walk	33516	1.0	0	0	0	0	0
Other mode	591	11.0	1379	54	526	366	2325
Total	223190	8.6	1306	70	502	456	2334

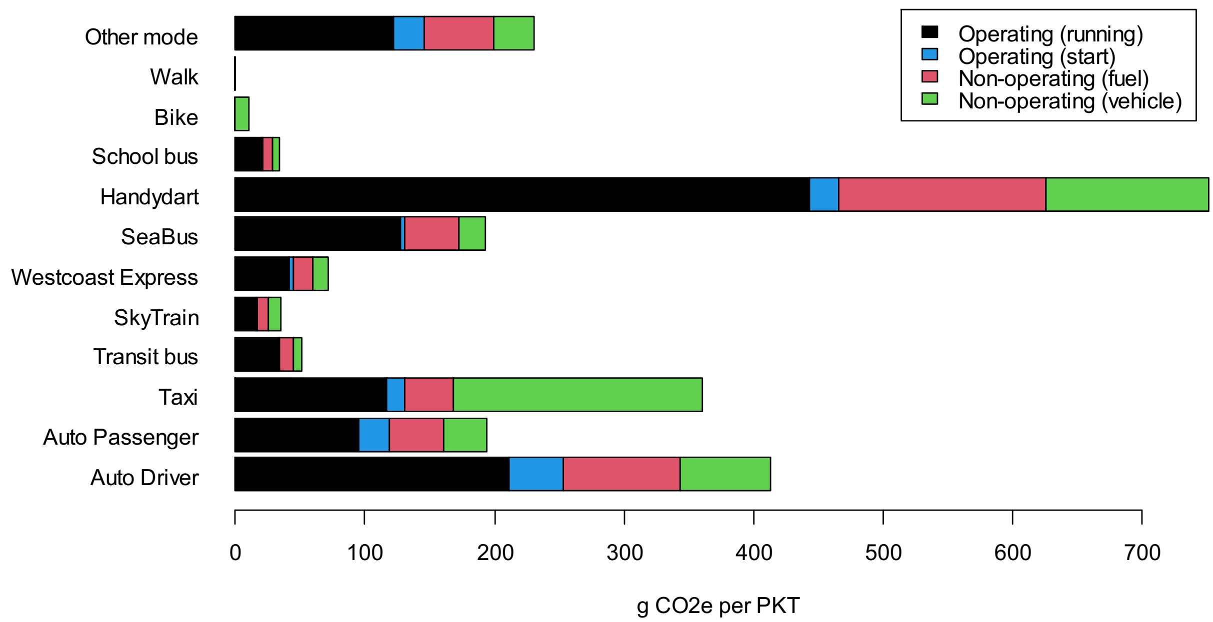

Figure 5-2. Average emissions intensity per PKT by primary mode

Table 5-5 gives average CAC emissions per trip by the same set of primary modes – again aggregating emissions from all trip segments.

Table 5-5. Average trip CAC emissions (g) by primary mode

Primary mode	CO	NOx	VOC	$PM_{2.5}$
Auto Driver	21.905	2.011	1.311	0.097
Auto Passenger	6.220	0.469	0.362	0.034
Taxi	2.987	0.165	0.204	0.073
Transit bus	1.825	0.786	0.125	0.027
Sky Train	2.195	0.572	0.145	0.022
West Coast Express	8.344	0.638	0.493	0.037
Sea Bus	4.541	0.419	0.288	0.022
Handy Dart	107.546	14.212	6.391	0.437
School bus	0.850	1.011	0.223	0.097
Bike	0.007	0.000	0.000	0.000
Walk	0.000	0.000	0.000	0.000
Other mode	41.020	2.402	4.649	0.090
Total	13.414	1.280	0.809	0.063

Table 5-6 reports summary statistics for further aggregated emissions up to the person and household levels, as both total daily GHG and GHG intensity per PKT. Emissions rates across the TDD sample vary widely, with interquartile ranges larger than the mean values. The 75th percentile persons and households are generating 8 to 10 times the daily emissions of the 25th percentile persons and households. Some of this is due to higher PKT, but emissions intensity (g CO2e per PKT) also varies by a factor of 3 to 5.

Table 5-6. Person- and household-level aggregate GHG measures

Measure	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Person-level total PKT	0.10	11.47	26.01	40.02	51.92	672.33
Household-level total PKT	0.16	21.59	47.95	73.10	96.60	1,463.80
Person-level total daily GHG (g CO2e)	0	1,347	5,483	10,814	14,158	396,433
Household-level total daily GHG (g CO2e)	0	3,502	11,964	19,753	26,562	589,654
Person-level GHG intensity (g CO2e per PKT)	0	82	232	251	385	2,700
Household-level GHG intensity (g CO2e per PKT)	0	122	269	265	388	2,406

Applying the TDD person and household sampling weights, the weighted mean daily PKT is 36.91 per person and 91.39 per household, generating weighted mean emissions of 10.18 kg CO_2e per person and 25.21 kg CO_2e per household. Weighted mean GHG intensity of travel is 251.6 or 276.6 g CO_2e per PKT, averaged at the person or household levels, respectively. The weighted median daily PKT is 21.22 per person and 61.80 per household, generating weighted median emissions of 3.90 kg CO_2e per person and 16.12 kg CO_2e per household. Weighted median GHG intensity of travel is 234.2 or 283.3 g CO_2e per PKT, averaged at the person or household levels, respectively. The household weighting has a greater impact than person weighting, due to a stronger relationship between weights and emissions at the household level. Household and person weights both range from 0.169 to 808.696, with median values of 26.087 and 24.453 and mean values of 47.736 and 39.569 for person and household weights, respectively. Person weights have a correlation of 0.052 with person-level GHG, whereas household weights have a correlation of 0.202 with household-level GHG.

As an external validation, in Figure 5-3 we compare our running emissions estimates to the emission rates from BC's Provincial emission factors by vehicle type and fuel type, which applied in 2017 (BC Ministry of Environment and Climate Change Strategy, 2022). Upstream fuel cycle emissions are included for battery electric and hybrid vehicles only, for comparability to the reference BC data. The central values are similar, but with greater variation in our estimates due to the inclusion of additional influencing factors (vehicle make, speed, road type, etc.).

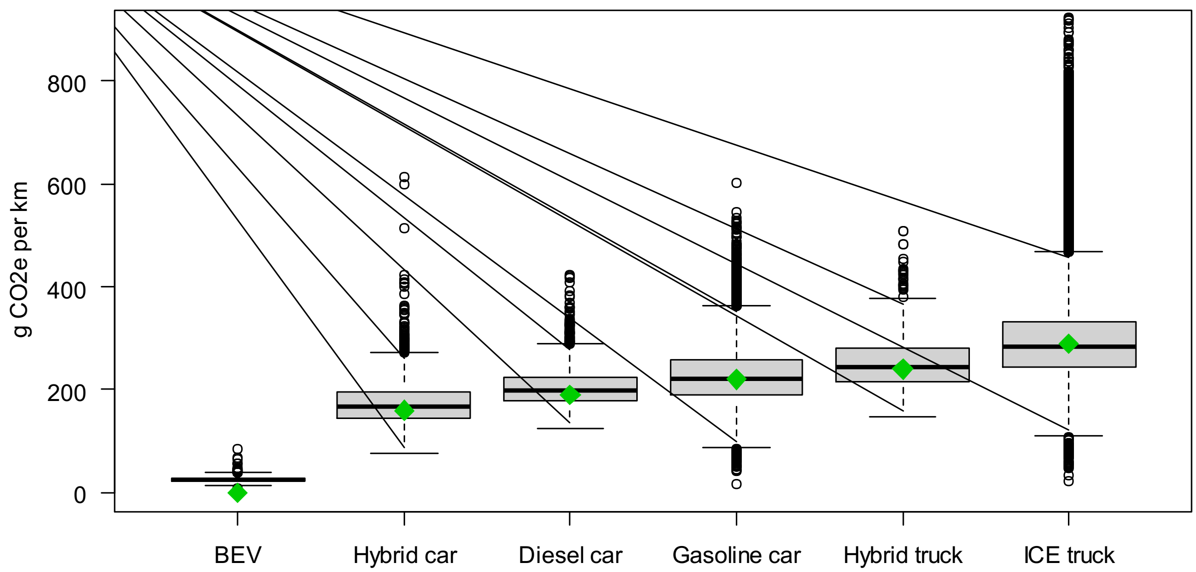

Figure 5-3. Comparison of our emission estimates for automobile trips (boxplots) to rates in BC Provincial guidance (green diamonds); including upstream fuel cycle emissions for BEV and hybrid powertrains for comparability

As another external validation, Wang et al. (2023) computed daily GHG emissions for the sample of trips in Toronto's 2016 household travel survey data. They report median personal daily GHG emissions from travel of 6.5 kg CO2e, and median GHG intensity of travel of 210 g CO2e per PKT. In comparison, we calculate median values of 5.5 kg CO2e/person/day and 232 g CO2e per PKT for the TDD. These values are similar, providing a good external validation on the estimates, despite different regions of analysis (Toronto is a larger but less dense region). In addition, there were several important differences in the estimation methods, including:

1. We include vehicle cycle emissions while they do not,
2. We include vehicle make/model adjustments to MOVES-modeled fuel efficiency by vehicle class/fuel, which they do not,
3. We use vehicle-specific fuel and powertrain types (gasoline, diesel, HEV, PHEV, and BEV) rather than assuming all passenger vehicles are gasoline-fuelled and all buses are diesel-fuelled,
4. We include dynamic passenger occupancy for automobile (from the TDD) and the primary transit modes (from operational data) rather than fixed occupancy by mode and time period (extracted from a travel demand model),
5. Our transit emission factors (per VKT) are based on measured fuel consumption data, rather than MOVES estimates (petrol buses) or manufacturer information (electric buses and trains),
6. We use a fixed GHG intensity for Provincial electricity *consumption*, rather than a dynamic GHG intensity for Provincial electricity *production*,

7. We attribute automobile emissions equally to all vehicle occupants, rather than only to the driver, and
8. We estimate emissions from all reported trips (with necessary assumptions) rather than excluding “other” modes.

Note also that due to skewed distributions and varying trip lengths and household sizes, these aggregate measures vary greatly if using mean versus median values, or aggregating by trip, person, or household. For further comparisons, mean daily GHG emissions per person from travel has been reported as 6.8 kg CO2e in Quebec City in the early 2000’s (Barla et al., 2011a), and just 0.6 kg CO2e in Xiamen City, China in 2015 (L. Xu et al., 2018).

5.3.2. Consequential emissions

Applying the estimated local values and literature elasticities we generate the MAER (marginal to average emissions ratios) given in Table 5-7. The MAER scaling factors are applied to trip segments by mode (multiplying by the previously-calculated attributional g CO_2e), and then summed to trip total consequential (marginal) emissions estimates in g CO_2e.

Table 5-7. MAER applied to the TDD emissions estimates

Mode	ε_e^{θ}	ε_v^{p}	MAER
Auto driver or passenger	0.040	0.977[1]	0.978
Motorcycle or taxi	0.040	0.977[1]	0.978
Transit bus	0.160	0.365[1]	0.467
SkyTrain	0.050	0.332[1]	0.365
Westcoast Express	0.050	0.135[1]	0.178
School bus	0.160	0.365[1]	0.467
Shuttle	0.100	0.858	0.872
SeaBus, Aqua Bus, ferry	0.050	0.431	0.459
HandyDart	0.100	0.763	0.787
Bicycle, walk, wheelchair	0.000	1.000	1.000

[1] From local data; others from Bigazzi (2019, 2020)

Figure 5-4 illustrates the consequential versus attributional (i.e., marginal versus average rate) emissions estimates by trip. The trip-level comparison aggregates segment-level differences of multi-modal trips, which is particularly relevant for transit trips with substantial (high-emitting) access and egress segments. Figure 5-4 shows that the consequential and attributional accounting frameworks generate substantially different emissions estimates for some but not all trips. The ratio of consequential to attributional emissions estimates by trip averages 0.91 (0.97 if emissions-weighted) and ranges from 0.18 to 1.00, with 25th, 50th, and 75th percentile values of 0.98 (due to the preponderance of automobile trips).

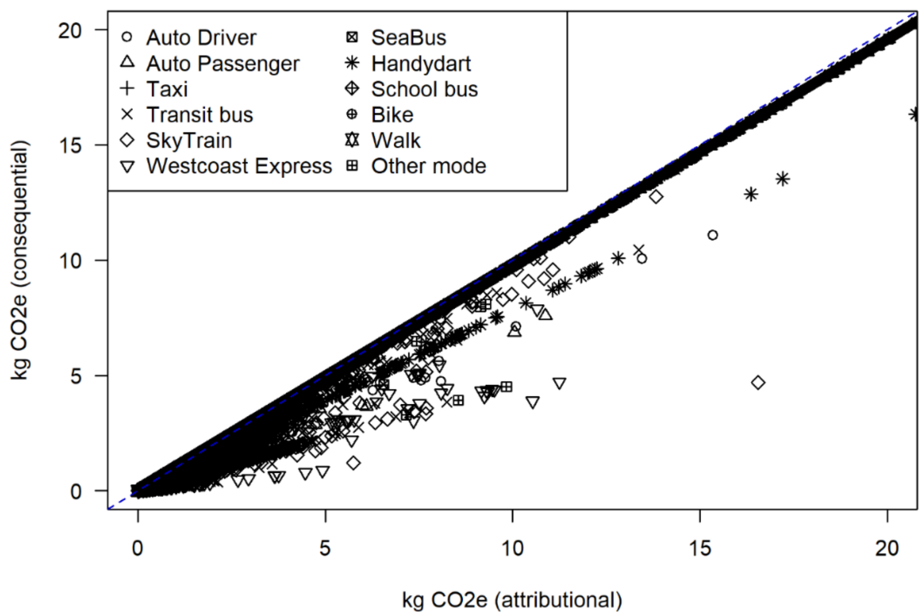

Figure 5-4. Trip-level attributional (average-rate) versus consequential (marginal-rate) emissions by primary trip mode; bounds truncated for legibility; blue dashed line denotes equivalent values

Given the variability in the effect of accounting framework on trip-level emissions, we estimated a regression model to examine the relationships between person and household-level factors and the difference between the two types of emissions estimates (in g CO2e). The results show that differences between the estimates are larger for people and households who use more low-MAER modes (particularly transit). Applying a consequential (vs. attributional) framework disproportionately increases the apparent climate impacts of travel for licensed drivers, younger (<19 years of age) and older (≥65 years of age) travellers, and households with more vehicle ownership or higher income, and disproportionately decreases the apparent climate impacts of travel for car-share members, larger households and renters.

5.3.3. Relationship between Emissions and Walkability

Table 5-8 shows the association between individual, household, and built environment factors and individual daily GHG emissions from travel (g CO_2e). Results of similar model specifications for local air pollution emissions (CO, PM2.5, and NOx) and the consequential CO_2e emissions are given in Appendix H

References

Eriksson, U., Arvidsson, D., Gebel, K., Ohlsson, H., & Sundquist, K. (2012). Walkability parameters, active transportation and objective physical activity: Moderating and mediating effects of motor vehicle ownership in a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 123. https://doi.org/10.1186/1479-5868-9-123

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Liao, Y., Lin, C.-Y., Lai, T.-F., Chen, Y.-J., Kim, B., & Park, J.-H. (2019). Walk Score® and Its Associations with Older Adults' Health Behaviors and Outcomes. *International Journal of Environmental Research and Public Health*, *16*(4), 622. https://doi.org/10.3390/ijerph16040622

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Thielman, J., Rosella, L., Copes, R., Lebenbaum, M., & Manson, H. (2015). Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *Preventive Medicine*, *77,* 174–180. https://doi.org/10.1016/j.ypmed.2015.05.011

Wasfi, R. A., Dasgupta, K., Eluru, N., & Ross, N. A. (2016). Exposure to walkable neighbourhoods in urban areas increases utilitarian walking: Longitudinal study of Canadians. *Journal of Transport & Health*, *3*(4), 440–447. https://doi.org/10.1016/j.jth.2015.08.001

Appendix H Across each type of emissions analyzed, reduced emissions are consistently associated with living in more walkable areas. Walkability results are presented as change in travel-related emissions compared to the reference level of least walkable areas. A graded relationship (dose-response) was shown across walkability bins for CO_2 emissions – with each increase in walkability associated with further reductions in CO_2 emissions, all of which were significantly different from the reference level. Levels 3 through 5 are also significantly different from level 2. The results for consequential CO_2 emissions are similar to those for attributional CO_2 emissions, but with a slightly stronger relationship to walkability. For $PM_{2.5}$ and NOX, more walkable (e.g., all walkability bins compared to the reference "least walkable" level) neighbourhoods were also associated with statistically significant reductions in emissions. However, although CO and VOC emissions were reduced across all walkability bins compared to the reference level, the reductions were not monotonic nor statistically significant across all walkability bins.

Conversely, more greenness around the home location was associated with higher travel emissions. After adjusting for walkability and greenness, sidewalk connectivity around the home location was not statistically significant, but regional transit and vehicle accessibility were both associated with significantly higher travel-related emissions.

Across all models and emissions, reporting female gender (compared to male) was associated with lower emissions, as was being in the youngest age group (5-18). Having a driver's licence, and a higher ratio of vehicles to adults living in the home, were also associated with significantly higher emissions estimates across all models. Higher household income tended to be associated with higher emissions, however these results were not consistently statistically significant. Additionally, being a full-time student, or a non-worker/non-student was associated with significantly lower emissions across all models compared to full-time workers.

Table 5-8. CO2e emissions (g/day) model estimation results

	Model 1[1]	Model 2	Model 3
Gender			
Male	Reference	Reference	Reference
Female	**-4512**	**-4490**	**-4501**
Age			
5-18	**-2904**	**-3112**	**-3215**
19-64	Reference	Reference	Reference
65+	-246	-464	-537
Driver's License			
No	Reference	Reference	Reference
Yes	**12295**	**12037**	**11892**
Car share			
+1	**-652**	-461	-224
Status			
Full time employed	Reference	Reference	Reference
Full time student	**-5461**	**-5555**	**-5608**
Part time employed/student or self-employed	**-2680**	**-2865**	**-2946**
Non-worker/non-student	**-11007**	**-11196**	**-11323**
Household income			
< $50,000	Reference	Reference	Reference
$50,000 - $100,000	**1686**	**1250**	**1045**
>$100,000	**3336**	**2390**	**2022**
Household size			
+1	**-564**	**-507**	**-686**
Household vehicles			
Vehicles < Adults	-[3]	Reference	Reference
Vehicles > = Adults	-	**3438**	**3054**
Bicycles			
+1	-	**1025**	**862**
Regional Accessibility[2]			
Vehicle	-	32	**74**
Transit	-	**103**	**59**
Sidewalk connectivity			-1113
Walkability			
1	-	-	Reference
2	-	-	**-1657**
3	-	-	**-3168**
4	-	-	**-4394**
5	-	-	**-4561**
Greenness			
1	-	-	Reference
2	-	-	**1331**
3	-	-	**1236**
4	-	-	**2679**
5	-	-	**3357**

[1] Bolded values indicate statistical significance at $p<0.05$

[2] Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

[3] '-' indicates variables not included in the model specification

Figure 5-5 illustrates the model results, relative to the median daily GHG emission rate of 5.48 kg CO_2e per day (applied to the middle bin 3). Daily GHG emissions are half as high in bin 4 versus bin 1, with only a small reduction between the 4th and 5th bins. In percentage terms, emissions rates fall by 19 to 22% at each successive walkability tier until bin 5, at which they fall by 4%.

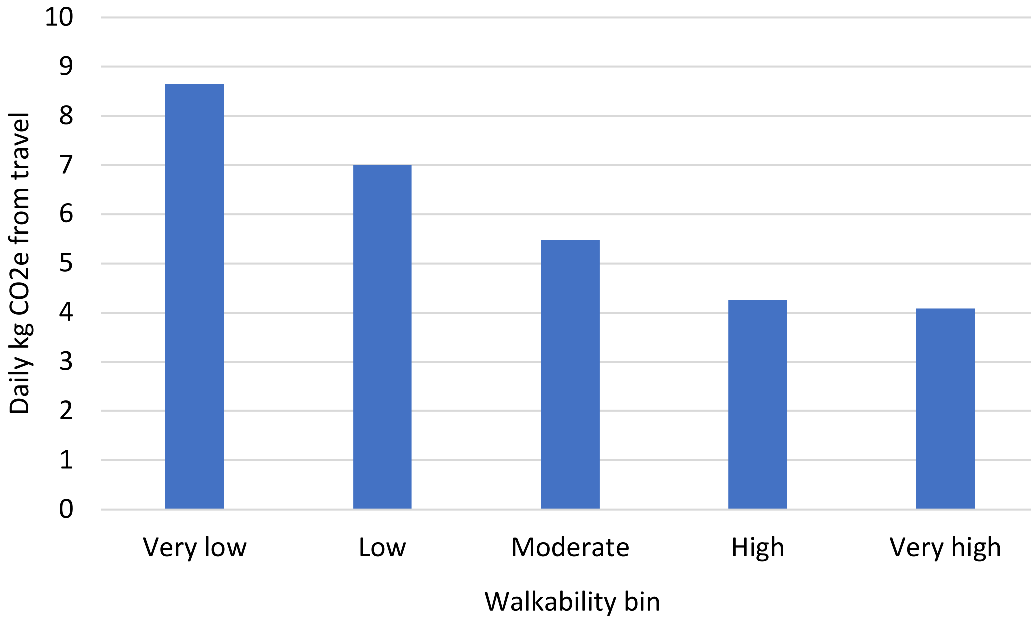

Figure 5-5. Illustration of GHG model results by walkability bin (assuming median GHG emissions for the middle bin)

5.4. Discussion

This chapter described the process of generating emissions estimates for all household travel reported in TransLink's 2017 Trip Diary Data. These emissions estimates were then used to investigate the factors influencing travel-related emissions in Metro Vancouver, which are presented in a subsequent chapter. To provide the best possible information for the statistical analysis, the estimation methods prioritized precision, consistency, sensitivity, and comprehensiveness. We used state-of-the-art models and the best available data to produce emissions estimates that are sensitive to vehicle make and type, occupancy, congestion, and other factors.

The statistical analysis results are consistent with previous findings in other locations which tended to find both individual and neighbourhood factors were associated with the individual emissions generated for daily travel purpose. Previous work across multiple locations have found that individuals and households living in more walkable neighbourhoods tended to generate lower travel related emissions, which may be attributed to the features of these neighbourhoods promoting the use of active travel modes, as opposed to private vehicles, being used to make daily trips (Darwish et al., 2023; L. D. Frank, Jr, et al., 2000, p. 200; Rickwood et al., 2008; Steemers, 2003; A. Wang et al., 2023; Wu et al., 2019). Additionally, these current results found similar patterns in individual characteristics which tended to be associated with emissions generates, including that higher income households tend to produce higher travel based emissions, which has previously been attributed to these households making more driving trips and owning more household vehicles (Barla et al., 2011b; Brand & Preston, 2010; Kahn, 1998; Ko et al., 2011; Sider et al., 2013).

Two novel aspects of our methodology are applying a vehicle-model adjustment to the MOVES-modelled emissions rates to account for both congestion/roadway effects and sub-vehicle-class variation in efficiency, and accounting for dynamic transit vehicle occupancy in attributing vehicle emissions to passengers. In contrast to the more common method of using fixed per-PKT emission rates by mode, our approach reveals highly dynamic intra-modal emissions intensity. This sensitivity to trip and traveller attributes beyond trip distance and mode is important for the subsequent analysis of the factors that influence emissions from household travel.

In addition, to our knowledge this is the first study to apply a consequential accounting framework to estimate the climate impacts of household travel. By reporting both attributional and consequential values, the results provide insights into the bias that can result from application of an inappropriate framework. We hope this methodical innovation advances the state of practice in climate analysis for the transportation sector.

Despite these strengths, the emissions data must be qualified with the caveat that they are estimates only, relying on the TDD, modelling tools (e.g., MOVES), additional data sets (e.g., NRCAN fuel economy database), and various assumptions (e.g., imputing missing vehicle data). Each model and data source has its own uncertainties, which are compounded in a modelling effort such as this (Dey et al., 2019; Frey, 2007). We have employed measured data wherever possible (e.g., transit operations), but a comprehensive accounting requires best estimates where direct information is lacking.

5.5. Conclusions

Modelling results showed that individual, household, and neighbourhood characteristics are all associated with travel-related emissions. When controlling for other factors, living in more walkable areas was associated with generating lower travel-related emissions. The largest emissions reductions are obtained by increasing walkability over the first 4 bins, with roughly half the daily emissions for bin 4 versus bin 1; the emissions benefits of increasing walkability further to bin 5 are much smaller (a 4% reduction).

5.6. References[24]

1.2. [24] **The full set of references used for this analysis are provided in the References section in References**

Eriksson, U., Arvidsson, D., Gebel, K., Ohlsson, H., & Sundquist, K. (2012). Walkability parameters, active transportation and objective physical activity: Moderating and mediating effects of motor vehicle ownership in a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 123. https://doi.org/10.1186/1479-5868-9-123

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Appendix H.

Health Impacts

6. Obesity, Diabetes & Hypertension with Walkability – Longitudinal Adult Associations Between Walkability and Incident Obesity, Hypertension, and Type 2 Diabetes[25]

6.1. Background

Obesity and obesity-related diseases continue to adversely impact health and economic indicators across low, middle, and high income countries (Shekar & Popkin, 2020; World Health Organization (WHO), 2016). The prevalence of obesity worldwide has tripled in the last 50 years and is responsible for nearly three million premature deaths annually (World Health Organization (WHO), n.d.). Overweight and obesity are linked to increased risk of numerous chronic conditions including type 2 diabetes mellitus (T2DM) and high blood pressure (HBP), which are leading causes of cardiovascular disease and premature mortality globally (Leon & Maddox, 2015; Mills et al., 2020), as well as many cancers.

Living in walkable environments has been linked to significantly higher levels of PA and active travel across multiple age groups (Carlson et al., 2017; Cerin et al., 2017; L. Frank et al., 2016; Grasser et al., 2012; J. Sallis et al., 2016). Research has shown several macro-level, built environment features support walkability, including, having a mix of land uses in close proximity (i.e. destination diversity), greater residential density, higher retail floor area ratio, and a well-connected road network (L. D. Frank et al., 2005; Saelens & Handy, 2008). Among adults, there is growing evidence linking GIS-measured walkability to lower prevalence of obesity and metabolic disorders. Several recent reviews show generally consistent inverse relationships between walkability and body weight or obesity, hypertension and diabetes (S. Barbosa et al., 2019; Chandrabose, Cerin, et al., 2019; L. D. Frank et al., 2022; Jones et al., 2021; J. Sallis et al., 2016; Tarlov et al., 2020a), though findings are mixed. Obesity is the most studied of these outcomes, although most research to date has been cross-sectional. Longitudinal studies have commonly utilized a single baseline walkability measure, with repeated health measures over time. This chapter aims to contribute to our understanding of temporal relationships between longitudinal, objectively measured walkability and reported health outcomes.

Using data from an observational, longitudinal cohort in British Columbia, this study investigated associations between change in objectively-measured walkability and incident obesity, HBP, and T2DM. We hypothesized that walkability would be inversely related to odds of becoming obese or starting treatment for HBP or T2DM at follow up. In secondary analyses, we additionally studied whether relationships differed across demographic characteristics, including sex, age, and income.

[25] For the full article associated with this study, please see
Appendix D.

6.2. Methods

6.2.1. Analytic sample

The current study used data from the British Columbia Generations Project (BCGP), the largest longitudinal health study in British Columbia. Details have been published elsewhere but, in brief, BCGP prospectively follows a cohort of nearly 30,000 adults from 35 to 69 years of age (Dhalla et al., 2019). This analysis includes data only from participants residing in the Metro Vancouver and Fraser Valley Regional Districts to maximize potential change in walkability over time (n=12,181). Between 2009 and 2013, participants were recruited to complete baseline questionnaires on health, lifestyle factors and medical histories and roughly half of the full sample had physiological measures collected in person at an assessment center. From 2016 to 2019, participants were invited to complete follow-up surveys on health and lifestyle factors, with approximately three-quarters of the original sample contributing data.

6.2.2. Exposure Variable

GIS-based walkability index: Participant-level walkability was assessed using a validated composite index which includes four built environment features: land use mix ((LUM) diversity of destinations), intersection density ((IDENS) street connectivity), net residential density ((NRD) housing density), and commercial floor-to-area ratio ((CFAR) ratio of floor area to lot size) (L. D. Frank et al., 2010a). A walkability score was created for each postal code which, on average, covers roughly 19 Canadian households and has been shown to provide acceptable positional accuracy, especially in urban areas (Khan et al., 2018; Pinault et al., 2020). The index was applied to a 1km road network buffer from participants' postal code centroid. Participants provided their residential history since childhood. An average of each walkability component feature was calculated for participants' residential locations from 2000-2006 (baseline) and 2012-2016 (follow up). We created the baseline and follow up walkability indices by calculating z-scores for each of the 4 components (LUM, IDENS, NRD, CFAR) using 2006 mean and standard deviations for the main urbanized areas of the region excluding rural hinterlands (*Statistics Canada*, n.d.). Standardizing to baseline regional walkability provides a measure of how individuals' walkability compares to the region and how it has changed over time. Change in walkability was the sum of zCFAR + zLUM + zIDENS + zNRD at follow up minus the sum in baseline. We additionally quintiled the change in walkability score to explore the relationship between walkability and the outcomes of interest in more depth.

6.2.3. Outcome Variables

Obesity: At baseline, participants (n=8,100) had height and weight measured at an assessment center; participants (n=3,696) not attending an assessment center provided self-reported height and weight. At follow up, all height and weight data were self-reported. BMI was calculated as the weight in kilograms divided by the height in metres squared and a binary obesity variable was created (BMI ≥30 or BMI <30). Incident obesity was defined as shifting from not obese at baseline to obese at follow up.

Hypertension: At both baseline and follow up, participants were considered to have prevalent hypertension if they reported currently being treated for high blood pressure or hypertension. Those not treated for hypertension at baseline and treated at follow up were considered to have incident hypertension.

Diabetes: At baseline, participants were considered to have type 2 diabetes if they reported being currently under treatment for diabetes and having been diagnosed with type 2 diabetes. At follow up, participants reported whether they were currently under treatment for type 2 diabetes. Incident T2DM was defined as a change from not being treated at baseline to currently being treated for at follow up.

6.2.4. Covariates

Participant demographics were collected through the health and lifestyle questionnaire and included age, male/female sex. Racial and ethnic descent was classified as "White or European", "Some other descent", or "Unknown". Baseline income was dichotomized into "≤74,999" or "≥$75,000", to approximate above or below median income in the Vancouver area during baseline data collection. We also adjusted models for the length of time (in years) between the baseline and follow up assessment.

6.2.5. Statistical Analysis

Descriptive statistics compared baseline participant characteristics across change in walkability quintiles using ANOVA for continuous and χ^2 for categorical variables. We used mixed effects regression models to assess associations between change in walkability (as a continuous variable) with binary incident obesity, T2DM, and HBP status, in separate models. We also modeled change in obesity status by quintiled change in walkability. Mixed model analyses allow for missing observations in studies with repeated measures, avoiding bias associated with complete case analysis (Gabrio et al., 2022). To account for non-independence of repeated measures, we included participant ID as a random effect. We assessed clustering by Forward Sortation Area (the geographical unit designated by the first 3 digits in Canadian postal codes) and found it accounted for less than 1% of total variance so did not include it in models. All models adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments. We conducted a sensitivity analysis including only those with self-reported height and weight data at both assessments to test the robustness of results. We additionally explored associations within individual subgroups, including sex (female/male), age (above/below 60 years), and baseline income (above/below $75,000). All analyses were conducted in Stata Version 16.1 (StataCorp, College Station, TX).

6.3. Results

6.3.1. Descriptive statistics

We included those participants with walkability data at both time points (N=9,932). The time between study assessments ranged from 2.7 to 9.3 years, with a mean 5.5 years. At baseline, participants were on average 55 years of age, and nearly 70% were female.

The majority (80%) were White or of European descent, and roughly 60% had an income over $75,000 CAD. Approximately 16% of the sample were obese, and 12% and 2% were being treated for hypertension and T2DM at baseline, respectively. There were differences in age, length of follow up and education level across change in walkability quintiles, though no obvious pattern was discernible. We did not observe any differences in baseline obesity, HBP or T2DM across change in walkability groups. As expected, those living in the most walkable neighbourhoods at baseline had the least change in walkability between study assessments.

6.3.2. Model results

Odds ratios and confidence intervals for all models are presented in Table 6-1, whereas the figures show the effect size and 95% CIs. Change in walkability was inversely associated with incident obesity in both unadjusted and adjusted models (Figure 6-1). In adjusted analyses, a 1-unit increase in the walkability change score was associated with a 9% reduction in odds of becoming obese (OR=0.91, 95% CI 0.85, 0.98). In those with self-reported height and weight data only, there was a slightly larger decrease in odds of incident obesity (OR 0.88, 95% CI 0.79,0.98). Change in walkability was not associated with incident HBP or T2DM in unadjusted or adjusted models.

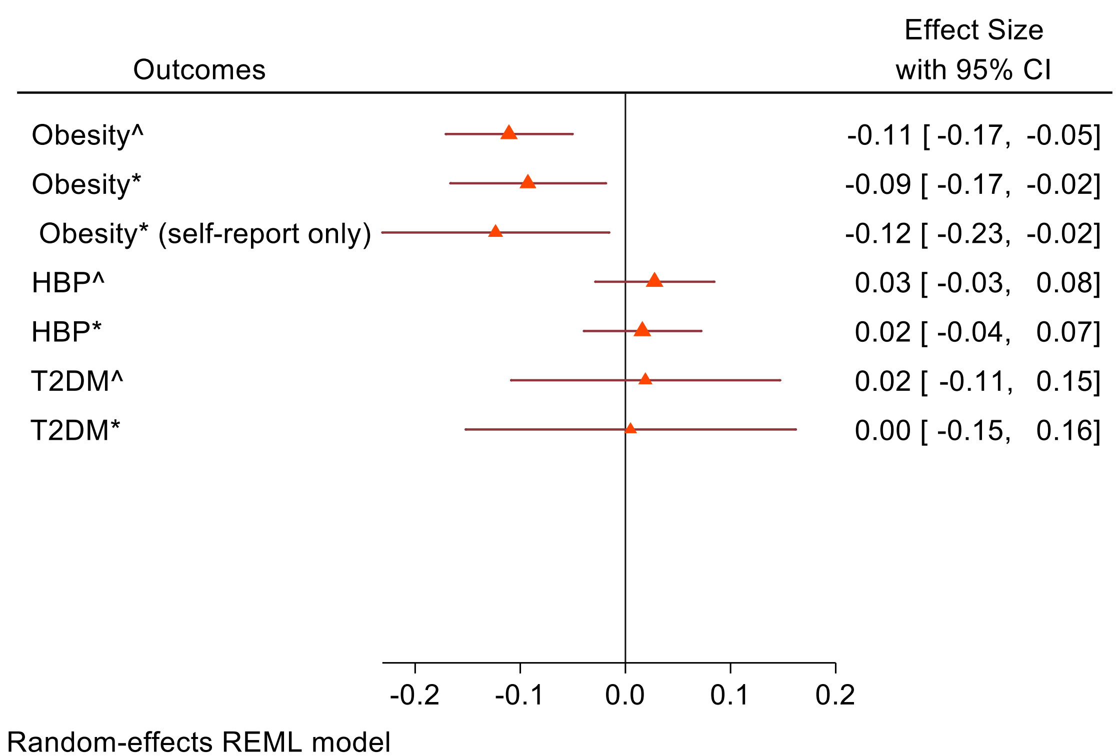

Figure 6-1: Incident obesity, HBP and T2DM

^Unadjusted models

*Adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments.

Figure 6-2 shows the association between change in walkability quintiles and incident obesity. Compared to quintile 1, those in quintile 5 had a 51% reduction in odds of becoming obese (OR=0.49, 95% CI 0.27, 0.88). Confidence intervals overlapped the null value for other quintiles, though the reduction in odds of incident obesity suggested a graded inverse association with greater change in walkability.

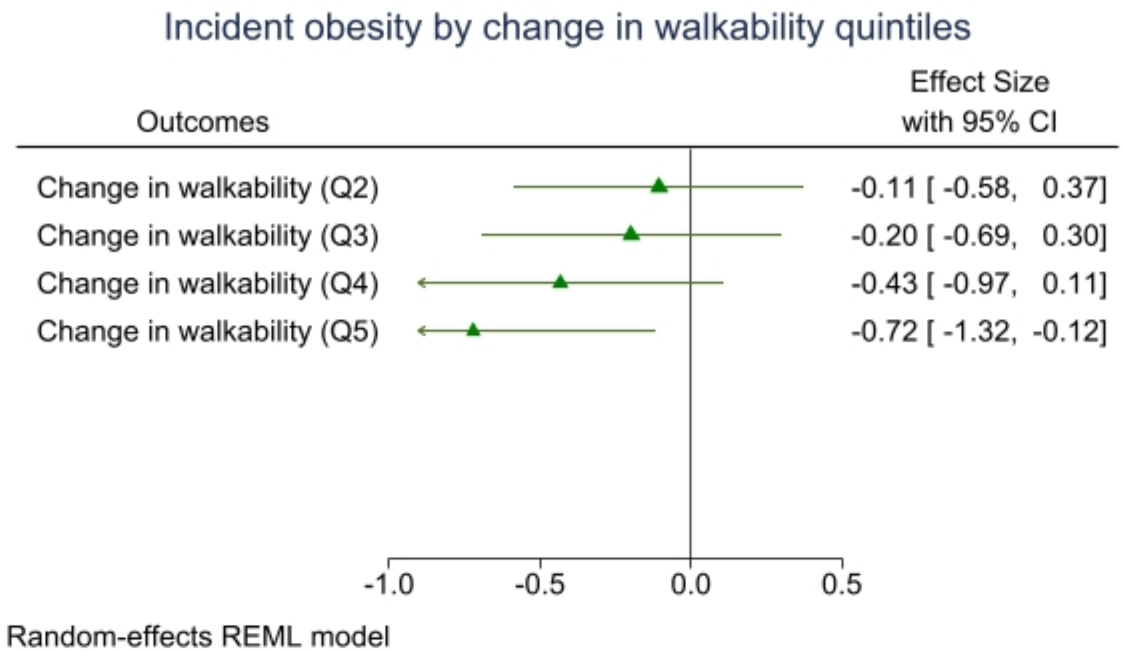

Figure 6-2: Incident obesity by change in walkability quintiles

All models adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments.

Change in walkability was associated with an 10% reduction in the odds of becoming obese in females (OR=0.90, 95% CI 0.82,0.98), while results among males were imprecise (Figure 6-3). A similar reduction in odds of obesity at follow up was observed among those who were less than 60 years old at baseline (OR=0.91, 95% CI 0.83,0.99), while this relationship was imprecise in older adults. Results by income were imprecise though suggestive that higher household income was associated with a slightly greater reduction in odds of obesity (OR=0.91, 95% CI 0.83, 1.0) compared to the lower income group.

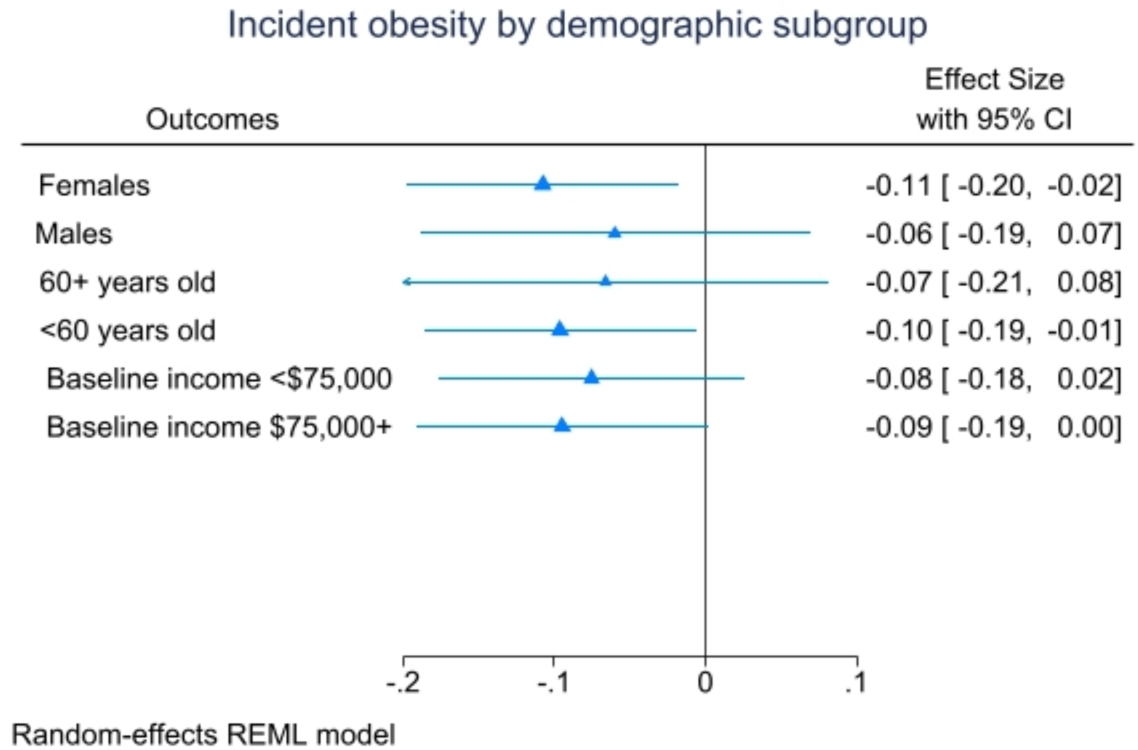

Figure 6-3: Incident obesity by demographic subgroups.

All models adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments.

Table 6-1: Odds ratios, p-values, and 95% confidence intervals for models

	Odds Ratio	**p-value**	**95% CI**	**95% CI**
Becoming obese+	**0.895**	**0.000**	**0.843**	**0.951**
Becoming obese*	**0.911**	**0.014**	**0.847**	**0.981**
Becoming obese (self-report only)*	0.884	0.025	0.794	0.984
Treated for HBP+	1.028		0.972	1.088
Treated for HBP*	1.016	0.571	0.961	1.074
Treated for T2 Diabetes+	1.019	0.771	0.897	1.158
Treated for T2 Diabetes*	**1.005**	0.952	0.859	1.175
Incident obesity by change in walkability quintiles				
Quintile 2	0.899	0.663	0.558	1.449
Quintile 3	0.820	0.431	0.500	1.344
Quintile 4	0.649	0.115	0.379	1.111
Quintile 5	**0.486**	**0.018**	**0.268**	**0.884**
Incident obesity by age				
60 and over	0.936	0.377	0.809	1.084
Under 60	**0.908**	**0.035**	**0.830**	**0.993**
Incident obesity by sex				
Female	**0.898**	**0.019**	**0.821**	**0.982**
Male	0.942	0.360	0.828	1.071
Incident obesity by income				
Baseline income <$75,000	0.927	0.141	0.839	1.025
Baseline income $75,000+	**0.910**	**0.052**	**0.827**	**1.001**

6.4. Discussion

We found change in walkability was associated with a significant reduction in obesity. The effect was strongest among women, adults 60 years and younger, and those with higher incomes. The risk of becoming obese decreased with greater change in walkability over time. We did not observe a relationship between walkability and incident HBP or T2DM. It is likely that the follow up period may have been insufficient to observe changes in these longer-term, chronic disease outcomes. Much of the research on walkability and health outcomes has been cross-sectional or utilized a single baseline measure of walkability with repeated health outcomes (Chandrabose, Rachele, et al., 2019a; Lai et al., 2023). The current study expands the longitudinal evidence supporting urban design as an effective approach to reducing the significant public health burden of obesity and obesity-related conditions.

6.5. Conclusions

This unique study provides longitudinal evidence on the benefits of increased neighbourhood walkability on reduced incidence of obesity in urban dwelling adults. While we found no evidence of impact on downstream chronic disease the analysis was limited by relying on self-reported blood pressure and diabetes incidence, as well as insufficient follow up. Longer monitoring would help elucidate this relationship and the length of exposure required to modify risk. As obesity remains a significant public health concern, policies and investments to support walkable communities are justified.

6.6. References[26]

[26] The full set of references used for this analysis are provided in the References section in
Appendix D.

7. Mental Health with Walkability & Greenspace – Multifaceted Impacts of Green Space and Walkability on Mental Health: Depression and Anxiety in Focus[27]

7.1. Background

Mental health refers to the overall state of an individual's well-being and their capacity to positively impact the community, while effectively managing the everyday challenges of stress ((WHO), 2022). The term "mental health conditions" encompasses mental disorders, psychosocial disabilities, and other mental states characterized by considerable distress, impaired functioning, or a potential risk of self-harm (Perrino et al., 2019). Mental disorders have a significant impact on the global burden of disease, affecting communities and people of all ages in both high and low-income countries (WHO (World Health Organization), 2018).Depression stands as a significant public health issue affecting 344 million individuals globally in 2019 ("GBD Mental Disorders Collaborators. Global, Regional, and National Burden of 12 Mental Disorders in 204 Countries and Territories, 1990–2019: A Systematic Analysis for the Global Burden of Disease Study 2019," 2022). Based on the 2012 Canadian Community Health Survey (CCHS), approximately 4.7% of Canadians aged 15 and above exhibited symptoms consistent with a diagnosis of major depression (C. Pearson et al., 2013a).

The research indicates that depression is estimated to affect approximately 10.8% of the global population throughout their lifetime (Lim et al., 2018). While it is estimated that about 11.3% of Canadians experienced a major depressive episode at some point in their lives (C. Pearson et al., 2013b). Depression is identified by symptoms such as a loss of interest or enjoyment in activities, decreased energy levels, and depressed mood (World Health Organization, 2017) (2). Depression differs from normal mood fluctuations and daily emotional responses. During a depressive episode, individuals experience persistent feelings of sadness, irritability, or emptiness, along with reduced interest in activities, lasting for most of the day, nearly every day, for at least two weeks. Additional symptoms include difficulty concentrating, overwhelming guilt or low self-esteem, a sense of hopelessness about the future, thoughts of death or suicide, disrupted sleep, appetite changes, and persistent fatigue (Perrino et al., 2019).

Anxiety disorders stand as the second most common mental disorder globally, affecting approximately 301 million individuals in 2019 (Núñez-González et al., 2020). These disorders are characterized by intense feelings of fear and worry, accompanied by associated behavioral disturbances. The severity of these symptoms is significant enough to cause either notable distress or substantial impairment in daily functioning (Perrino et al., 2019). In the Canadian context, the prevalence of diagnosed mood and anxiety disorders has shown a notable increase. In 2019, it was estimated that about 4.4 million Canadians, or 14% of those aged 12 and older residing in the provinces, had a diagnosed

[27] For the full article associated with this study, please see Appendix E.

mood or anxiety disorder. This shows an increase from 3.7 million individuals, or 12%, in 2015. Importantly, this rise has been particularly significant among young adults aged 18 to 34, where the prevalence increased from 13% in 2015 to 17% in 2019 ("Statistics Canada. Canadian Community Health Survey, 2019: Mental HealthStatistics. Canada Catalogue No. 11–001-X," 2020).

Mental health is influenced by a multifaceted interplay of factors, extending beyond individual characteristics to encompass a range of health determinants. These include elements at the individual, family, community, and structural levels, all of which can either bolster or compromise mental well-being (Perrino et al., 2019; Shen, 2014; *World Health Organization (WHO). Mental Health Action Plan 2013–2020*, 2013). Hirschfeld and Weismann (2002) identified several risk factors for depression, such as being female, having medical illnesses, experiencing early-life trauma, and facing adverse life events. These risk factors encompass various individual-level attributes, underscoring the significance of investigating environmental risk factors as well in understanding this major public health concern (Hirschfeld & Weissman, 2002). The association of built and natural environment with mental health remains an underexplored domain. While some studies have found a positive correlation between increased walkability or green space and reduced levels of depression and anxiety (Beyer et al., 2014; Hartig et al., 2014), the relationships are often not straightforward, and the mechanisms underlying these associations are not fully understood (McCormack & Shiell, 2011).

The primary objective of this study is to investigate the relationship between key elements of the urban environment—specifically, walkability and green space—and clinically diagnosed depression and anxiety. Complementing this, the secondary objective delves into the underlying mechanisms that drive these associations.

7.2. Methods

Data sources:

The study integrated data from three sources: BC Generations Project (BCGP) (BCGP, 2019), the Canadian Urban Environmental Health Research Consortium (CANUE) (CANUE, n.d.), and the Where Matters: Health & Economic Benefits Study (*Where Matters: Health & Economic Benefits Study*, n.d.).

Green space assessment:

The normalized difference vegetation index (NDVI) is a widely used measure to assess the health and density of vegetation in an area, and it is derived from satellite imagery. The NDVI for the residential neighbourhood was derived from the CANUE dataset. The categories applied for NDVI as a categorical variable are obtained from NDVI quintiles. The NDVI levels used are as follows: very low – 1st quintile (0.22,0.316], low – 2nd quintile (0.316,0.39], medium - 3rd quintile (0.316,0.39], high - 4th quintile (0.39,0.48], very high - 5th quintile (0.48,0.81].

Walkability assessment:

The Where Matters Study (*Where Matters: Health & Economic Benefits Study*, n.d.) constructed a walkability index for the Greater Vancouver region in British Columbia, utilizing postal codes. This index was developed by integrating data from different sources, including Statistics Canada (StatsCan, n.d.) and CanMap (*DMTISpatial. CanMap® GIS Data for GIS Mapping Software - DMTI Spatial.*, n.d.), and it is specifically linked to the BCGP cohort, focusing on residential postal codes. In comparison to the CANUE walkability index, the Where Matters index incorporates extra factors to evaluate walkability and has been established for the years 2006, 2011, and 2016, utilizing the following measures:

a) Residential Density: The number of residential units per acre within a neighbourhood.

b) Commercial Density: The area designated for commercial use within a neighbourhood.

c) Land use mix: A measure of the different purposes of land use in a neighourhood. A higher value indicates even distribution between purposes of land use such as residential, commercial, entertainment, and office development.

d) Street Connectivity: The number of street intersections in a neighourhood. A larger number of intersections would lead to increased connectivity and movement.

The walkability index used in the current study is the sample standardized walkability index. The categories applied for the walkability index as a categorical variable are obtained from walkability index quintiles. The walkability index levels used in the analysis are as follows: very low – 1st quintile [-6.1,-1.86], low – 2nd quintile (-1.86,-0.363], medium - 3rd quintile (-0.363,1.25], high - 4th quintile (1.25,3.03], very high - 5th quintile (3.03,13.8].

Depression and anxiety were evaluated separately as both continuous variables and categorical variables, utilizing a cutoff score of 10 to distinguish between different levels. Descriptive statistics were used to summarize the characteristics of the study sample, including demographics and relevant variables. Univariate descriptive analysis was conducted to assess the distribution of variables of interest, which includes exposure variables (i.e., NDVI and walkability index), outcome variables (i.e., depression and anxiety), and covariates (i.e., income, education, marital status, health perception, alcohol intake, smoking, sleep duration, activity category). Continuous variables were analyzed to reveal means, standard deviations, and interquartile ranges, while categorical variables were presented in terms of frequencies. The study used bivariate analysis to examine the relationships between exposure and outcome variables, as well as the associations between covariates and both exposure and outcome variables. We employed generalized linear models for the multivariable analysis. We examined the relationship between green space and depression, as well as anxiety, and also looked at how walkability correlates with these mental health conditions. Logistic regression was used for analyzing relationships with categorical mental health outcomes, while linear regression was applied for continuous mental health scores. This included overall scores as well as individual components of depression and anxiety questionnaires. In the regression analysis the following potential confounding variables were identified based on the literature: age, sex, education level, occupation, income, physical activity, sleep pattern, dietary intake, smoking habits, and alcohol intake and the variables retained in the final model were selected by backward selection using the Akaike Information Criteria (AIC). Model goodness of fit was assessed by Area Under the Curve (AUC) from Receiver Operating Characteristics (ROC). Sensitivity analysis was performed to compare the participants with complete data and participants with missing values.

7.3. Results

The initial sample collected in this study was 9,238. After removing the participants with missing data, a total of 5,085 participants with complete information were considered for the analysis, of which 213 (4.1%) were categorized as depressed, and 4872 (95.8%) as not depressed. The mean age of the overall sample was 61 years (SD = 9).

Table 7-1 presents the univariable and multivariable logistic regression analyses exploring the association between the walkability index and anxiety condition using complete cases (n=5085). Participants living in areas with very high walkability had a statistically significant increased odds of anxiety (OR=1.43, 95% CI: 1.03–1.98), indicating that people living in areas with very high walkability had increased odds of experiencing anxiety, even after adjusting for demographic, lifestyle, and health-related variables. Table 7-2 demonstrates the linear regression analyses on the relationship between walkability index and the total score of anxiety. The fully adjusted models revealed that individuals in areas with very high walkability had a statistically significant increase in the total anxiety score ($\beta=0.36$, $p<0.01$). This trend remained even after adjusting for confounding variables, indicating a strong positive association between high walkability and anxiety scores. Table 7-3 displays the results from the linear regression analyses exploring the relationship between walkability index and individual components of anxiety. For areas with very high walkability, the unadjusted analysis showed a statistically significant positive association across multiple components, such as 'Nervous' ($\beta=0.11$, $p<0.0001$), 'Worrying1' ($\beta=0.08$, $p<0.001$), and 'Afraid' ($\beta=0.05$, $p=0.01$). This relationship generally held in the minimally and fully adjusted models, particularly for the components 'Nervous' and 'Worrying1' ($p<0.01$).

Table 7-1: Univariable and multivariable logistic regression using complete cases (n=5085) for the relationship between walkability index and anxiety condition

Outcome: Anxiety (Yes – No)			
	Unadjusted model	**Minimally adjusted model[a]**	**Fully adjusted model[b]**
Independent variable	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
Walkability index			
Very low	Ref	Ref	Ref
Low	1.28 (0.83 – 1.98)	1.18 (0.86 – 1.62)	1.22 (0.88 – 1.70)
Medium	1.32 (0.86 – 2.04)	1.02 (0.74 – 1.42)	1.03 (0.73 – 1.45)
High	1.12 (0.72 – 1.75)	0.96 (0.70 – 1.34)	1.02 (0.72 – 1.43)
Very high	**1.74 (1.16 – 2.64)**	**1.35 (1.00 – 1.84)**	**1.43 (1.03 – 1.98)**

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

Table 7-2: Univariable and multivariable linear regression using complete cases (n=5085) for the relationship between walkability index and the total score of anxiety

Outcome: Anxiety total score						
	Unadjusted model		**Minimally adjusted model[a]**		**Fully adjusted model[b]**	
Independent variable	**β**	**p-value**	**β**	**p-value**	**β**	**p-value**
Walkability index						
Very low	Ref		Ref		Ref	
Low	0.16	0.23	0.10	0.47	0.10	0.43
Medium	0.04	0.76	0.14	0.53	-0.12	0.37
High	0.12	0.36	-0.01	0.95	-0.01	0.92
Very high	**0.46**	**<0.001**	**0.39**	**<0.01**	**0.36**	**<0.01**

[a] Minimally adjusted model is adjusted for age, sex, and income
[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

Table 7-3: Unadjusted, minimally adjusted and fully adjusted linear regression using complete cases (n=5085) for the relationship between walkability index and the scores of anxiety components separately

Outcome: Anxiety component scores							
	Unadjusted analysis						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.02 (0.51)	0.03 (0.21)	0.02 (0.52)	0.03 (0.21)	0.01 (0.71)	0.03 (0.19)	0.02 (0.25)
Medium	0.00 (0.89)	0.00 (0.86)	-0.02 (0.45)	0.02 (0.41)	0.01 (0.52)	0.02 (0.49)	0.02 (0.33)
High	0.03 (0.34)	0.02 (0.36)	0.00 (0.90)	0.03 (0.19)	0.00 (0.89)	0.02 (0.32)	0.03 (0.21)
Very high	**0.11 (<0.0001)**	**0.08 (<0.001)**	**0.06 (0.02)**	**0.09 (<0.001)**	0.03 (0.18)	**0.06 (0.01)**	0.05 (0.01)
	Minimally adjusted analysis[a]						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.00 (0.95)	0.02 (0.38)	0.00 (0.98)	0.02 (0.36)	0.00 (0.81)	0.03 (0.27)	0.02 (0.37)
Medium	-0.02 (0.38)	-0.01 (0.57)	-0.05 (0.09)	0.01 (0.82)	0.00 (0.88)	0.00 (0.89)	0.00 (0.87)
High	0.01 (0.77)	0.00 (0.96)	-0.02 (0.42)	0.02 (0.45)	-0.02 (0.36)	0.00 (0.86)	0.00 (0.84)
Very high	**0.1 (<0.001)**	**0.07 (0.01)**	0.05 (0.09)	**0.08 (<0.01)**	0.02 (0.36)	**0.05 (0.05)**	0.04 (0.09)
	Fully adjusted analysis[b]						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.01 (0.71)	0.02 (0.33)	0.00 (0.89)	0.03 (0.31)	0.01 (0.75)	0.02 (0.31)	0.02 (0.43)
Medium	-0.02 (0.39)	-0.02 (0.38)	**-0.54 (0.04)**	0.00 (0.86)	-0.01 (0.79)	-0.01 (0.82)	0.00 (0.97)
High	0.01 (0.79)	0.00 (0.95)	-0.03 (0.33)	0.02 (0.53)	-0.02 (0.36)	0.00 (0.89)	0.01 (0.76)
Very high	**0.09 (<0.001)**	**0.07 (0.01)**	0.04 (0.12)	**0.07 (<0.01)**	0.02 (0.36)	**0.05 (0.04)**	0.03 (0.18)

[a] Minimally adjusted model is adjusted for age, sex, and income
[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

7.4. Discussion

Our study investigated the relationship between the walkability index and depression. We did not observe any significant association between walkability and depression as defined by the depression score. However, in the continuous outcome analysis, measured as the total score of depression, higher walkability was associated with a higher depression score in unadjusted analysis, reaching statistical significance for high and very high levels of walkability. However, these associations were considerably attenuated in both minimally adjusted and fully adjusted models. The lack of a significant association in the minimally adjusted model, which considered age, sex, and income, suggests that these factors may be confounding the relationship between walkability and depression. This is in line with previous literature that has identified age, sex, and income as significant determinants of mental health. The fully adjusted model further attenuated the relationship between walkability and depression, underscoring the possible role of other variables such as education, health perception, history of depression, alcohol consumption, smoking, and sleep duration in influencing this association. On the other hand, the unadjusted regression model on the association between the walkability index and various components of depression showed significant associations between high and very high walkability indices and multiple depression components, namely interest, depressed mood, confidence, concentration, and suicidal thoughts. However, these associations were attenuated in the minimally adjusted and fully adjusted models, suggesting that confounding variables may be playing a considerable role.

For anxiety, in the unadjusted analysis, participants residing in areas with a "very high" walkability index were 1.74 times more likely to report experiencing anxiety compared to those living in areas with a "very low" walkability index. Although the magnitude of the relationship attenuated with adjustment, the association remained statistically significant in the fully adjusted model. This suggests that while confounding variables play a role, there is a unique and positive association between high walkability and the likelihood of experiencing anxiety. Similarly, in the linear regression model examining continuous anxiety scores, a significant association was observed in the "very high" walkability index category. In the unadjusted model, living in a "very high" walkable area was associated with a higher total anxiety score. This association remained robust in both minimally adjusted and fully adjusted models, indicating that high walkability is associated with increased total anxiety scores, irrespective of the covariates adjusted for. The study also assessed the relationship between walkability indices and various components of anxiety. In the unadjusted analysis, a significant association was observed only in the "very high" walkability index category across multiple anxiety components, such as nervousness, worrying1, worrying2, relaxation, annoyance, and fearfulness. After adjusting for age, sex, and income in the minimally adjusted model, we noticed a slight attenuation but the significance was maintained for many of the anxiety components like nervousness, worrying1, and relaxation, particularly in very high walkability areas. Further adjustments for education, health perception, history of depression, alcohol intake, smoking, and sleep duration in the fully adjusted model did not dramatically alter the outcome, especially in the "very high" walkability index category. This suggests that walkability may indeed have a unique relationship with individual components of anxiety, independent of several other factors.

This study was designed to investigate the relationship between presence of green space, measured through NDVI and various measures of depression. While some analyses suggested a potential protective effect of green space on depression, most of the results indicated no consistent association between green space and depression. Such inconsistent findings present a complex narrative and underscore the multi-faceted impact of green spaces on mental health. For instance, the availability of green space might help improve concentration and confidence but not necessarily sleep quality. This multifaceted impact has implications for public health interventions and urban planning. This complex relationship is also highlighted by other studies. A cross-sectional study by Cottagiri et al in 2021 showed an inverse association between self-reported clinical diagnosis of depression in relation to an increase of NDVI within a 500 m buffer of the participant's residence (Cottagiri et al., 2022). There are plenty of research showing the inverse relationship between green space and depression (Cottagiri et al., 2022; Gariepy et al., 2014; Krols et al., 2022; Liu et al., 2019; R. Wang et al., 2019). Interesting, a longitudinal study by Astell-Burt et al in Australia in 2022 revealed that a 10% increase in green space was associated with higher levels of antidepressant prescription (Astell-Burt et al., 2022). In addition, a study by Helbich et al in 2021 showed there was no statistically significant evidence that people with less urban residential greenness had higher depression or anxiety scores than those exposed to higher levels (Helbich et al., 2021).

7.5. Conclusions

The complexities unveiled in our studies have significant implications for urban planning and healthcare policies. A one-size-fits-all approach to public health interventions based on walkability or green spaces would be insufficient. Policymakers and healthcare providers should adopt a multidimensional approach that accounts for these intricate relationships.

7.6. References[28]

[28] The full set of references used for this analysis are provided in the References section in Appendix E.

8. Cancer Risk with Walkability & Greenspace - The Effect of Residential Greenness and Walkability on Cancer Risk in the Greater Vancouver Region[29]

8.1. Background

Cancer is the leading cause of death in Canada with lung, breast, colorectal, and prostate cancer accounting for approximately half of the cancer cases diagnosed[1,2]. Two out of five Canadians are expected to receive a diagnosis of cancer in their lifetime resulting in one in four cancer-related deaths after diagnosis. Furthermore, due to aging population demographics, Canada is expected to face an increased burden of cancer[1]. Despite advances in detection and treatment, lung cancer is the leading cause of death in Canada with a 5-year survival of 19%[1]. While estimated mortality rates for breast cancer declined by 49% from 1986 to 2020[2], improvements are mainly limited to women with early-stage cancers[3,4]. The incidence of colorectal cancers is lowest among persons under 50 years but is increasing in younger age groups[1,5,6]. Similarly, the incidence of prostate cancer has been decreasing since 2007, yet it is the most commonly diagnosed cancer in men accounting for 20% of new cases in 2021[1,3]. Cancer morbidity and mortality can be mitigated by interventions reducing exposure to risk factors. Smoking, alcohol consumption, physical activity, and diet have been shown to affect cancer risk[15], but interventions to influence these factors are focused on individual-level behavior change which can be ineffective if they fail to account for multi-faceted socio-cultural barriers to change[7,8]. The built environment, which influences behaviors, can be altered to reduce cancer incidence[7].

With studies mainly focusing on the built environment and mortality rates, the mixed associations reported for NDVI, and the lack of research for walkability with cancer risk, it is essential to further investigate the causal associations using longitudinal study designs. Through this study, we examined the effect of residential greenspace and walkability on the risk of lung, colorectal, breast, and prostate cancers. We hypothesize that after accounting for socio-demographic and other individual factors, the built environment with infrastructure promoting healthier lifestyles such as increased physical activity, or access to urban green space would lead to a lower risk of cancer outcomes compared to areas with poorly built infrastructures. However, the decreased risk could potentially be offset by collinear factors such as increased air, noise, and light pollution.

8.2. Methods

Data Sources: We conducted a longitudinal analysis using secondary data merged from multiple sources, *viz.* the BCGP cohort, Where Matters project, and environmental exposures from CANUE described earlier. We additionally used data from the British

[29] For the full article associated with this study, please see Appendix F.

Columbia Cancer Registry. Based on passive annual follow-up, the British Columbia Cancer Registry provided information on mortality and cancer diagnoses which were categorized according to the International Classification of Diseases for Oncology, third edition (ICD-O-3) site codes. Only primary cancer diagnoses for each cancer type were considered for their individual analysis.

A total of 10,929 BCGP participants were included in the study sample (Figure 8-1). To be eligible, participants had to be residing in the Greater Vancouver region. Participants who developed cancer prior to enrolment and with missing information about the year of enrolment, were excluded from the analysis.

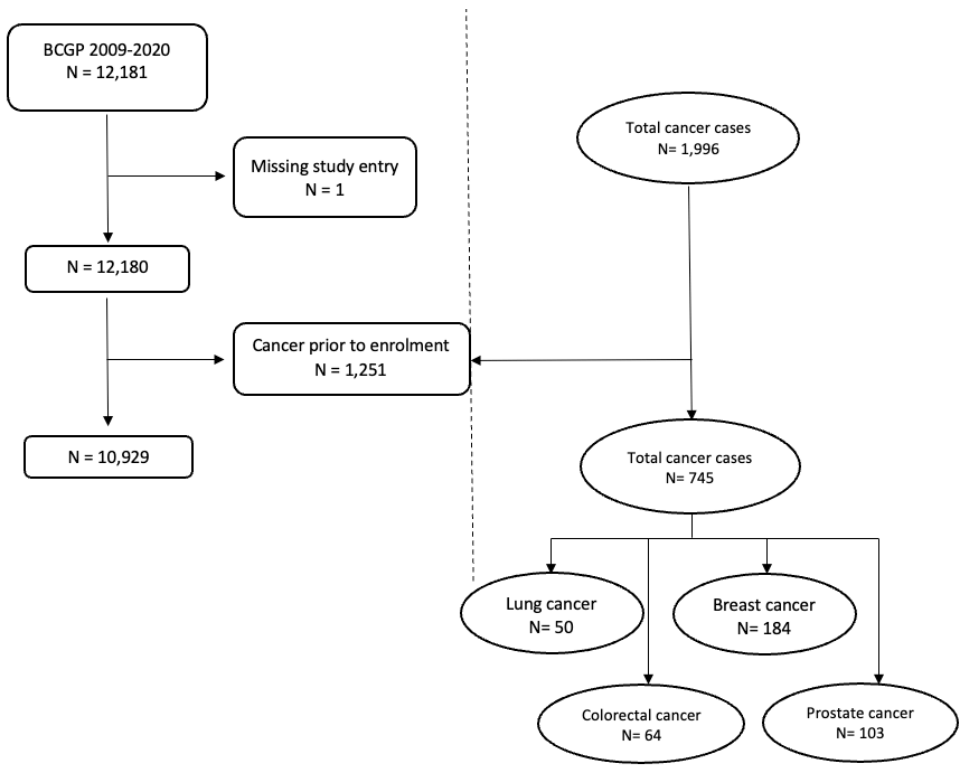

Figure 8-1: BCGP Sample and Cancer Case Distribution

Statistical Analysis: We conducted separate time-varying Cox proportional hazards models to assess the hazard ratio for the primary diagnosis of each cancer type based on the annual environmental exposures. Participants were censored at the year of cancer diagnosis, death, or end of follow-up in 2020. The analyses for lung and colorectal cancers were conducted in the entire sample, while the analyses for breast and prostate cancers were restricted to females and males respectively. The environmental exposures were classified into three groups of high, medium, and low exposures based on approximately equal sample size. Age, sex, race, marital status, education level, and income were considered as socio-economic and demographic factors, while alcohol intake, smoking habits, hormonal replacement therapy (HRT), contraceptive use, family history of the primary cancer diagnosis, and air pollution factors (NO_2) were considered as risk factors. Variables were selected for each cancer type based on established risk factors, researcher assumptions, and change in effect estimates. Due to the limited number of incident cases, the number of variables in the models estimating the hazard ratio for lung and colorectal cancers were limited to a maximum of 7 and 9, respectively. After variable selection, a second model was created which accounted for collinear environmental exposures. NO_2 concentrations were adjusted in NDVI models, while NDVI and NO_2 exposures were included in walkability models. The assumption of proportional hazards was verified by using Schoenfeld residuals. In case of deviations from the proportional hazards assumption, we introduced interaction terms with time for continuous variables and stratified by categorical variables.

8.3. Results

The eligible study sample consisted of 10,298 participants. The average age of the participants was 55 years and were mostly female (70%). The majority of the participants (83%) had a level of education greater than high school. Approximately 83% of the population was Caucasian and 61% had moderate to high total family income of ≥$75,000. Only 5% of the participants were current smokers while 90% were current drinkers. The average length of follow-up was 9 years with participants accounting for a total of 97,083 person-years. A total of 50 lung cancer, 64 colorectal cancer, 184 breast cancer, and 103 prostate cancer cases were developed over follow-up. The results from the Cox analyses studying the association between the primary environmental exposures and individual cancer risks are presented in Tables 2-5.

Associations with lung cancer risk

There was no significant association between NDVI and lung cancer risk in the primary model (

Table 8-1). Similarly, the CanALE walkability index showed no significant associations while comparing the lung cancer risk in moderate (HR = 0.94, 95% CI = 0.46 - 1.89) and high (HR = 0.76, 95% CI = 0.37 - 1.58) walkable regions to the lowest walkable regions. Results for the Where Matters walkability index were similar to those of the CanALE estimates in magnitude and trend. Although the findings were not statistically significant, an increase in both CANUE and Where Matters walkability metrics showed noticeable decreasing trends for lung cancer hazards. Model 2, which was additionally adjusted for collinear environmental exposures showed similar estimates and trends to those from Model 1.

Table 8-1: Results for lung cancer: Hazard ratio using Cox proportional models

N = 10,929	Lung Cancer (N= 50)		
Environmental Exposures	**Model 1[a]**	**Model 2**	**Cases (N)**
Normalized Difference Vegetation Index			46 (10,261)
Medium	0.78 (0.37, 1.63)	0.76 (0.36, 1.62)[b]	
High	0.94 (0.48, 1.86)	0.92 (0.45, 1.89)[b]	
Canadian Active Living Environment			45 (10,124)
Medium	0.94 (0.46, 1.89)	0.91 (0.45, 1.87)[c]	
High	0.76 (0.37, 1.58)	0.73 (0.32, 1.64)[c]	
Where Matters Walkability Index			44 (10,026)
Medium	0.94 (0.43, 2.04)	0.93 (0.42, 2.03)[c]	
High	0.89 (0.42, 1.86)	0.83 (0.37, 1.89)[c]	

a: adjusted for age, sex, race, family history of lung cancer, and smoking history

b: age, sex, race, family history of lung cancer, smoking history, tertiles of rolling averages of nitrogen dioxide concentrations

c: age, sex, race, family history of lung cancer, smoking history, and tertiles of NDVI and rolling averages of nitrogen dioxide concentrations

Associations with colorectal cancer risk

Colorectal cancer risk was not significantly associated with NDVI, the CanALE walkability index, and the Where Matters walkability index in the primary model (Table 8-2). However, there was a decreasing trend in risk when comparing participants with the higher NDVI exposures to those with the lowest NDVI exposure (HR = 0.73, 95% CI =0.37, 1.46. Adjusting for rolling averages of NO_2 in Model 2 did not result in changes in estimates for any of the exposures.

Table 8-2: Results for colorectal cancer: Hazard ratio using Cox proportional models

N = 10,929	Colorectal Cancer (N= 64)		
Environmental Exposure	**Model 1[a]**	**Model 2**	**Cases (N)**
Normalized Difference Vegetation Index			58 (9,856)
Medium	1.00 (0.54, 1.89)	0.99 (0.53, 1.84)[b]	
High	0.73 (0.37, 1.46)	0.70 (0.36, 1.35)[b]	
Canadian Active Living Environment			59 (9,912)
Medium	1.08 (0.57, 2.05)	1.02 (0.54, 1.96)[c]	
High	1.08 (0.57, 2.08)	0.96 (0.47, 1.96)[c]	
Where Matters Walkability Index			56 (9,824)
Medium	0.95 (0.46, 1.95)	0.93 (0.45, 1.93)[c]	
High	1.20 (0.61, 2.33)	1.15 (0.56, 2.37)[c]	

a: adjusted for age, sex, race, income, family history of colorectal cancer, alcohol intake, and smoking history

b: adjusted for age, sex, race, income, family history of colorectal cancer alcohol intake, and smoking history tertiles of rolling average of nitrogen dioxide concentrations.

c: adjusted for age, sex, race, income family history, alcohol and smoking history, and tertiles of NDVI and rolling average of nitrogen dioxide concentrations.

Associations with breast cancer risk

There were no statistically significant findings for breast cancer with any of the exposures of interest. However, models for NDVI showed protective point estimates across all levels of greenness [Medium vs. Low NDVI: HR =0.87, 95% CI=(0.59, 1.26) and High vs Low NDVI: HR=0.81, 95%CI= (0.55, 1.19)] (Table 8-3). Model 2 did not show any changes in estimates for any of the exposures.

Table 8-3: Results for breast cancer: Hazard ratio using Cox proportional models

N = 7,611	Breast Cancer (N= 184)		
Environmental Exposure	**Model 1**[a]	**Model 2**	**Cases (N)**
Normalized Difference Vegetation Index			162 (6,813)
Medium	0.87 (0.59, 1.26)	0.85 (0.58, 1.24)[b]	
High	0.81 (0.55, 1.19)	0.80 (0.54, 1.19)[b]	
Canadian Active Living Environment			161 (6,727)
Medium	1.26 (0.87, 1.85)	1.25 (0.85, 1.84)[c]	
High	0.99 (0.66, 1.48)	0.93 (0.60, 1.45)[c]	
Where Matters Walkability Index			157 (6,653)
Medium	0.89 (0.60, 1.32)	0.87 (0.58, 1.30)[c]	
High	1.00 (0.67, 1.48)	0.94 (0.61, 1.44)[c]	

a: adjusted for age, marital status, income, education status, race, family history of breast cancer, alcohol intake, smoking history, history of oophorectomy/hysterectomy, history of hormone replacement therapy

b: adjusted for age, marital status, income, education status, race, family history of breast cancer, alcohol intake, smoking history, history of oophorectomy/hysterectomy, history of hormone replacement therapy, and tertiles of rolling averages of nitrogen dioxide concentrations

c: adjusted for age, marital status, income, education status, race, family history of breast cancer, alcohol intake, smoking history, history of oophorectomy/hysterectomy, history of hormone replacement therapy, and tertiles of NDVI and rolling averages of nitrogen dioxide concentrations

Associations with prostate cancer risk

There was no significant association between NDVI and prostate cancer risk in the results from Model 1 (medium vs. low NDVI: HR = 0.85, 95% CI =0.49, 1.46, high vs. low NDVI: HR = 1.12 95% CI =0.68, 1.83). Similarly, while analyzing the CanALE (medium vs. low walkability: HR = 1.27, 95% CI =0.76, 2.11, high vs. low walkability: HR = 1.24 95% CI =0.73, 2.12) and Where Matters (medium vs. low walkability: HR = 0.90, 95% CI =0.54, 1.49, high vs. low walkability: HR = 1.02 95% CI =0.62, 1.69) walkability indices, there were no significant associations or noticeable trends in prostate cancer risk. No significant associations were observed in Model 2 either after adjusting for collinear environmental exposures (Table 8-4).

Table 4. Results for prostate cancer: Hazard ratio using Cox proportional models

Table 8-4: Results for prostate cancer: Hazard ratio using Cox proportional models

N = 3,318	Prostate Cancer (N= 103)		
Environmental Exposure	**Model 1[a]**	**Model 2**	**Cases (N)**
Normalized Difference Vegetation Index			96 (3,116)
Medium	0.85 (0.49, 1.46)	0.80 (0.46, 1.38)[b]	
High	1.12 (0.68, 1.83)	1.01 (0.60, 1.69)[b]	
Canadian Active Living Environment			94 (3,070)
Medium	1.27 (0.76, 2.11)	1.32 (0.78, 2.22)[c]	
High	1.24 (0.73, 2.12)	1.57 (0.86, 2.86)[c]	
Where Matters Walkability Index			92 (3,052)
Medium	0.90 (0.54, 1.49)	0.96 (0.57, 1.62)[c]	
High	1.02 (0.62, 1.69)	1.22 (0.70, 2.14)[c]	

a: adjusted for age, income, education status, race, family history of prostate cancer, and alcohol intake

b: adjusted for age, income, education status, race, family history of prostate cancer, alcohol intake, and tertiles of NDVI

c: adjusted for age, race, family history of prostate cancer, smoking history, tertiles of NDVI and rolling average of nitrogen dioxide concentrations

8.4. Discussion

Our study investigates the association between residential environmental exposures of greenness (NDVI) and walkability with cancer risk using a longitudinal cohort design. Although none of the effects were statistically significant we observed some important trends.

Greenness and cancer risk

While there were no statistically significant associations between NDVI exposure levels and lung cancer risk both medium and high exposure to greenness showed protective estimates when compared to low exposure. Even though air pollution is a known lung carcinogen, the estimates were unchanged following adjustment for Nitrogen dioxide exposure, potentially due to the low levels of air pollution in British Columbia.). However, even at low concentrations air pollution is known to cause medical complications with increased hospitalizations and attributed deaths in British Columbia[36]. This highlights the importance of accounting for the effects of multiple collinear environmental exposures and emphasizes that in our urban sample the health benefits of greenspace are outweighed by increased air pollution. Medium NDVI exposure had no effect on colorectal cancer risk. But a protective trend was noticed while comparing the highest NDVI exposure to the lowest exposure. Our analyses for lung and colorectal cancers were hampered by the low number of incident cases, 50 and 64 respectively. Previous research has shown a protective trend with lung cancer and no association with colorectal cancers, emphasizing the complexity of the impact of greenspace on health[24,30,31]. A study by Huang et al. (2022) found a 5% decrease in lung cancer risk using a Cox proportional hazards model with baseline covariates and lung cancer (HR: 0.95, 95% CI: 0.91–0.99)[28] while Kayyal-Tarabeia et al. (2022) found a 25% reduction in risk with a unit IQR increase in NDVI (HR = 0.75, 95% CI: 0.66–0.85)[29]. A third study by Sakhvidi et al. (2021) found no association between NDVI at a 100 m buffer and lung cancer risk (HR = 0.870, 95% CI= 0.691 - 1.095) but still exhibited a decreasing trend with increasing NDVI[32]. Both Huang et al. (2022) and Kayyal-Tarabeia et al. (2022) had a considerably larger number of cases and longer follow-up periods. Consequently, the finding of no statistically significant associations from the primary analysis could be a chance finding or an attribute of the limited number of cases developed in the cohort due to the short follow-up time. The proportional hazards Cox model performs better with more events and longer follow-up which helps in informed censoring.

While assessing breast cancer risk using measures of greenness, findings have been mixed. Sakhvidi et al. (2021) and Kayyal-Tarabeia et al. (2022) found a decreased risk of breast cancer incidence[29,32], while Huang et al. (2022) found no association with NDVI[28]. Our findings, although statistically non-significant, exhibited protective estimates with increased NDVI exposure. The estimates in the high and medium NDVI levels were similar to each other which could also suggest a plateauing of the effect of greenness on breast cancer risk. We also found no association between NDVI and incidence of prostate cancer. While using low NDVI as the reference group, high NDVI exposure had higher point estimates of prostate cancer compared to medium NDVI exposure (medium vs. low NDVI: HR = 0.85, 95% CI =0.49, 1.46, high vs. low NDVI: HR = 1.12, 95% CI =0.68, 1.83), but the estimates are likely the attribute of the wider confidence intervals, due to limited male sample size living in areas with the highest NDVI exposure, and not an actual increase in cancer risk. Moreover, the estimate in the participants with the highest NDVI exposure reduced to a null effect after accounting for air pollution (HR = 1.01, 95% CI: 0.60–1.69).

From our findings and previous research, we surmise that living in areas with increased green space can potentially decrease the risk of lung, colorectal and breast cancer. While we could account for NO_2 as an air pollution factor, there may be other significant collinear exposures, such as ambient night light and noise pollution that we have not considered in our analysis. Although NDVI is a popular method for measuring surrounding greenness[33], several other vegetation indices are available and [34.] the choice of metric, including using discrete measures such as park or tree count, impacts research findings. Depending on the type of greenness (urban greenspace amenities vs. dense vegetation), increased exposure could enhance health, through factors such as increased physical activity and other physiological and psychological impacts[35].

Walkability and cancer risk

To our knowledge, there are no longitudinal studies investigating the direct effect of residential walkability on the risk of lung, colorectal or prostate cancer risk in the general population, making our study the first of its kind. A recent study in a female population by India-Aldana et al. (2023) reported no association of colorectal cancer and reduced risk of post-menopausal breast cancer with increasing neighbourhood walkability[37]. Apart from the difference in the study population, their measure of walkability was based on averaged z-scores of the population and commercial densities in New York city, USA. A study by Keats et al. (2020) based on the Atlantic PATH cohort found no association between quintiles of the CanALE index and all-cancer risk[21]. Given that different cancer types have different etiologies, it is important to conduct epidemiologic studies for each cancer type an using incidence cancer cases that occur after the exposures were measured. Although statistically non-significant, while examining lung cancer risk we found protective estimates for all levels of walkability when compared to the lowest level in addition to decreasing risk with increasing walkability. We did not find any significant associations while examining the effect of walkability on colorectal and prostate cancer risk and the estimates presented with relatively wider confidence intervals precluding any extrapolation. While assessing breast cancer risk, all but one hazard ratio estimates were below or at the null effect of 1, potentially signaling no association between walkability with breast cancer risk. Given the dearth of research longitudinally examining walkability and cancer risk, future studies, with longer follow-up duration and consequently more cancer diagnoses, is required to assess these potential findings.

The differences in estimates from the CanALE and Where Matters walkability indices could be the result of multiple factors. One is the difference in geographical units utilized to estimate the exposure. The Where Matters walkability was created at the residential postal code level while the CanALE index was created by using dissemination areas (DA) as the smallest unit. Dissemination areas are larger geographical units comprised of multiple postal codes. Secondly, the WM index also considers commercial floor area and land use mix to measure walkability, in addition to the residential and intersection density assessed by CanALE. As a result, we believe the WM index captures greater variability in the exposure. Moreover, the WM index is longitudinal in nature and able to account for changes in the participant's exposure over time.

8.5. Conclusions

Through our study, we were able to identify potential protective trends for greenness and walkability on certain cancer types. Individual-level behaviour interventions can influence public health considerably. As an example, due to effective public health campaigns about the ill effects of smoking, we have seen decreasing trends in tobacco-use and lung cancer incidence. However, lung cancer is still the leading cause of cancer death in Canada and other avenues, such as modifying the built environment, must be explored to reduce its burden on a wide-reaching scale. Given the complex nature of the built environment and the potential for interaction between multiple environmental factors, further research is required to confirm our findings.

8.6. References[30]

[30] The full set of references used for this analysis are provided in the References section in Appendix F.

9. Regulatory & Fiscal Approaches to Transportation & Land Use Investment[31]

9.1. Changes to Municipal & Regional Regulatory Environment

Regulatory and fiscal approaches are two distinct strategies governments use to manage various economic, social, and environmental objectives. Regulatory policies involve the establishment and enforcement of laws, rules, and regulations by the government to guide behavior and address various social, economic, or environmental issues. Governments attempt to regulate markets and ensure fair competition, protect the environment, enforce health and safety standards and more. Fiscal approaches refer to government spending, taxation and borrowing to influence the economy. Some fiscal tools include subsidies, grants, gas taxes and congestion charges. Regulatory and fiscal policies are powerful tools that can shape how public transportation services are funded, managed, and operated. These tools also play a crucial role in shaping land use patterns, development decisions and the overall built environment. Governments have a tremendous amount of influence to guide development in ways that promote economic prosperity, environmental sustainability, social equity, and community well-being.

Prior to November 30, 2023, B.C.'s municipal governments had significant authority for shaping their land use policy and influencing development within their jurisdictions. However, following the Royal Assent of three new housing statues, Bill 44, 46 & 47, the provincial government has enacted major housing legislation that changes the powers of city councils, city planning officials and citizens and aims to increase density across most of BC municipalities. Bill 44 requires local governments to update zoning bylaws to allow either a minimum of one secondary suite or detached accessory dwelling unit, a minimum of three to four dwelling units, or a minimum of six dwelling units (near transit) on lots currently zoned for single-family homes and duplexes in municipalities above 5000 people. It also limits the use of public hearings for certain residential projects that are consistent with official community plans and zoning bylaws and requires municipal governments to update official community plans every five years with public input and in a manner that reflects projected housing needs. Bill 46 introduces amenity cost charges ("ACCs") as a new development financing tool to help local governments cover increased capital costs associated with providing or altering amenities to benefit development and any associated increase in population of residents or workers. Bill 47 requires municipalities to designate land within 800 metres of rapid transit stations and 400 metres of major bus exchanges as transit-oriented development areas, and to permit development in accordance with the prescribed minimum density levels within such areas. Through regulations, transit-oriented development (TOD) areas have now been defined. The regulations will prescribe 104 TOD Areas in 31 municipalities throughout B.C. within the first year of the legislation coming into effect. Bill 47 also removes most

[31] For more details on the review of performance-based funding (PBF), please see Appendix A.

parking requirements for developments in these areas. These bills override municipal government authority over land use planning.

The legislation and the accompanying regulations and guides are part of the Provinces' Homes for People action plan, which builds on the 2018 Homes for B.C. plan. These legislative changes are part of the provincial government's efforts to streamline the delivery of homes, services, and infrastructure for growing communities throughout BC and eliminate restrictive zoning policies. A report prepared by BC Stats shows that BC's population growth rate has surged over the past three years due to higher national immigration targets. Nearly 150,800 migrants came to the province in 2022, roughly 52,000 of whom were permanent immigrants. Assuming Canada strictly maintains its annual immigration targets, B.C.'s population is projected to steadily increase through 2046, from 5.5 million people in 2023 up to 7.9 million (+ 48.6%) in 4046. All development regions of BC are anticipated to see population growth; however, the most significant growth will be in the Mainland / Southwest region where most immigrants settle. The province and Metro Vancouver need to anticipate and plan for long-term challenges and opportunities associated with increased population growth,

Recently the provincial government had ventured into previous municipal jurisdiction over land-use planning with two other pieces of legislation, designed to support the Homes For People action plan. In September 2023, the Ministry of Housing selected ten municipalities to meet housing target orders under the authority of the Housing Supply Act (Bill 43), over the next five years between October 2023 and September 2028. Metro Vancouver municipalities that are affected by these housing targets are: City of Delta, City of Port Moody, City of Vancouver, District of North Vancouver, and District of West Vancouver. In 2022, legislation was passed to enable the Ministry of Transportation and Infrastructure to purchase land in areas near transit stations for the purpose of transit-oriented development. Previously, the ministry was only able to purchase land that was directly related to transit projects. Municipalities have traditionally had jurisdiction to oversee land use within their boundaries, but this has rapidly changed in BC with the Royal Assent of Bill 43 in November 2022.

The vision for Metro 2050 is to have a region of diverse and complete communities connected by sustainable transportation choices where residents live in neighbourhoods that offer a range of opportunities to live, work, play, and learn. This comprehensive plan recognizes that policies and strategies need to work together to ensure that land development and transportation planning are aligned. The Mayor's Council, the collective voice of Metro Vancouver mayors on transit and transportation, recognizes that the more people who use transit, the more cars we remove from the road, lowering GHG emissions and keeping our air clean. Encouraging densification and complete communities near transit hubs, promotes citizens to take transit. Furthermore, a well-functioning public transit system is a critical part of meeting federal and provincial climate action targets as outlined in the Federal government's 2030 Emissions Reduction Plan. To align with both federal and provincial targets of significantly lowered emissions by 2030, transit services and bike lanes need to be expanded and thus funded. An urgent transit expansion is required to keep up with the growth in the region.

Transportation infrastructure investments are the responsibility of the Provincial Government. The B.C. government has the goal to make 30% of all trips taken in the province by active transportation (AT) and public transit, essentially doubling the percentage of trips by 2030. Through funding to municipalities and partnerships with non-profits, the Ministry of Transportation and Infrastructure is spending money to build active transportation facilities, such as bike lanes, delivering education and encouragement programs, enforcing rules that make the roads safer for everyone and evaluating their progress to make sure they are on the right path. In 2019, the Ministry created an Active Transportation Design Guide which contains recommended policies, specifications, standards, and guidelines to be followed in the development of active transportation infrastructure in British Columbia. The goal of this free design guide is to help communities build safe, effective active transportation infrastructure. The province recognizes that making active transportation an option for more people will reduce gas emissions as is stated in the CleanBC Strategy. Provincial charitable non-profits such as Hub Cycling and the BC Cycling Coalition work with communities to promote safer and accessible cycling. On a federal level, the Government of Canada launched the Active Transportation Fund (ATF) in 2021, to invest $400 million over five years to build new and expanded networks of pathways, bike lanes, trails, and pedestrian bridges in addition to supporting active transportation planning and stakeholder engagement activities. Governments at every level recognize that expanding and promoting active transport, especially public transit, is crucial to meeting emissions reduction targets. WMII also demonstrates that active transportation has health benefits for the population.

Metro 2050 also includes regional targets for protecting half the land base for nature and expanding tree canopy cover. The provincial government also recognizes the importance of greenspace for improving the mental health and well-being of citizens and the need to preserve the natural environment by reducing urban sprawl (contained in the British Columbia Complete Communities Guide). What are the fiscal and regulatory strategies employed by government to support greenspace and urban tree canopy preservation? The unintended result of densification will be losing backyards and trees on private property. Zoning regulations can mandate minimum greenspace requirements for new developments or that a certain percentage of land within urban areas be dedicated to greenspaces such as parks. Grants or tax incentives could be provided to community organizations, municipal governments, or private landowners to ensure the preservation of a certain percentage of land for greenspace. Provincially, British Columbia has a system of areas managed by BC Parks. Municipalities have powers to establish parks and develop Official Community Plans (OCPs) that include provisions for greenspace protection and management. With the focus of the new provincial government legislation and Federal government housing policies on increasing housing supply through densification, municipalities must ensure greenspace conservation is not overlooked.

9.2. Performance-Based Funding

Where Matters proposes a Performance-Based Funding model for transportation and land use infrastructure investments. Performance-Based funding (PBF) is a mechanism in which a funder financially rewards an agent upon the achievement of pre-agreed upon results (Alshehri, 2016; Musgrove, 2011). PBF schemes include, but are not limited to, bonus payments, prizes, grants, loans or long-term financing contracts (Gold et al., 2014). In most cases, the funder delegates an aim or desired outcome to an agent, who is then responsible for the delivery of those aims and outcomes. One method of measuring performance could be based on evaluating the extent to which communities are becoming more walkable with a range of transportation options. Standardized, consistently measured data, such as those leveraged for Where Matters II, should be considered as a key resource to evaluate environmental change in communities over time.

PBF approaches to management, budgeting and resource allocation have been used for decades across many sectors with the goal of improving programmatic and financial efficiency and accountability. Governments, parliaments, citizens, the private sector, non-governmental organizations (NGOs), civil society, international organizations, and donors all commonly use performance funding mechanisms as an alternative to traditional forms of funding that disburse funds before delivery, or based on inputs (Rodriguez et al., 2014). PBF mechanisms can be contracts between organizations and governments, different levels of government, public or private service providers, governments and individuals, or society organizations. The primary strength of PBF is that it has a results-based structure used to provide timely and efficient guidance to projects. The term 'principal' in this section is used to refer to those responsible for designing and implementing the PBF mechanism, and 'agent' is used to describe those responsible for delivery of the desired objective.

9.2.1. Description of Existing PBF Literature

Although applications of PBF are common, literature and studies covering PBF are overwhelmingly concerned with a few key sectors: global development finance and aid, higher education, healthcare, and social service delivery. The global health sector has been a pioneer in implementing PBF mechanisms, followed by other sectors including education, energy, and climate (Rodriguez et al., 2014). In climate finance, PBF programs aimed at preserving or restoring ecosystem services have also grown in popularity over the last two decades (Snilsveit et al., 2019). In the Global North, healthcare systems have also been early adopters of PBF models over the last twenty years; Australia, Brazil, New Zealand, the US, and several European countries have all introduced some PBF to their national healthcare systems (Gold et al., 2014). In North America, the Social Service and Higher Education sectors have also been pioneers in implementing results-based mechanisms (Hawkins et al., 2019).

Literature on performance-based approaches to funding and financing has broad sectoral coverage. Generally, the earlier PBF was applied in individual fields or sectors, the more experiences were evaluated and documented in the literature (Warnecke et al., 2015). The most abundant literature on PBF is found in its use in global development and aid, specifically in the climate, education, and health sectors (Martínez et al., 2012). There is also significant literature on performance-based approaches in higher education,(Baker et al., 2006; De Boer et al., 2015; Harnisch, 2011; Salmi & Hauptman, 2006) as well as its use in the delivery of social and health services (Barker et al., 2018; Gold et al., 2014; Hawkins et al., 2019; Zlatinov & Gillette, 2018).

Existing literature on PBF can be grouped into the following categories: specific project evaluations, reports on the implementation and monitoring challenges of PBF approaches (Johnson & Zajonc, 2006; OECD, 2020; M. Pearson et al., 2010; Perakis & Savedoff, 2015), and meta-evaluations of particular performance-based approaches (Vivid Economics, 2013). Other literature reviews (see Warnecke et al., 2015; Oxman & Fretheim, 2009) have connected the availability of literature on performance-based approaches to the experience with PBF in different sectors. Some findings and papers are sector-related, while other findings provide considerations and lessons that can be applied in different contexts (Oxman et al., 2009). The most common PBF literature, which covers results-based approaches to development finance and aid, mostly covers its application for meeting its desired aims or objectives (Johnson & Zajonc, 2006; Perakis & Savedoff, 2015, 2014); There is also a significant body of literature evaluating the efficiency and cost of performance-based approaches (Oxman et al., 2009; Poister et al., 2014; Warnecke et al., 2015). Although there is a significant body of literature documenting sector-specific experience with performance-based approaches, there are few resources that connect or compare PBF approaches across sectors, nor is there much information on PBF approaches in North America outside of healthcare, education, and social service delivery programs. Performance-oriented administration is a common practice in government in Europe and North America and has been rigorously studied (Bleyen et al., 2017); however, the literature on the mechanism connecting funding to performance is scarce compared to studies on the efficiency and outcomes of specific models. Despite performance-based funding being often used across many different sectors, there is currently a lack of PBF related to walkability studies.

When discussing PBF, one noteworthy program is The Livable Centers Initiative (LCI), developed by the Atlanta Regional Commission (ARC). Like Metro Vancouver, ARC is charged with considering issues from a regional perspective. The LCI program awards planning grants to local governments to prepare and implement plans to enhance existing activity centers and corridors thus incentivizing local jurisdictions to re-envision their communities as more walkable, mixed-use, and transit-friendly. The LCI program goals are threefold: Encourage a diversity of housing, employment, commercial, shopping and recreation land uses at the transit station, local and regional center level; enhance access to a range of travel modes including transit, roadways, walking and biking and increase roadway connectivity to provide optimal access to all uses within the study area; foster public-private partnerships and sustained community support through an outreach process. The program also awards Federal transportation funding to implement the transportation elements (i.e. streetscapes, pedestrian connections) of LCI studies. Since its creation in 2000, the LCI program has invested over $312 million in more than 130 communities throughout the Atlanta region, helping pay for planning studies and the construction of transportation projects such as sidewalks and intersection improvements, to bring those visions to life. In addition, the ARC board has allocated $600 million through

2050 for transportation projects resulting from completed LCI studies. The LCI process involves collaboration between local governments, the ARC, and community stakeholders. The program is unique in that, every December, the Land Use Coordinating Committee (LUCC) holds an Ideas Exchange meeting where counties are invited to attend, and then the formal application opens in early January. The LCI program is unique in that the various levels of government work in a coordinated effort to reward creating mixed-use development. Appendix A provides an overview of a wide range of local and international PBF case study examples reviewed as part of this study.

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11. Appendix A: Performance-Based Funding

11.1.1. Performance-Based Funding (PBF): Differences in Application Across Sectors

Innovative applications of PBF have resulted in an abundance of terms used to describe the various strategies through which it is applied, and there is no universal framework for aggregating, understanding and comparing PBF strategies across sectors (M. Brown et al., 2019; M. Pearson et al., 2010; Rodriguez et al., 2014). Different sectors use the same terminology for different PBF models, or different terminology for the same models. For instance, **contracting-for-results**, **results-driven contracting**, and **outcome-based contracting** are all terms for similar mechanisms in social service delivery (N. M. Brown, 2019; Hawkins et al., 2019). In some cases, the term 'performance' is a broad term synonymous with 'results' that encompasses 'inputs', 'outputs', and 'outcomes'; In other cases, 'performance' specifically refers to inputs and outputs, while only outputs are considered results. With the ambiguity of PBF, almost anything can be considered a performance measure (including inputs), however, applications of PBF in this document are narrowly focused on cases where financial or non-financial incentives have been explicitly linked to and dispersed based on targeted and measurable outcomes.

The following section summarizes the differences in application of common performance-based methods grouped by sector, with the intention of clarifying the similarities and differences in applications of PBF across sectors.

11.1.2. Performance-Based Approaches in Global Development Financing and Aid

In response to concerns surrounding the effectiveness of aid spending, performance and results-based approaches to development financing became popular mechanisms for development aid since the early 2000s (Perakis & Savedoff, 2014). Almost all foreign aid programs and projects have at least some specific outcomes and results monitoring processes, but some models are more direct in connecting their incentive structures to quantifiable results and outcomes (Janus et al., 2015). Financing institutions and organizations such as the British Department for International Development (DfID), German Kreditanstalt für Wiederaufbauthe (KfW), Swedish International Development Agency (SIDA), and the Australian Agency for International Development (AusAID) were early promoters of PBF instruments, as well as development agencies such as Center for Global Development (CGD) and the Global Partnership on Output-Based Aid (GPOBA) (Rodriguez et al., 2014).

Musgrove (2011) and Pearson (2010) have both created comprehensive glossaries of terminology related to PBF approaches in the development sectors, with the most common instruments being:

- Results-Based Financing;
- Results-Based Aid; and
- Challenge-Linked Financing.

Descriptions, examples, and case studies of these PBF models, as well as various sub-categories, are provided in the following section.

11.1.2.1. Results-Based Financing

Results-Based Financing (RBF) in global development refers to any program that rewards the delivery of one or more outputs or outcomes by one or more incentives (Musgrove, 2011). RBF is typically a contract between a national or sub-national government and an implementing agency such as an NGO, for-profit organization, non-profit organization, or sub-national government (Grittner, 2013). Most times, RBF payments are additional or 'top-ups' to traditional or current sources of funding (such as a results-based bonus). In these models, the relationship between results and payments can be both linear or non-linear (Musgrove, 2011

In the global development and aid literature, **Performance-Based Financing, Pay-for-Performance (P4P), Performance-Based Payment** and **Performance-Based Incentives (PBI)** can all be synonyms for RBF; however, the term "performance" in this context means that payments are only made to providers, not beneficiaries.). **Performance-Based Contracting (PBC)** is another subset of RBF that sets a fixed price for a desired output and adds a variable component that can either reduce payment for poor performance, or increase payment for good performance relative to the standard or benchmark defined in the contract (Hawkins et al., 2019).

RBF Program Examples:

- **The Global Fund,** which is an international financing partnership that aims to fight HIV, tuberculosis (TB), and malaria in 130 countries. The program uses a PBF mechanism that evaluates program performance, and funding is released based on progress towards country-owned targets and indicators. Performance data is used to stop grants, reduce funding, or accelerate funding (V. Y. Fan et al., 2013).
- **The World Bank's Conditional Cash Transfer Programs**, which are social assistance programs aiming to reduce poverty. In development finance, Conditional Cash Transfer Programs typically reward the behaviour of an individual, such as providing money to families contingent upon certain

verifiable actions, generally minimum investments in children's human capital such as regular school attendance or basic preventative health care (see World Bank Group's RBF for Health portal for specific projects at *www.rbfhealth.org*).

- **The World Bank's Voucher Programs**, where vouchers are handed out to targeted individuals who redeem them at service providers. Service providers then get reimbursed for the vouchers (see World Bank Group's RBF for Health portal for specific projects at *www.rbfhealth.org*).

> **RBF In-Depth Example 1: The Amazon Fund** was the first large-scale international effort to promote forest conservation using a performance-based mechanism. The agreement between Norway and Brazil transferred development financing to Brazil on the basis of verified reductions in carbon emmisions from slowing the rate of deforestation. Norway pledged US $1 billion to the Amazon Fund for the period from 2008 to 2015. Transfers from Norway to Brazil were designed to reward an outcome (reduced emissions from deforestation) based on satellite imagery that measures changes in deforested area.
>
> The agreement saw Norway pay Brazil a fixed amount for each "unit" of progress at US$5 per ton of CO_2 emission reductions. Avoided deforestation rates were calculated based on data from Brazil's National Center for Space Research using satellite imagery, and 'avoided deforestation' was the change in the current years deforestation rates compared to the average between 1996 and 2005 (this 5 year period was shifted forward every five years to create a new baseline). The amount of reported reduced gas emissions was independently reviewed by a technical committee of independent experts. Brazil had full discretion over the way it reduced deforestation, and international funds were channelled through the Amazon Fund into environmental programs that would further contribute to forest conservation.
>
> Information on annual deforestation rates, emissions reductions and payments can be found on both Norwegian and Brazilian official websites and the Norwegian International Climate and Forest Initiative (NICFI) websites.
>
> Sources: (Correa et al., 2019; Forstater et al., 2013; Wertz-Kanounnikoff & Angelsen, 2009)

11.1.2.2. Result-Based Aid

Results-based aid (RBA) is a performance-based aid contract between a donor and a national or sub-national government (Grittner, 2013). In these models, the recipient of the fund achieves specific outcomes, and governments link the disbursement of the fund to the verification of the achievement of those outcomes (Perakis & Savedoff, 2015). In this context, **Output-based aid (OBA)** is accepted to be a synonym for RBA, and output does not usually include results better classified as outcomes (Musgrove, 2011). **Cash-on-Delivery (COD)** is a subset of RBA that refers to outcomes rather than just outputs and is distinguished from RBA as the principal has minimal oversight of how the agent achieves the desired outcomes (Musgrove, 2011). RBA has been applied in most infrastructure sectors and social sectors (GPRBA, 2021).

RBA Program Examples:

- **The United States Millennium Challenge Corporation**, which allocates aid to 'reward' developing countries for a commitment to good governance and development as measured by a series of third-party policy indicators (see (GPRBA, n.d.) for specific projects).

- **The European Union's EU Budget Support Program**, which offers three budget support programs (Good Governance and Development Contracts, Sector Reform Contracts, and State Building Contracts) designed to address a specific development objective (see https://ec.europa.eu).

- **The World Bank's Program for Results**, which provides incentives to enhance the quality and availability of services and disbursement is linked to specified results (see https://www.worldbank.org/en/programs/program-for-results-financing).

Results-Based Aid In-Depth Example 1: The GAVI Alliance Immunization Services Support (ISS) Program was established in 2000 with the aim to increase immunizations in developing countries through a results-based funding mechanism between the World Health Organization, the World Bank, and many other private and public agencies. It was considered to be an innovative approach to funding vaccination programs and one of the first to pay governments for "units of progress".

The GAVI ISS program paid for increases in the number of immunized children, which represents a development outcome: vaccination is a strong proxy for improved child health and may be correlated with the quality of a country's healthcare system (Murray and Evans 2006). The ISS program provided a fixed payment of US$20 per additional child vaccinated. The program took country ownership seriously and did not impose specific requirements on how vaccination programs were to be rolled out or how reward funds were to be used.

A total of 62 countries received funding from the ISS Program between 2000 and 2010. The funding model was for five years, with the first three years as initial investment and in subsequent years, countries were paid based on increases in numbers of children immunized. The program gave countries wide discretion on how they would achieve increases in immunizations, and external evaluators monitored countries reporting on immunization progress.

Sources: (Gandhi, 2015; Perakis & Savedoff, 2015; Trap et al., 2011)

Results-Based Aid In-Depth Example 2: Salud Mesoamérica 2015 (SM2015) was a five-year RBA initiative aimed to reduce equity gaps in maternal and child health across Central America starting in 2010, funded by the Bill and Melinda Gates Foundation, the Inter-American Development Bank (IDB) and the Spanish Government. The pilot operated in seven countries, and a portion of funding to government was contingent upon progress toward health-related development goals. SM2015 was a large regional initiative, for which a portion of program funding is paid on the basis of measured results (up to 50% of counterpart funding, which is at least 50% of input-based funding provided by the project's donors). The program provides conventional investment funds alongside a performance component, and countries received grants but were also required to finance a portion of the program costs themselves. If the goals of the initiative were achieved, countries were reimbursed for 50% of the amount they contributed. Through this program, funding could only be used to implement specific evidence-based interventions in targeted areas, and activities were required to be targeted at the poorest 20% of the population.

The indicators directly measure outcomes (for example, reductions in prevalence of anemia) or outputs that are associated with desired outcomes (for example, increases in neonatal care provided within 24 hours of birth), and the program did not pay for a single outcome but instead uses 8 to 12 outcome and output indicators which measure important features of the countries' health systems in the areas of prenatal, neonatal, and maternal health. About 8 to 12 indicators were selected on average for each country, and five of which were common across countries in order to make regional comparisons. Examples of indicators used include contraceptive use, anemia prevalence, DTP3 vaccinations and antenatal care visits. SM2015 payments are made on the basis of targets rather than in proportion to progress.

The SM2015 website maintained by the IDB has published country-level information about the program.

Sources: (Bhushan & Calleja, 2015; El Bcheraoui et al., 2018; Mokdad et al., 2015, 2018; Perakis & Savedoff, 2015)

RBA In-Depth Example 2: United Kingdom Department for International Development (UK DFID) Cash-on-Delivery Pilot in the Ethiopian Education Sector was a project intended to improve access to and the quality of lower secondary education in Ethiopia through the use of COD Aid. UK DFID negotiated an RBA program with the government of Ethiopia, making it the first program to be directly inspired by the idea of COD Aid. In this pilot, the amount of aid provided was directly related to the magnitude of outcomes achieved, rather than activities provided or outputs produces (Tobin et al., 2015). The pilot aimed to improve access and quality of education of secondary students in specific regions of the country, specifically, the pilot intended to increase the number of grade 10 students sitting and passing the national examinations in 2012, 2013 and 2014. To incentivize these outcomes, the DFID offered the Government of Ethiopia a fixed dollar amount per student sitting and passing the national exams in these years.

Rewards payments were based on the number of additional sitters and passers within each region per year, compared to the number the previous year. The program paid for each additional boy or girl who sits the lower secondary exam and for each boy or girl who passes the exam, rewarding the Ethiopian government in proportion to the progress made on these measures. DFID contracted an independent consulting agent to verify results reported by the government. During this pilot, the DFID published independently conducted annual reviews as well as a final review (Tobin et al., 2015) and provided detailed performance data at the disaggregated level, available at its open data portal. In terms of accountability to British taxpayers, DFID has provided key information on its website, especially in terms of the program's budget and design.

Sources: (Bhushan & Calleja, 2015; Holzapfel & Janus, 2015; Perakis & Savedoff, 2014; Tobin et al., 2015)

11.1.2.3. Challenge-Linked Financing

Challenge-linked Financing (CLF) is a term for 'awards' or 'prizes' in the development sector, and includes funds or other rewards for development solutions, typically through a competitive process (Bhushan & Calleja, 2015). Notable CLF models include the Grand Challenge programs, the Small Medium Enterprise (SME) Innovation Trust Fund, and the USAID's Development Innovation Ventures. (Bhushan & Calleja, 2015).

CLF Program Examples:

- **The Global SME Finance Innovation Trust Fund**, which promotes innovative ways to provide sustainable financing of SMEs in low-income countries (see https://www.gpfi.org/publications/inception-report-sme-finance-forum-and-interim-progress-report-global-sme-finance-innovation-trust).

- **Bill and Melinda Gates Foundation Grand Challenges in Global Health**, which uses a family of grant programs to overcome bottlenecks in developing new tools and methods to improve health in the developing world (see https://gcgh.grandchallenges.org)

- **Canada, Bill and Melinda Gates Foundation, United Kingdom Grand Challenge Canada**, which supports innovative ideas to overcome health problems in low- and middle-income countries (see https://www.grandchallenges.ca)

- **Bill and Melinda Gates Foundation Grand Challenge Exploratio**n, which uses a tiered grant mechanism to support innovative ideas to solve key health and development problems for those most in need (see https://gcgh.grandchallenges.org/about)

- **United States Development Innovation Ventures**, which supports the discovery of new and innovative ways to address complex development problems (https://www.usaid.gov/div)

Challenge-Linked Financing In-Depth Example: The United States Millennium Challenge Corporation (MCC) provides economic assistance through a competitive selection process to developing nations that demonstrate positive performance in three areas: ruling justly, investing in people, and fostering economic freedom. MCC compacts are five-year grant agreements, proposed and implemented by well-governed countries. This PBF model is unique from others previously described as the disbursement-linked indicators are used to evaluate a country for initial funding based on past performance. Indicators used by the MCC include Political Rights, Girls Primary Education Completion Rate, Public Expenditure on Health, Fiscal Policy, and 1-Year Consumer Price Index. Indicators are monitored by independent auditors including the World Bank Institute, World Health Organization, and Heritage Foundation.

As of 2019, the MCC has signed 37 grant agreements, known as compacts, with 29 countries. The MCC provides detailed financial results and impact data for specific initiatives and links the financial and objective/outcome data at the initiative specific level and presents this through its own online data portal (Link data portal).

Sources: (N. M. Brown, 2019; Johnson & Zajonc, 2006)

11.2. Incentive-Based Funding Mechanisms in Higher Education

In the higher-education sector, PBF is a model of funding where the budget of an institution is linked to the performance of that institution, usually over a period of 2-4 years (Alshehri, 2016). PBF first appeared as a model for funding in higher education in the late 1970s, but was later abandoned by most governments (Harnisch, 2011). Many national and sub-national governments have re-adopted performance-based approaches to higher-education funding including Australia, Canada, Chile, Hong-Kong, and the United States as well as many European countries (Alshehri, 2016; De Boer et al., 2015; Jongbloed & De Boer, 2020; Miao, 2012).

PBF approaches in higher education vary in terms of what is considered 'performance' and how it is attached to funding. Common performance indicators include number of degrees attained, exams passed, credits earned, students from underrepresented groups, PhD graduates, and employability indicators (De Boer et al., 2015; Miao, 2012). There are two common performance-based approaches to funding in higher education:

- Performance Agreements; and
- Performance Set-Asides (Clark et al., 2018).

11.2.1. Performance Agreements

Performance Agreements, also known as **Performance Contracts**, are negotiated agreements between states and institutions to achieve results within a timeframe (De

Boer et al., 2015; Harnisch, 2011). The contracts are binding documents that are typically tailored to each university. In exchange for a funding allocation, institutions come to an agreement with the state regarding benchmarks and goals. In most cases, if these targets are not met, institutions lose all or a portion of the funding in the next round of performance agreements (D. W. Lang, 2016).

Examples of countries that use performance agreements:

- **Australia**, where 20% of budget for education and research is based on Mission-Based Compacts. In these Compacts, agreement to certain performance targets is a condition for funding (Australia Department of Education, 2020).

- **Ontario (Canada),** where about 2% of educational operating grants are linked to performance through Strategic Mandate Agreements (Ontario, 2018)

- **The Netherlands**, where 7% to 32% of budget for education and research at higher education institutions is linked to Performance Agreements (De Boer et al., 2015).

- **Scotland**, where 85% of budget for education and research at higher education institutions is connected to Outcome Agreements (Scottish Funding Council, 2020).

Performance Agreement In-Depth Example 1: The Netherlands

Since 2012, portion of higher education funding in the Netherlands has been based on performance agreements, where universities make agreements with government on how they will improve the education they provide. Performance agreements are aimed at improving the quality of education in higher education institutions with the goal of reducing drop-out rates, and situating Dutch higher education institutions among the most competitive knowledge economies (De Boer et al., 2015).

The agreements have specified indicators used to improve student success and education quality including: student degree completion, student drop out rates, share of Year 1 students switching programs, students in honors programs, teaching intensity and academic staff qualifications, and share of overhead costs. In terms of connecting these indicators to funding, a share of 7% of the education component of the institutions annual budget was tied to these agreements, with the remainder of funding allocated based on a standard formula. If institutions did not meet their targets at the end of the four-year period that the performance agreements covered, they stood to lose a portion of this funding during the next four years. Progress towards results was monitored by an independent review committee at a mid-term basis, based on reports provided by the institutions.

In 2017, performance agreements were replaced by quality agreements, which have a similar concept but are focused more on student outcomes.

Sources: (De Boer et al., 2015; Jongbloed & De Boer, 2020)

11.2.2. Performance Set-Asides

In Performance Set-Asides, a base funding is provided to all institutions, and a small portion is set-aside as a competitive fund for universities that produce results that meet or exceed certain performance targets (Miao, 2012). Performance Set-Asides may be a “bonus” fund or a separate portion of a regular state appropriation (Harnisch, 2011).

Example of Performance Set-Asides:

- **The Pennsylvania State System of Higher Education** sets aside 8% of its institutional budget, equivalent to about $36 million, to reward schools for meeting or exceeding eight performance measures that encompass a variety of key areas such as degree completion, retention, and faculty productivity. In this model, all targets need to be met in order for institutions to receive a share of these funds, and those that exceed requirements receive a larger portion (Miao, 2012).

Performance Set-Aside In-Depth Example 1: Ontario Strategic Mandate Agreements

Strategic Mandate Agreements (SMAs) are agreements between the Ontario Ministry of Training, Colleges and Universities (MTCU) and the publicly funded education institutions in the province. SMAs were first introduced in 2014, through which higher education institutions were required to articulate distinctive goals and report on outcomes annual. SMAs are intended to promote student success and institutional excellence through five priority areas: Enhancing the student experience to improve student success and outcomes; Innovation in teaching and learning excellence; improving access and equity for qualified students; enhancing applied research/research excellence; and innovation, economic development and community engagement. In total there are about 20 metrics, both system-wide metrics and institution-specific metrics. System-wide metrics include graduate employment rates, student satisfaction survey results, graduation and retention rates, and other equity-based metrics such as proportion of Aboriginal, first generation, students with disabilities, and francophone students at an institution. Institution-specific metrics include number of students studying abroad, spin-offs and highly-cited researchers.

SMAs were seen to be the first step in a process where the program would eventually evolve into one where funding is attached to institutions based on their successes at achieving their goals. As of 2020, funding is not tied to institutions meeting their SMA targets, however, the SMA program has presented an opportunity for the MTCU to engage in a dialogue with institutions about performance, with the intention that the program will transition to tying these metrics to outcomes based funding as part of the third round of SMAs.

Sources: (De Boer et al., 2015; Jongbloed & De Boer, 2020)

11.3. Incentivizing Results in Social Service Delivery

Performance-based approaches to social service delivery are used as a means to incentivize the goals and desired outcomes of specific social programs (Hawkins et al., 2019). In a 2013 national US survey, 22% of large non-profit organizations had performance-based mechanisms as all or partial funding sources (Gold et al., 2014). There are three common models for performance-based approaches to social service delivery and contracting:

- Outcomes-based grants and contracts;
- Incentive prizes and challenges; and
- Pay for Success initiatives.

A detailed description of these mechanisms as they relate to social service delivery and examples of how these mechanisms have been operationalized is provided below.

11.3.1. Outcomes-Based Grants and Contracts

Outcome-Based Grants and Contracts (OBCs) are bilateral agreements between a principal and a social service provider. Under these agreements, at least a portion of payment is connected to measurable outcomes, and the service providers payment is based on successfully achieving those outcomes (Barker et al., 2018). How OBCs are operationalized varies, but the critical component is that the service provider is paid on achievement of specified outcomes. For example, if a government was paying a service provider for a program to help unemployed persons find work, an OBC would connect payment to the achievement of that outcome, such as the quantity of unemployed persons who found sustained employment through the program (Zlatinov & Gillette, 2018). In contrast, a more traditional (non-OBC) arrangement would likely connect payment to the number of training classes delivered or persons who enrolled in the program (Zlatinov & Gillette, 2018).

Outcome Based Contract Example 1: Tennessee Department of Children's Services

The Tennessee Department of Children's Services (DCS) began exploring the use of performance measures in the early 2000's with the aim of reducing its reliance on out-of-home care and time it takes to place children in permanent homes. In 2005, the DCS began a year-long pilot with five service providers, with contracts that are grounded in a longitudinal database maintained by the Center for State Child Welfare Data, containing foster care trajectories of all children in out-of-home care. In these pilots, agencies were initially measured against their past performance rather than the performance of other agencies, and contracts were developed based on a 'baseline-target-actual' method to measure change in agency performance over time. These methods were agency specific, and metrics included exits-to-permanency, care days used, and rate of re-entry to care. In the decade following, the service evolved to include 'performance banding' where agencies were placed in to high-, mid- and low-performance bands.

The payment structure for the programs is developed into two parts, a blended rate per day and a performance bonus or penalty. When providers exceed their baseline performance rate, DCS returns apportion of the savings generated back to the provider. The program successfully improved agency performance and as of 2009, all DCS contract agencies work under the PBC protocol. Once fully implemented in 2010, Tennessee's new model nearly cut in half the average time a child spends in temporary care, from more than 22 months to 14.

Sources : (Barker et al., 2018; Hawkins et al., 2019)

11.3.2. Pay for Success Initiatives

Pay-for-Success Initiatives (PFS), also commonly referred to in the social service sector as **Social Impact Bonds (SIBs)**, are contracts that enable a principal to pay the service provider only when they meet certain targets or goals related to a desired outcome (Barker et al., 2018). A SIB is not a real 'bond' but a loan from private funders to service providers (Harvard Kennedy School Government Performance Lab, 2017). In an SIB, an investor provides funds to the service provider until they achieve specific outcomes, at which point the investor plus interest is reimbursed to the investor by the principal. If the service provider does not achieve the target, they may not receive all or a portion of their initial funding. Examples of outcomes used in previous SIB programs include the number of former offenders that do not return to prison, or the number of unemployed individuals who are successful in finding sustained employment. The parties to the contract agree to the measured outcomes, and metrics used for the outcomes are evaluated by an independent auditor (Zlatinov & Gillette, 2018).

Examples of Pay for Success Initiatives:

- The world's first PFS in **Peterborough, England**, provided services designed to reduce recidivism for individuals being released from jail (RAND, 2016).
- **New York City** has an ongoing PFS project that provides cognitive behavioral therapy to juveniles incarcerated at Rikers Island (Hawkins et al., 2019)
- **British Columbia** hospitals introduced an activity-based funding policy as opposed to lump sum funding which resulted in a decreased volume of cases and an increased number of surgeries (Sutherland et al., 2016).
- **Connecticut** has an ongoing PFS project providing substance abuse treatment to parents in child-welfare-involved families with the goal of reducing out-of-home placements (Social Finance, 2016)
- **The DC Water Authority** issued the US's first environmental impact bond in 2016 to fund installation of green infrastructure intended to reduce stormwater and sewage runoff into polluted waterways (DC Water, 2016).

The literature and case studies reviewed in this report are not intended to be exhaustive, rather the goal is to provide a general overview of how performance-based approaches are operationalized across sectors.

12. Appendix B: Community Design Characteristics – Walkability: Exploring the Relationship Between Walkability and Neighbourhood Change

12.1. Introduction

Walkability is a measure of how supportive an area is of walking for both recreation and functional purposes. While generally a desirable neighbourhood characteristic, there is a growing body of research suggesting that those who need walkable neighbourhoods most, such as low-income residents, are increasingly unable to afford to live in them. The purpose of this paper is to explore the relationship between walkability and neighbourhood social change, investigating how walkability and gentrification have changed in Metro Vancouver during a 10-year period from 2006 to 2016, and how the two processes are related.

Using the Walkability Index as a measure of walkable urban environments, the analysis found that the most walkable neighbourhoods in the region were those nearest the urban core (downtown City of Vancouver); however, the greatest relative changes in walkability during the study period were in more suburban and rural municipalities.

Gentrification was evaluated using two methods, the David Ley Social Status Index and multiple individual indicators of change. Both comparative analysis methods found distinct patterns associated with walkability during the study period, with findings suggesting that while gentrification is taking place in both high and low walkability neighbourhoods, the actual social, economic, and demographic outcomes of the processes differ. There would be opportunity through further research to continue investigating the differences in these patterns and processes, perhaps using different measures of change and across additional time points.

A relationship between changes in walkability and gentrification couldn’t be established using the analysis methods employed; however, future research could build on the early findings of this study to further investigate changes in walkability and gentrification using more advanced quantitative methods, adjust the temporal scope of the study.

The findings of this paper suggest that walkable neighbourhoods are a resource that is not equally accessible by all residents, that people who might need walkable environments the most might have unequal access to them. As the Metro Vancouver region and many of its member municipalities are emphasizing walkable neighbourhoods on their urban planning agendas, it is important to consider whether the strategies deployed to operationalize the region’s policy goals are serving the regions diverse populations and how changes in built and social neighbourhood trajectories are connected.

12.2. Neighbourhood Change

In traditional urban theory, residential displacement is largely the root cause of shifts in changing neighbourhood dynamics, such as shifts in racial composition or population age (Freeman & Braconi, 2004), and that this displacement can lead to negative outcomes in both health and equity for displaced residents (Atkinson et al., 2009). The competition for space in desirable neighbourhoods can lead to existing residents being displaced by more affluent ones, and some scholars even argue that gentrification is an "overt revitalization strategy" that has been historically deployed by local governments, often in consortium with private developers (Hackworth & Smith, 2001; Lees, 2000; Ley, 2003).

Many debates have emerged over the last several decades about what constitutes and causes neighbourhood change. These critical debates have led to questions such as what exactly a neighbourhood constitutes, what is change, how should change be measured and over what time period. The following section provides a high-level overview of the prominent theoretical debates in neighbourhood change research, how neighbourhood change has been measured, as well as a discussion on the importance of context in scale in Canadian neighbourhood change research.

12.3. Theoretical Debates on Neighbourhood Change

Gentrification and neighbourhood change is a well-established area of research with significant theoretical divisions that have pervaded the literature for decades (Slater, 2003). While critical debates remain, a lot of the literature is concerned with two dominant drivers of urban change: class displacement, or demographic shift and economic restructuring that causes populations to change. The next section of this literature view covers some of the key debates in what constitutes neighbourhood change and gentrification.

12.3.1. Residential Migration as Neighbourhood Change

Discussions on residential migration dominate neighbourhood change literature, with much of the research focused on the characteristics of those moving in and out of neighbourhoods. Typically, the migration patterns follow more affluent population moving into an area for many reasons (real estate pressures, physical upgrades, proximity to cultural centers or jobs) and lower income and more socially vulnerable existing residents are displaced (Atkinson et al., 2009; Newman & Wyly, 2006; Wyly & Hammel, 1998). Marcuse (1985) distinguished between two forms of displacement, direct and indirect. Direct displacement is the process of lower income residents moving out because of evictions and rising rent prices, while indirect displacement is defined by lower-income residents being unable to afford to move into areas that they may have been able to previously (Marcuse, 1985).

Some researchers have historically argued that it is hard to draw a direct relationship between neighbourhood change as displacement, and that sometimes an influx of new residents does not always lead to low-income residents moving out (Lupton, 2004). Rose (1984) pointed out that some displacement is favorable for persons who own their home and hope to capitalize on favorable real estate prices. In other cases, ‘marginal-gentrifiers’ are persons who move to affordable neighbourhoods as an entry point to the city’s housing market, and the neighbourhood does not necessarily gentrify (Rose, 1984).

While displacement might be the dominant driver of urban social change, other processes are also often taking place that contribute to neighbourhood change such as in situ upgrading and generational demographic shifts (Hedman, 2011). Analyses evaluating neighbourhood change must address and attempt to isolate the process of displacement from other changes processes that may be at place by looking at regional trends and not neighbourhoods in isolation.

12.3.2. Neighbourhood Change as Demographic Shifts

Demographic shifts can also occur in cities where a younger middle-class population moves in and to an area that has a predominantly ageing working-class population. In studies that describe these shifts as a driver of neighbourhood change (Buzar et al., 2007; Hamnett, 1994), they argue that a growing number of young persons move to cities following graduation, and suggest some of the demographic shifts observed are because of higher death rates among an older working-class population than among a relatively young middle class (Bailey et al., 2017). In classic neighbourhood life-cycle theory, when a housing stock ages, younger and lower income households slowly replace more affluent residents who move away (Temkin & Rohe, 1996), which can be considered another process of urban change that is not necessarily gentrification and displacement.

At what point in the processes gentrification takes place is also important in understanding neighbourhood change and demographic shifts: a recently gentrified area may see a demographic outflow of older and (or) low-income households, but areas that are further along in the gentrification process may see an older cohort of gentrifies (Agbai, 2021). The implications of this for neighbourhood change research is that demographic shifts identified as an inflow of young persons may be a mark of early stage gentrification, while this shift may not mark late-stage gentrification.

12.3.3. Neighbourhood Change as in situ upgrading process

In situ upgrading is a process in which an existing residential population experiences a market compositional change, such as increased income or upward social mobility. Literature on in situ upgrading is scarce compared to residential migration, but some have pointed to it being a contributing factor to neighbourhood change in some cities, and being more prominent in working-class neighbourhoods with low turnover (McKinnish et al., 2010). In situ upgrading is also described as residents moving into a neighbourhood and being of an income below neighbourhood average, but subsequently experiencing steep income increases. In these cases, not all residents would experience income gains to the same extent, and the research on in situ upgrading has shown that it is typically young and highly educated persons that show substantial income gains following a period of in-migration (Hochstenbach & van Gent, 2015).

Isolating in situ neighbourhood change from other change process is challenging, as it requires measuring changing income composition of in-moving and out-moving households, instead of measuring changing income profiles in neighbourhoods and comparing them to regions or control neighbourhoods (Grigsby, 1986).

12.4. Measuring Neighbourhood Change

Based on the complexity of the debates on drivers of neighbourhood change, it would be hard to explain the phenomenon through a single decisive model of change. The three processes of urban change described in the previous section are not mutually exclusive, and all could be occurring within one neighbourhood at any given time, but the degree to which each is occurring would likely vary across neighbourhoods and regions.

What makes measuring neighbourhood change even more challenging is that the theoretical framework used to develop methodology for measuring change in one location may not be applicable to another. For example, Buzar (2007) suggested that social change in neighbourhoods within cities that are performing well economically vary significantly from declining or stable cities. Therefore, some means that underlying assumptions about certain indicators of gentrification, such as immigration status, education, and income, from other regions may not hold in Vancouver's regional context.

12.4.1. Indicators of Neighbourhood Change

In a systematic review of walkability literature, Anguelovski (2018) identified over 180 studies using various neighbourhood indexes to measure gentrification since 2000. There is no clear best practice for measuring neighbourhood change but there are some common methods where some may be more appropriate for certain contexts than others. Conceptualizations of gentrification historically focus on socioeconomic markers (e.g., income, housing values, education) (Glass, 1964; Slater, 2011), but more contemporary research argues neighbourhood change should be determined tough other factors such as macroeconomic trends, segregation, and housing stock (Meegan & Mitchell, 2001). Quantitative data used to measure change usually fall within the realm of the economic, sociocultural, and physical dimensions of neighbourhoods measured across time; and common indicators include median income, visible minority status, ethnicity, age, educational attainment, employment status, median home value, median rent, home ownership (Barton, 2016; Freeman, 2005; Hammel & Wyly, 1996; Walks & Maaranen, 2008). Less common quantitative indicators of neighbourhood change include age of home, mortgage information (lending), and counts of certain amenities and businesses such as coffee shops. Quantitative indicators are typically measured at the census tract level or equivalent due to data limitations and suppression (Barton, 2016). There is no definitive quantitively measures to measure urban change as a multidimensional process, but Hammel and Wyly (1996), among others, have argued that it is best to measure change across multiple indicators rather than just one variable to avoid an oversimplication of the phenomenon.

Some literature on neighbourhood change is concerned with whether relative or absolute change is the most relevant to measure in urban change (Lupton, 2004). Relative change often considered what is important for equity purposes, because the difference between neighbourhoods is what matters. A neighbourhood may see an absolute increase in a certain variable of change, but this would be a less significant indicator of change if the rest of the city experienced the same increase (Glass, 1964; Slater, 2011).

12.5. Gaps in Existing Walkability and Neighbourhoods Change Literature

There are two distinct but related gaps in walkability and neighbourhood change literature. First, most studies related to walkability and neighbourhood characteristics are evaluated across a city or region at one point in time. Cross sectional studies cannot assess a temporal relationship between input and outcome, this raises the question whether an increase in neighbourhood walkability over time is associated with increased changes in other neighbourhood characteristics (Timmermans et al., 2021). One notable exception is a study by Quastel (2012), that measured change over time in Vancouver, however, this study assumed walkability to be static, rather than an aspect of neighbourhoods that also changes over time. In reality, neighbourhoods experience different processes both physical and social change over time, and that change, and its effects may be non-linear. Second, most literature on walkability and gentrification has focused on measuring the relationship between specific urban design features that contribute to pedestrian-supportive environments and a neighbourhood's social characteristics rather than 'walkability' as factor of the built environment.

The relationship between walkability and neighbourhood change is an important issue as policy in Metro Vancouver is specifically aimed at increasing walkability in particular parts of the city. Evaluating the influence of built environment changes on neighbourhood social trajectories is important, as it may help understand why some neighbourhoods experience change while others remain stable, and potentially help identify predictors of future processes of gentrification (Zwiers et al., 2017). Given the emphasis on walkable environments in urban planning policy including the Regional Growth Strategy for Metro Vancouver, it is important to consider how the social and physical characteristics influence each other during the short and long term (Quastel et al., 2012).

12.6. Analysis Methodology

12.6.1. Measuring Walkability

For this analysis, walkability was measured using the walkability index proposed by Frank et al. (2005) to quantify the walkability across the region at the census block level for all three time points. For each census block group, the walkability index is a derived function of net residential density, retail floor area ratio (FAR), land-use mix, and intersection density. Net residential density is the ratio of residential units to land area devoted to residential use; Retail FAR is the retail building floor area footprint divided by retail land floor area footprint, which is a proxy measure of retail urban design (a low ratio is a proxy indicator of substantial surface parking and large setbacks); Intersection density measures the connectivity of the street network, measured as the ratio of number of intersections to land area of the block group. Land use mix is an entropy score based on five land use types (residential, retail, entertainment, office and institutional), with values normalized between 0 and 1, with 0 being single use and 1 indicating an even distribution of floor area across 5 uses (L. D. Frank et al., 2010b).

To develop the index, the z-scores of each variable are calculated so that the value distribution is normalized, and the walkability index is the sum of these scores for the four measures of urban form:

$$walkabiliy = \begin{bmatrix} (2 \times Z - intersection\ density) + (Z - net\ residential\ density) + \\ (Z - retail\ floor\ area\ ratio) + (Z - land\ use\ mix) \end{bmatrix}$$

Calculating walkability across the region using this measure is then used to create a walkability surface for the metropolitan region, which are maps of walkability index values to visualize walkability across a geographic area. Walkability surfaces and the absolute values of the variables used to calculate the surfaces have been provided by UBC Health and Community Design Lab. The walkability surface for the 2016 study year is illustrated in Figure 12-1 with highly walkable neighbourhoods appearing in green and low walkability neighbourhoods appearing in red.

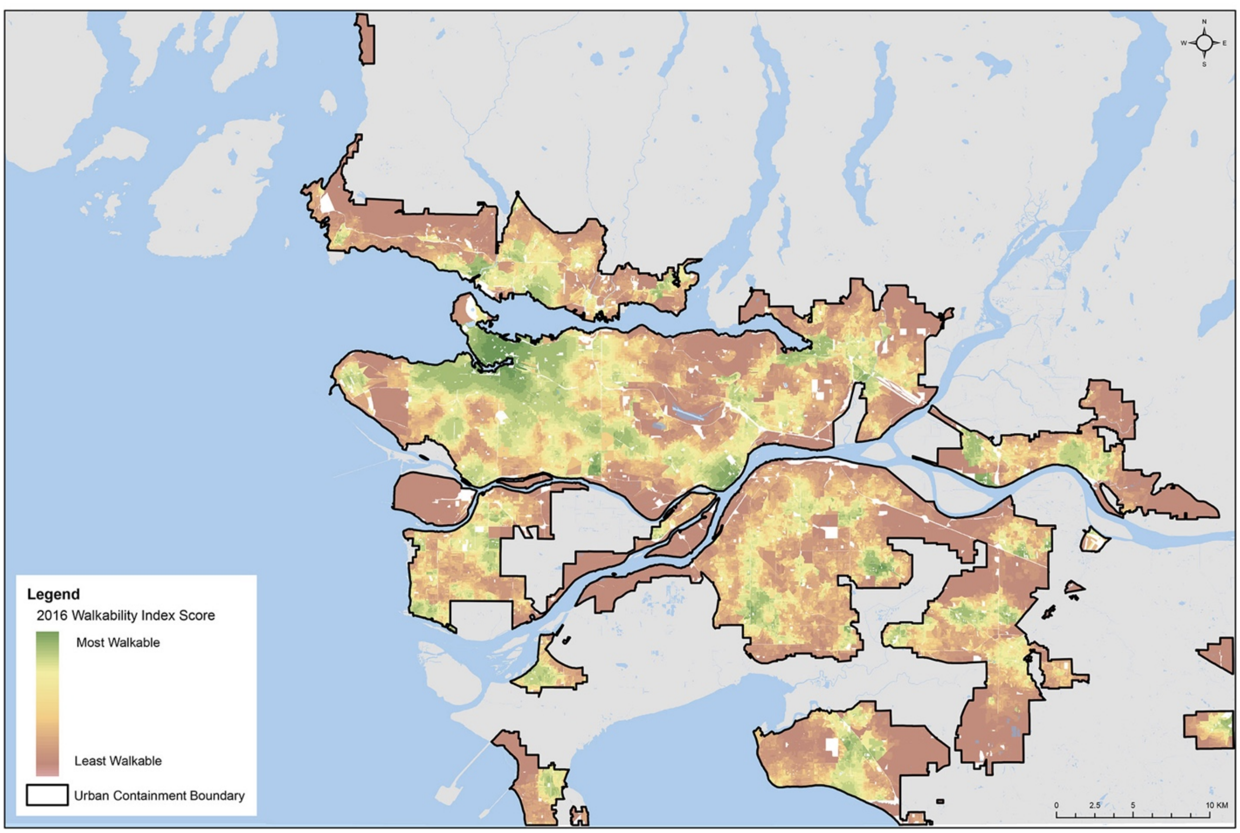

Figure 12-1: Walkability surface for the Metropolitan Vancouver Region, 2016

12.6.2. Measuring Longitudinal Changes in Walkability: Grand Mean Method

The original walkability index has been validated against actual travel behavior, with the weighting scheme of the urban form measures (each urban form measure is given equal weight, except intersection density has double the weight than others) determined through iterations of alternative schemes (L. D. Frank et al., 2010b). While the index does need to be modified for measuring longitudinal change, the results of the modified index would ideally involve little modification of the original index formula as well as the rank-order of the results (even if the magnitude changes). The preferable method would be the **grand mean method**, as this method is the most consistent with the original index formula. Using the grand mean to calculate the standard deviation and mean of the urban form measure z-scores means that the index formula itself does not need to be altered (as it would with POMS method). As the urban form measures are still standardized, the order on which they score cross sectionally isn't expected to change within each time point, even if the mean and standard deviation change, as they are all compared against the same values. Using POMS method or creating a "change in walkability" index would involve altering the original index formula, and how this would impact the validity of the index isn't known.

This method considered for measuring change in walkability was the **"Grand Mean"** method, where the z-scored values for each of the four variables would be calculated using the mean and standard deviation across all reference frames (study years). Using this method, the original walkability index would not be modified, but the new formula for calculating mean and standard deviation is shown below:

$$walkabiliy = \left[2 \cdot Z_{\substack{Intersection \\ Density}} + Z_{\substack{Net\ Residential \\ Density}} + Z_{\substack{Retail \\ FAR}} + Z_{\substack{Land\ Use \\ Mix}} \right]$$

Where:

$$z - score = \frac{(x - \mu)}{\sigma}$$

$$\mu = \frac{\left(\sum x_{2006} + \sum x_{2011} + \sum x_{2016} \right)}{n_{2006} + n_{2011} + n_{2016}}, \text{ and}$$

$$\sigma=\sqrt{\frac{\left(\sum\left(x_{2006}-\mu\right)^{2}+\sum\left(x_{2011}-\mu\right)^{2}+\sum\left(x_{2016}-\mu\right)^{2}\right)}{n_{2006}+n_{2011}+n_{2016}}}$$

The benefit of calculating z-scores using a grand mean is that it would not require changing the walkability index formula, and it would be possible to calculate z-scores using standard deviation and mean across all time points. It is expected that the standard deviation and mean for each variable do not change much using this method, and the index scores themselves are not expected to vary significantly, meaning that rank order across time points would be maintained. However, a criticism of this method might be that standardization across observations across time points obscures information about relative rank of an observation across a given point in time.

Standardizing across time points obscures information about relative rank of an observation across a given time point, but this is not expected to be a significant issue as this method was only used to measure across time points, and not to determine the rank order within time points.

12.6.3. Measuring Neighbourhood Change

There is debate about what constitutes the spatial and social dimensions of a neighbourhood. For quantitative analysis, both census tract (CT) and dissemination area (DA) boundaries are commonly used as an aerial unit of analysis. Measuring data at the dissemination area was initially considered as it would be a more granular analysis and may be easier to interpret a relationship between neighbourhood change and walkability (which is measured at the census block level), but there were several issues with data suppression for some of the variables at this scale. Further, the dissemination area boundaries changed between census years, particularly in downtown Vancouver. CTs are a larger unit analysis but still a common measure of neighbourhoods in quantitative research, and the CT boundaries in the greater Vancouver area have been relatively stable over time. There were some instances when the CT boundaries did change, but these were adjusted using *The Canadian Longitudinal Census Tract Database, 1971—2016* (Allen & Taylor, 2018*).*

Many indexes and methods have been developed, but neighbourhood change is context-specific, and many of the inherent assumptions about the relationship between certain variables made when developing indexes do not necessarily track to Metropolitan Vancouver context. This eliminates the possibility of using many of the pre-existing indicators and indexes of neighbourhood change found in United States and United Kingdom gentrification literature.

Several methods were explored for measuring neighbourhood change in Metropolitan Vancouver: (1) describing neighbourhood change using individual indicators, (2) using Principal Component Analysis to develop an index of change, and (3) using a gentrification index from the literature that has been previously validated in Canadian cities.

Using **individual indicators to measure change** is a simple and common method for measuring change in urban geography. Individual indicators, such change in demographic trends or change in median household income, is a straightforward and does not require interpreting any relationship between variables. The benefit of using this method is its simplicity, the relationship between individual indicators and walkability can be compared through discussion on how change in some indicators change in relation to change in walkability, or more walkable and less walkable environments. However, as discussed in the literature review, using a single indicator to measure neighbourhood change may oversimplify complex a phenomenon, which is why composite index of gentrification indicators across multiple variables is a popular method for understanding overall neighbourhood change.

Principal Component Analysis (PCA) is a popular method for studying social and economic change and the correlation of variables in urban geography research and has been used previously by Quastel et al. (2012) to measure neighbourhood change in Vancouver. PCA is an unsupervised method for transforming multiple correlated variables into a new set of uncorrelated principal components. A single principal component can include several variables that capture multiple dimensions of contemporary urban change, preserving as much variability as possible and translating variables into new components that are linear functions. In essence, PCA does the work of creating an index of change from many indicators of change and can often reveal relationships that were not previously suspected between variables (Rothschild, 2019).

PCA was considered as a method for measuring change, as it would be possible to create an index that captures several dimensions of contemporary urban change measured by occupational categories, household characteristics, and immigration status using indicators identified through the literature. However, the issue with using PCA for longitudinal change is that underlying relationship between variables (referred to as loading factors) such as median household income, educational attainment, employment status, race, and immigration status change significantly between the three study years. For reference, PCA was used to create principal components from common indicators of gentrification using 2006 and 2016 census data, comparing the biplots can show how the principal components and relationships between variables differ between these two time points:

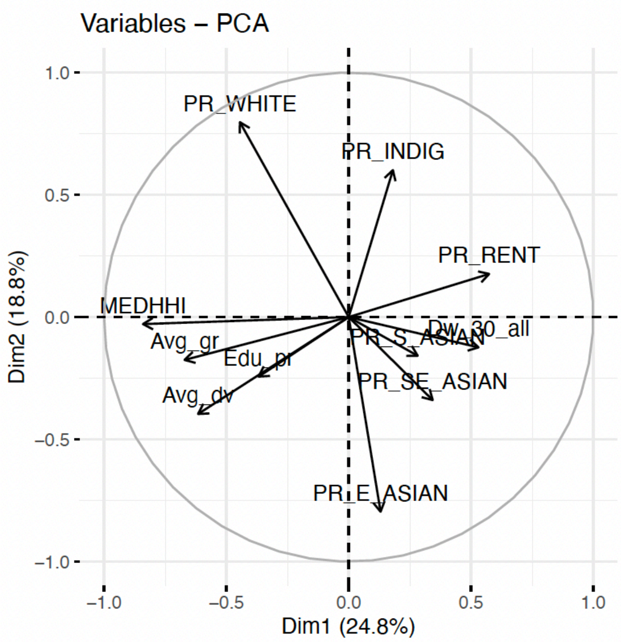

Figure 2: Biplot of Loading Matrix Variables 2006

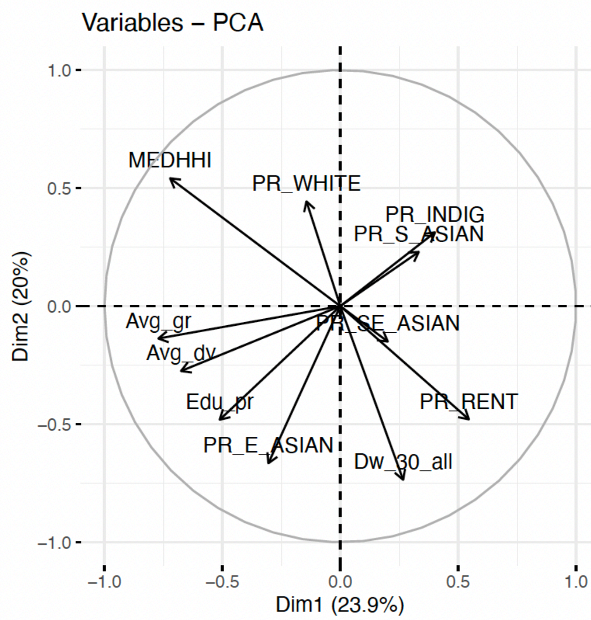

Figure 10: Biplot of Loading Matrix Variables 2016

As shown in the biplots above, the relationship between variables computed for two different time points are inconsistent, which means principal component analysis may not be able to create stable index of neighbourhood change across the study period.

The third method considered for measuring neighbourhood change was **using an established social status index** to measure neighbourhood change that has been validated in a Canadian, and preferably Metro Vancouver, context. David Ley's (1987, 1994) social status index is often cited in Canadian research and has been used to measure gentrification in Vancouver in several studies (Ley & Dobson, 2008). The index is a validated measure of neighbourhood social-economic status, and operationalizes gentrification in terms of social status, including measures of professional-managerial employment and the percentage of residents with post-secondary education across Census Tracts (CTs) (Ramos et al., 2021). The index is composed of only two indicators of social status, the percentage of population (aged 25+) with a college education and percentage of population working in managerial and professional occupations (Ley 1987; Ley 1994). These two percentages are added together and averaged across neighbourhoods over two time periods (e.g., 2006 and 2016), computed by averaging the percentage of professional managerial employment and post-secondary education:

$$Index = \frac{\left(\%\,Bachelors_2 + \%\,Managerial_2\right)}{2} - \frac{\left(\%\,Bachelors_1 + \%\,Managerial_1\right)}{2}$$

Subtracting the 2016 social status index from the 2006 index gives a measure of social status change in each census tract over the 10-year period, a change that is identified as an index of gentrification. The gentrification scores are then divided into quintiles to give a sense of the level of socioeconomic transformation that has occurred (Ramos et al., 2021).

The benefit of this method is that it's a simple interpretation of urban change that has been applied in the metropolitan Vancouver context. Validation of this index as a measure of socioeconomic status has been demonstrated in earlier research, showing strong correlations with other diagnostic variables like household income and monthly rent (Ley, 1986). One drawback of using this method is that in using only two indicators of social status to signify "neighbourhood change" does not offer the multidimensional interpretation of urban change that using PCA or more complex indices may. The method could capture residential displacement but may not capture in situ upgrading or demographic shifts, as demographic indicators like age and economic indicators like income are not incorporated in the index.

12.7. Summary

Three methods have been contemplated for measuring neighbourhood change: measuring the change of individual indicators, creating a change index using PCA, or using an index from the literature appropriate to the regional context. Of the three potential methods for measuring neighbourhood change, a blended approach that describes neighbourhood change using individual indicators, as well as measuring change using the social status index is proposed as the preferred method.

Using a blended approach would break the analysis into two parts. First, changes in individual indicators identified from the literature such as race, age, household income, and employment status, were compared for areas of "high walkability" and "low walkability" against control CTs (regional averages). Differences between how each category has changed over the time period were discussed. For instance, it may be found that changes to certain indicators of change are more correlated with changes in walkability than others. The purpose of describing these changes across individual indicators rather than an index, is that these discrepancies (if any) would be obscured in an index. While these findings about relationship between individual indicators may not be able to fit into a regression model or show holistic change on their own, they could inform future research on the topic.

The second method of measuring neighbourhood change uses the social status index to changes in walkability. This is a simple method for measuring neighbourhood change (defined as gentrification) that has been used previously for measuring change in Vancouver, and the index while only comprising of two variables has been shown to correlate with other variables of change like income and rent (Ley, 1996). While this method does potentially oversimplify "neighourhood change" as gentrification, the method should be sufficient to differentiate change through displacement from in situ neighbourhood upgrading, whereas a method like measuring change in median household income wouldn't. Further, comparing changes against regional and city averages tend to be an (imprecise) method for understanding if some of the changes in social status are related to demographic shifts rather than gentrification and displacement.

As described in the literature, multiple overlapping processes of urban change and displacement can be taking place in a neighbourhood at any one time. Combining these two methods is to use the social status index as the primary measure of neighbourhood change but support this analysis with a discussion of changes occurring in other indicators of urban change that may not be captured by the social status. The intention of this is to discuss other changes and processes that may be occurring that could inform future research on changes in walkability, such as demographic shifts occurring across the region, without necessarily modifying the social status index. For both portions of the analysis, the CTs of tracts of varying walkability were compared to control tracts, which were the metropolitan region measured as a whole, as the index would not reflect gentrification if the census tract difference was equal to the regions overall change. Both sections can also be controlled for proximity to rapid transit stations as well as distance to downtown cores using GIS.

12.8. Analysis

For analysis, both the baseline walkability of neighbourhoods at the start of the study period (2006) and changes in walkability from 2006 to 2016 are compared against indicators of neighbourhood change and the Social Status Index. Changes in walkability are measured using a modified version of the Frank et al. (2010) Walkability Index. Neighbourhoods have been operationalized as Census Tracts (CTs). There are 410 CTs in the Greater Vancouver Area in the 2006 Census, and 478 in the 2016 Census. CTs were matched between census years using the Canadian Longitudinal Census Tract Database (Allen & Taylor, 2018).

Histograms of the baseline walkability of the CTs and change in their walkability index scores from 2006 to 2016 are shown in Figure 12-2 and Figure 12-3 respectively. Both datasets are generally normally distributed but there are some outliers on the high end in the baseline Walkability Index scores.

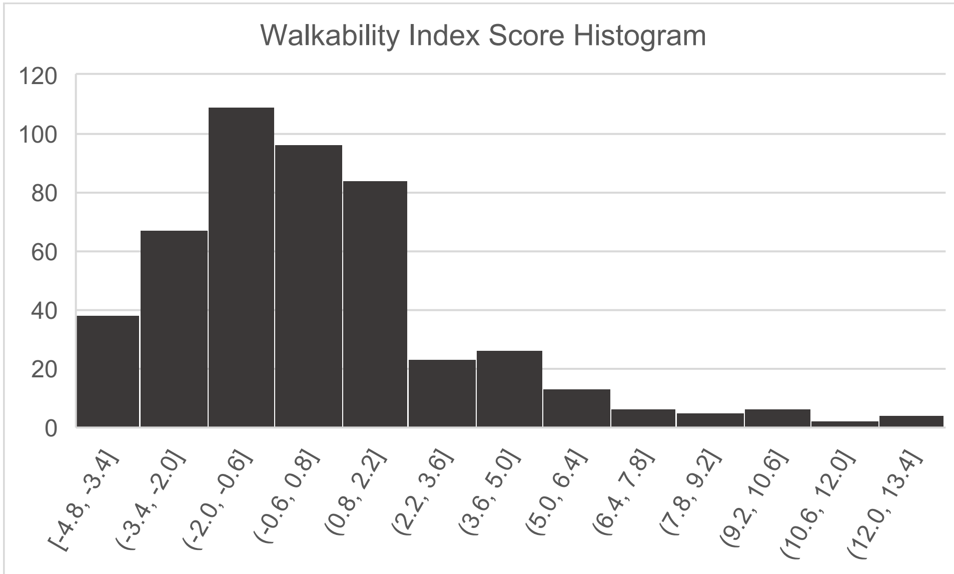

Figure 12-2: Walkability Index Score of Census Tracts (2006) Histogram

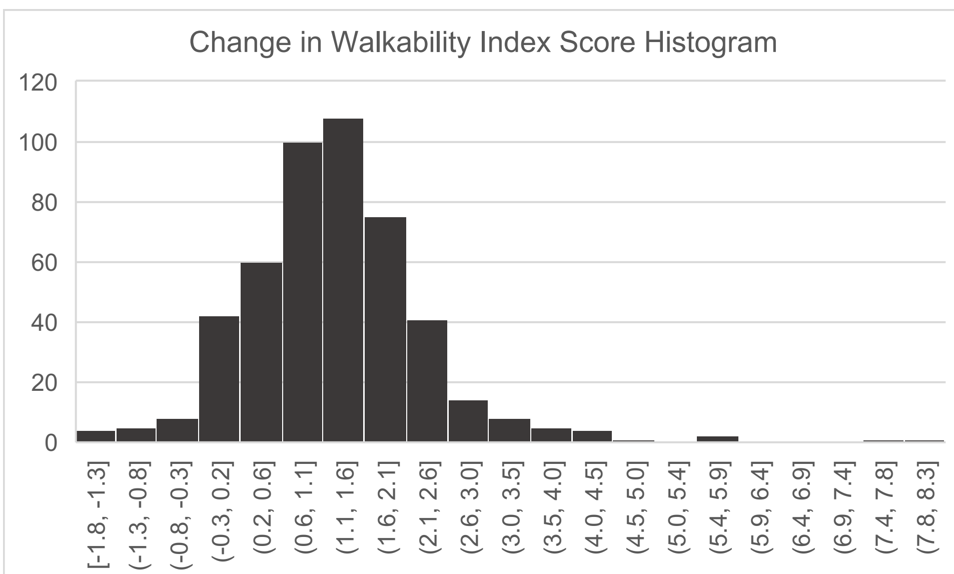

Figure 12-3: Change in Walkability Index Scores (2006 - 2016)

What was the baseline walkability of the study area in 2006?

Before measuring changes in walkability or gentrification, the baseline walkability of neighbourhoods and municipalities was established to understand the relative starting points, defined as the 2006 walkability index scores, of each area.

In Figure 12-4 the 2006 walkability index scores have been aggregated at the census tract level and divided into quintiles to illustrate the regional variation in baseline walkability. As expected, the City of Vancouver (understood to be the urban center of the region) has the highest concentration of walkable neighbourhoods, radiating outwards from its downtown core. Walkable neighbourhoods are also concentrated in the downtown core of the City of New Westminster (the oldest city in the region), the City of North Vancouver, and the downtown core of the City of Surrey.

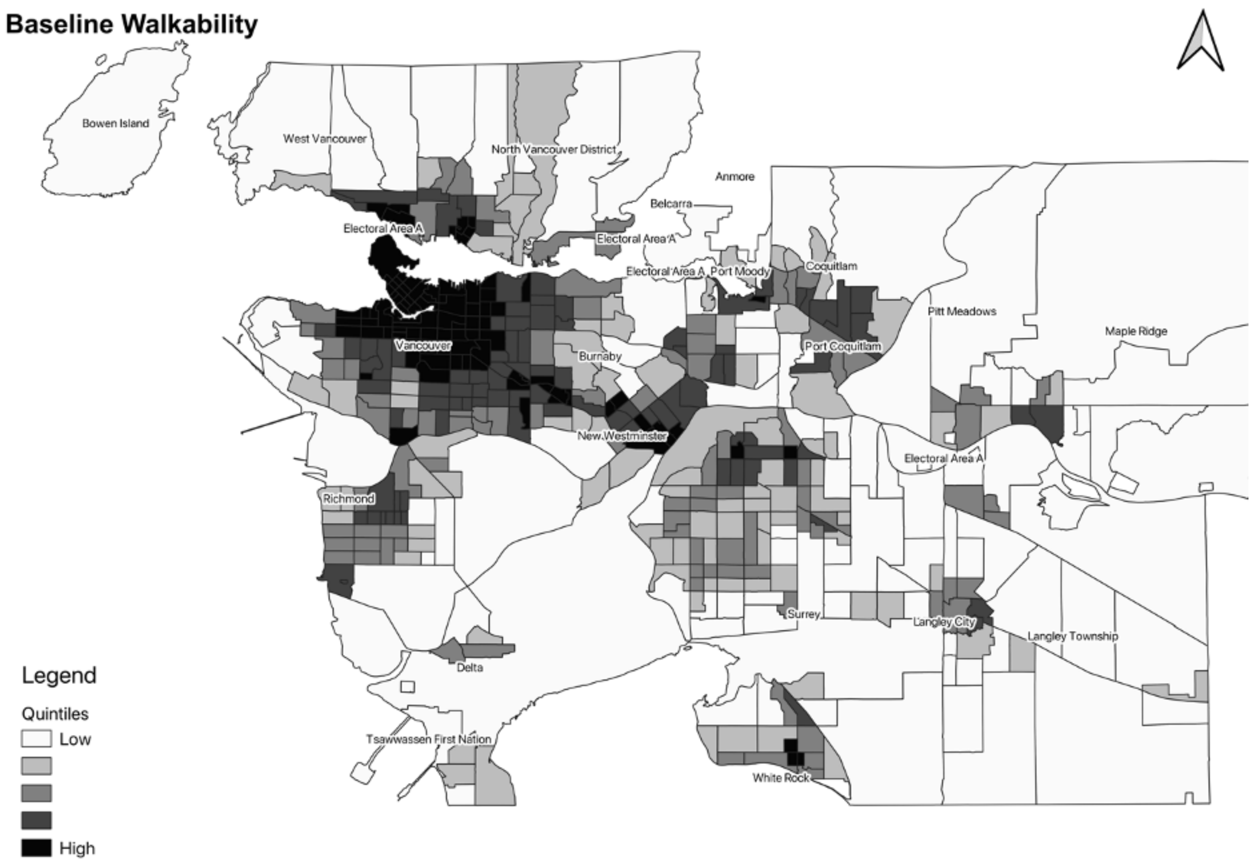

Figure 12-4: Distribution of Baseline Walkability of Metro Vancouver Census Tracts.

Baseline walkability index scores have also been aggregated at the municipal level to understand how each city measures against each other at the beginning of the study period. The actual index scores of the 25 Municipalities, Electoral Areas, and Treaty First Nations are shown in Table 12-1**.** When aggregated at the municipal level, the most walkable municipalities (and nations) in Metro Vancouver are the City of Vancouver, Capilano 5 (the Capilano 5 First Nations Reserve is located at the south-eastern boundary of West Vancouver), followed by The City of New Westminster and the City of North Vancouver. The least walkable locations are Pitt Meadows, Bowen Island, Belcarra, and the Musqueam First Nation Reserve No. 4 (located east of Canoe Passage near Westham Island). It is important to note that walkability index scores are normalized, so the scores of each municipality are described relative to each other.

Table 12-1: Baseline (2006) Walkability Index Scores of Metro Vancouver Municipalities

	Municipality	Base Walkability (2006)
1	Vancouver (C)	+1.1
2	Capilano 5 (R)	+0.9
3	New Westminster (C)	-0.1
4	North Vancouver (C)	-0.2
5	White Rock (C)	-0.7
6	Port Coquitlam (C)	-1.0
7	Tsawwassen (R)	-1.8
8	Burnaby (C)	-1.9
9	Langley (C)	-1.9
10	Richmond (C)	-3.2
11	Coquitlam (C)	-3.4
12	Lions Bay (VL)	-3.5
13	Surrey (C)	-3.5
14	Port Moody (C)	-3.5
15	West Vancouver (DM)	-4.1
16	North Vancouver (DM)	-4.1
17	Greater Vancouver A (RDA)	-4.2
18	Delta (DM)	-4.3
19	Anmore (VL)	-4.5
20	Maple Ridge (DM)	-4.5
21	Langley (DM)	-4.7
22	Pitt Meadows (DM)	-4.8
23	Bowen Island (IM)	-4.9
24	Belcarra (VL)	-5.1
25	Musqueam 4 (R)	-5.5

How did walkability change by municipality during the study period?

Using the modified Walkability Index, the 2006 Walkability Index Scores of each CT have been subtracted from the 2016 Walkability Index Scores, to see how walkability has changed in the region during the study period. The difference in each CT between the time periods has been calculated and divided into quintiles to illustrate the greatest and least differences in the region

As shown in Figure 12-5**,** the areas that saw the greatest increases in walkability (black) are dispersed throughout the region and do not show to be consistently concentrated in areas with baseline walkability. While downtown City of Vancouver did see relatively high increases in walkability, other areas surrounding the downtown core that had high baseline walkability were stable during the study period. In more suburban and rural areas, the City of Langley, White Rock, and Surrey were all municipalities with low baseline walkability but were shown to have concentrations of neighbourhoods with high increases in walkability.

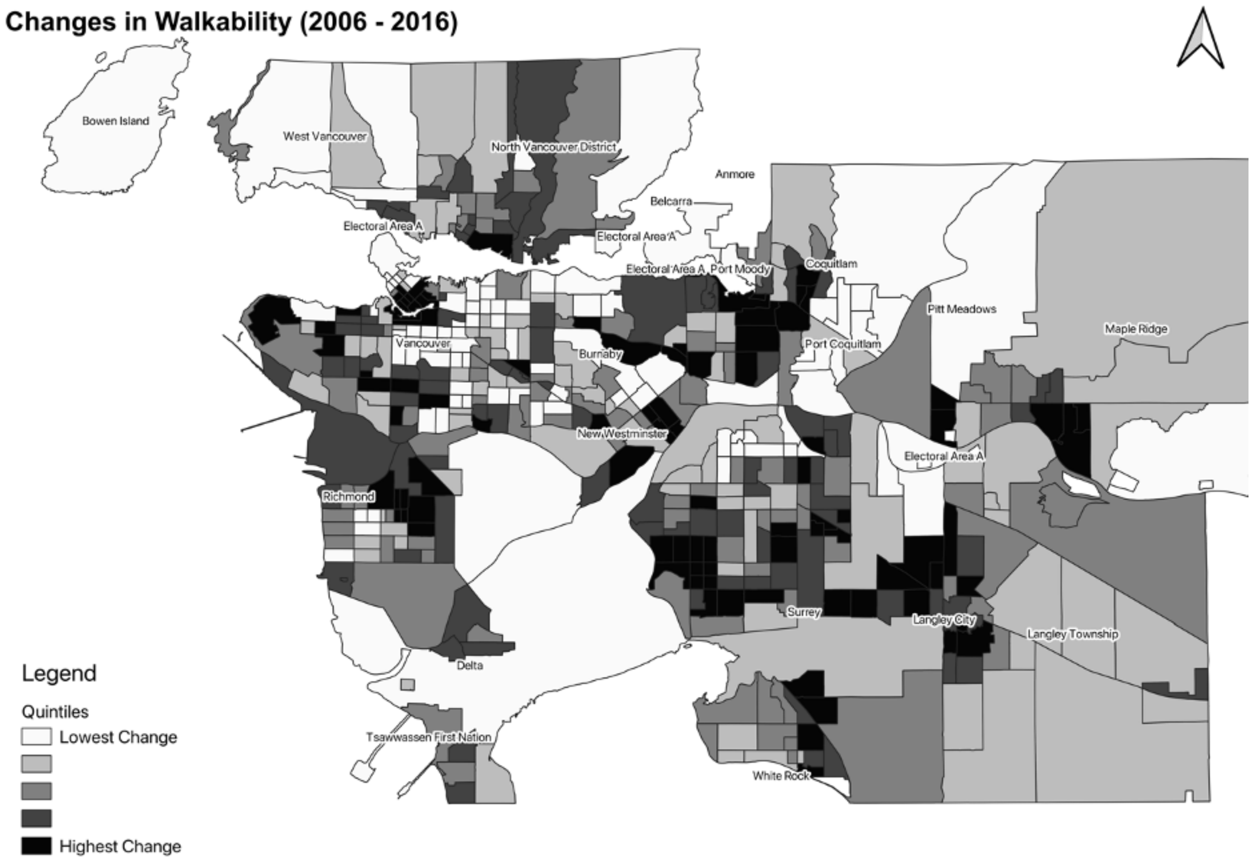

Figure 12-5: Distribution of Changes in Walkability of Metro Vancouver CTs (2006-2016).

Changes in walkability have also been aggregated at the municipal level to understand how each City, Nation and Electoral Area changed relative to each other during the study period. Shown in Table 12-2 the District of North Vancouver that had the highest relative increases in walkability, followed by the City of Langley, and the Capilano 5 First Nation Reserve. Despite being the most walkable municipality in the base year, the City of Vancouver ranked 11th in increases in walkability index score and only slightly higher than the regional average. Tsawwassen and Port Coquitlam both saw decreases in walkability index scores, likely due to low-density development in those municipalities during the study period.

Table 12-2: Change in Walkability of Metro Vancouver Municipalities (2006-2016)

	Municipality	Base Walkability (2006)	Walkability 2016	Change in Walkability (2006-2016)
1	North Vancouver (DM)	-4.1	-1.6	**+2.6**
2	Langley (C)	-1.9	+0.1	**+2.1**
3	Capilano 5 (R)	+0.9	+2.8	**+1.9**
4	New Westminster (C)	-0.1	+1.5	**+1.6**
5	North Vancouver (C)	-0.2	+1.4	**+1.5**
6	Surrey (C)	-3.5	-2.2	**+1.3**
7	White Rock (C)	-0.7	+0.6	**+1.3**
8	Richmond (C)	-3.2	-2.0	**+1.2**
9	Port Moody (C)	-3.5	-2.4	**+1.2**
10	Coquitlam (C)	-3.4	-2.3	**+1.1**
11	Vancouver (C)	+1.1	+2.2	**+1.1**
12	Burnaby (C)	-1.9	-0.9	**+1.0**
13	Langley (DM)	-4.7	-3.8	**+0.9**
14	Maple Ridge (DM)	-4.5	-3.6	**+0.9**
15	Greater Vancouver A (RDA)	-4.2	-3.4	**+0.9**
16	Pitt Meadows (DM)	-4.8	-3.9	**+0.8**
17	Musqueam 4 (R)	-5.5	-4.7	**+0.8**
18	Delta (DM)	-4.3	-3.5	**+0.8**
19	West Vancouver (DM)	-4.1	-3.4	**+0.7**
20	Anmore (VL)	-4.5	-4.0	**+0.5**
21	Bowen Island (IM)	-4.9	-4.5	**+0.4**
22	Lions Bay (VL)	-3.5	-3.2	**+0.3**
23	Belcarra (VL)	-5.1	-4.9	**+0.2**
24	Tsawwassen (R)	-1.8	-2.0	**-0.2**
25	Port Coquitlam (C)	-1.0	-1.8	**-0.8**

While Table 12-2 ranked each municipality based on relative walkability index scores at the start of the study period (baseline walkability), Figure 12-6 shows how the changes in each score impacted the relative rank of each location by the end of the study period. Rankings of the top five locations were consistent between 2006 and 2016, with the exception of the Capilano 5 First Nation Reserve which surpassed the City of Vancouver as the most walkable in the region. Walkability Index ranking of other locations remained relatively consistent, with the exception of the District of North Vancouver which went from the 16th to 8th most walkable.

Anecdotally, the Capilano 5 Reserve (shown in Figure 12-7) has been the site of major commercial and residential development during the study period. Because the land area is small relative to other municipalities surrounding it, new development had a higher contribution to relative rank than development of similar scale would have in larger municipalities.

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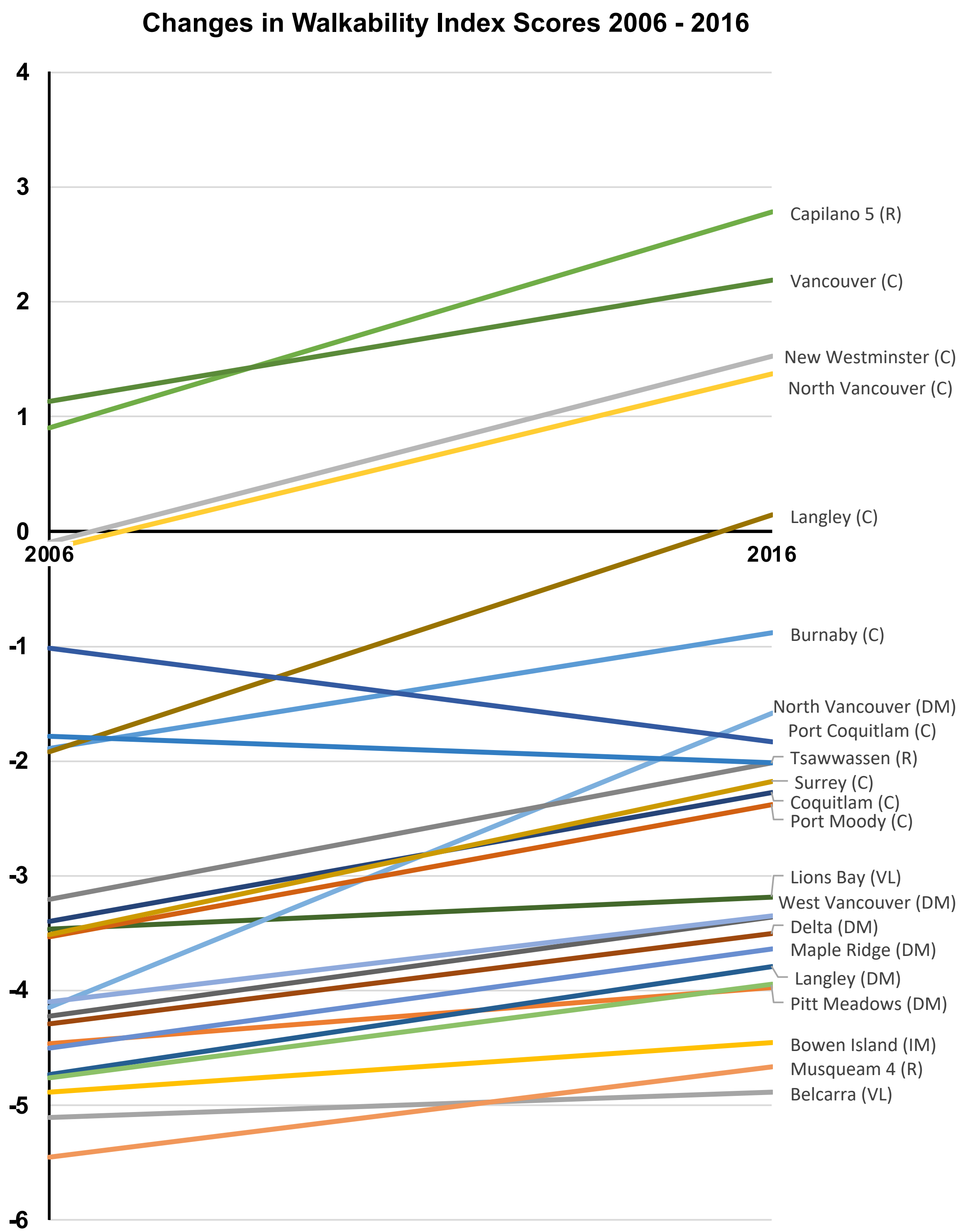


Figure 12-6: Changes in Walkability Index Scores 2006 – 2016

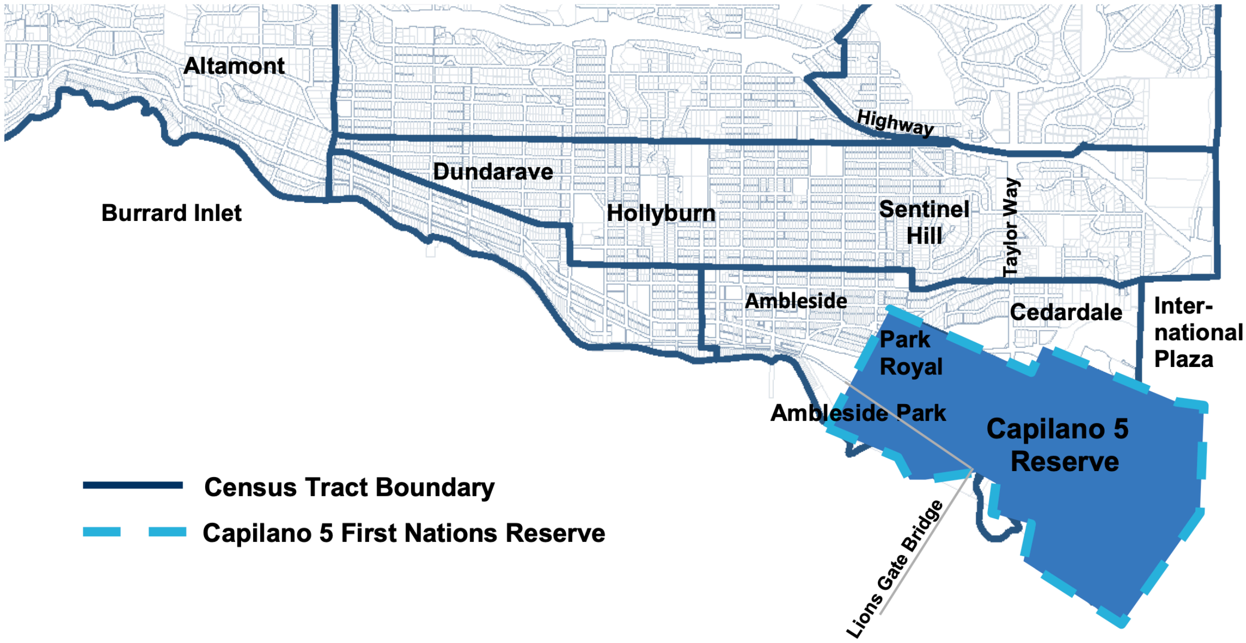


Figure 12-7: Capilano 5 Reserve had the highest Walkability Index score in Metro Vancouver in 2016 (Image Source: District of West Vancouver Planning Department)

12.1. Detailed Review of Change in The Walkability Index: 2006 to 2016

The walkability index is the composite of the four component measures added together. To conceptualize how these four variables have interacted and changed from 2006 to 2016, a walkability index normalizing these measures across the study period was created. This index was created through calculating z-scores for each component variable which represent the distribution of each measure across the 10-year study period. The grand mean and grand standard deviation of each component measure were calculated in the normalization process. Each measure was then added to create a walkability index which can represent changes over time through the delta between each index score.

Each component measure z-score was calculated as:

$$Component\ Measure\ z\ score = \frac{x - grand\ mean}{grand\ standard\ deviation}$$

The longitudinal walkability index was then calculated using the same formula as the original walkability index:

$$Longitudinal\ Walkability = zNRD + zCFAR + 2 * zIDens + zLUM$$

Where:

Longitudinal Walkability = Walkability Index, calculated using the grand mean and standard deviation

zNRD = Net Residential Density z-score

zCFAR= Commercial Floor Area Ratio z-score

zIDens = Intersection Density z-score

zLUM = Land Use Mix z-score

Calculating the walkability index in this way allows us to see how the change in each area has kept pace with the rest of the region. Each value contained in the walkability index exists across a distribution with 0 as the average. Much of the region has had relatively stable walkability from 2006 – 2016. Figure 12-8 shows that 60% of the region has remained in the same walkability quintile, while 40% of the region has shifted over the 10 year period.

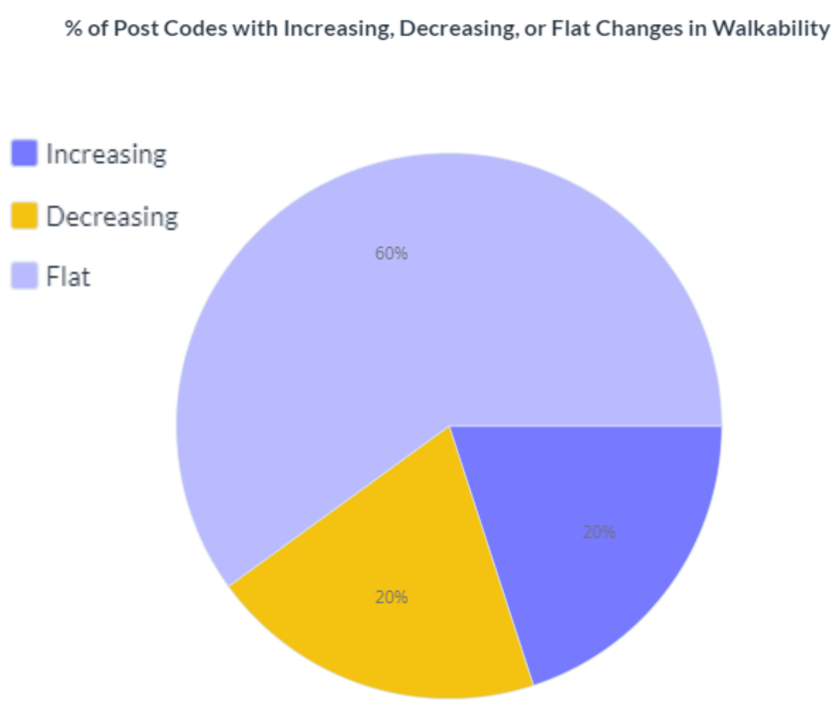


Figure 12-8: Distribution of Changes in Walkability 2006-2016.

The Sankey diagram (Figure 12-9) and subsequent maps shown below further explore these changes across Metro Vancouver.

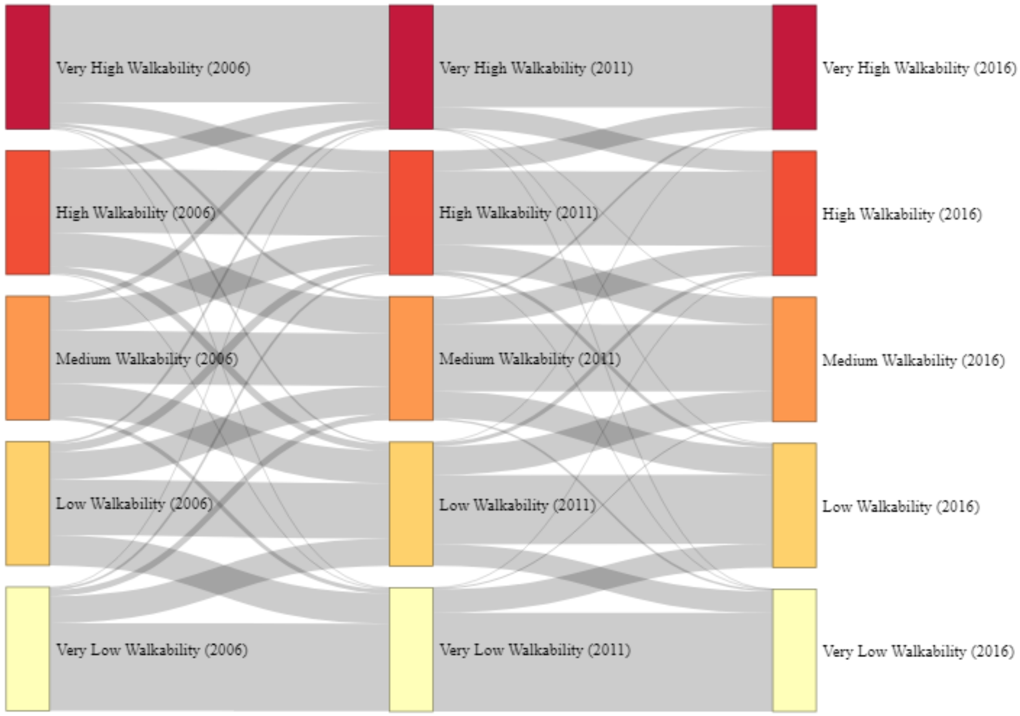


Figure 12-9 Sankey Diagram of Changes in Walkability 2006 - 2011- 2016

The Sankey diagram shows that for most places, walkability does not change significantly. However, some places shift up or down between 1 quintile. From 2006-2016, the index shows the burgeoning urban areas of the metro region increasing walkability the most. Surrey, Langley, Maple Ridge, and Port Moody are a few with the most notable changes. Looking within the study period, from 2006-2011 and 2011-2016 it is shown when the most change in areas across Metro Vancouver occurred. The increases in walkability remained consistent across the time period for many suburban areas, while areas such as the City of Vancouver and the City of North Vancouver experienced the largest changes relative to the region from 2011-2016. This pattern reflects policy initiatives in the region such as the densification of the Cambie corridor following the construction of the Canada Line and transit-oriented development in Port Moody following the completion of the Evergreen Line Skytrain extension. The longitudinal changes in the walkability index are visualized from 2006-2011, 2011-2016, and 2006-2016, in Figure 12-10, Figure 12-11,and Figure 12-12 shown below.

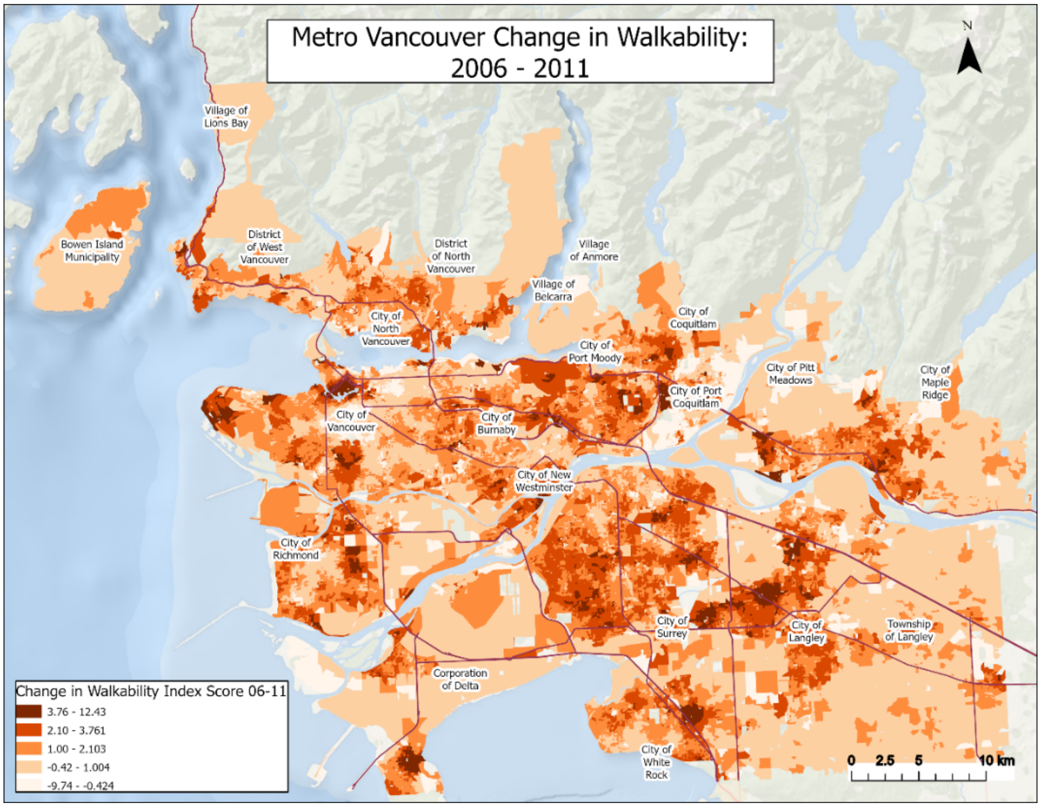


Figure 12-10 Metro Vancouver Change in Walkability Index Score 2006 - 2011

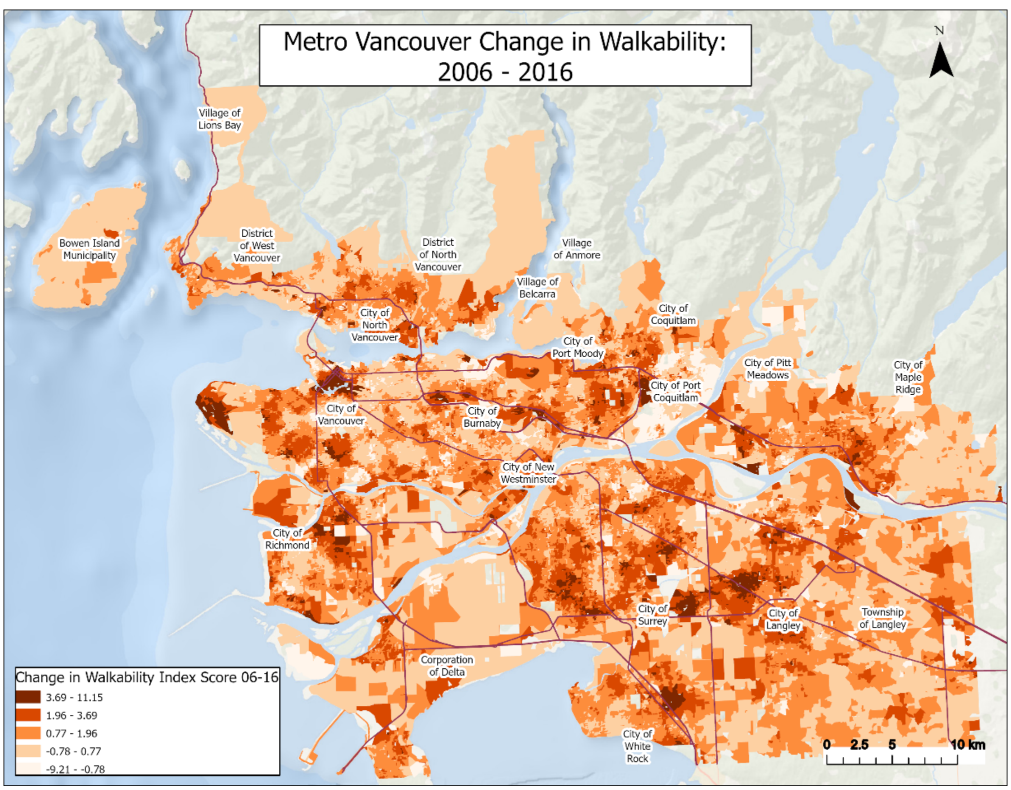


Figure 12-11 Metro Vancouver Change in Walkability Index Score 2006 - 2016

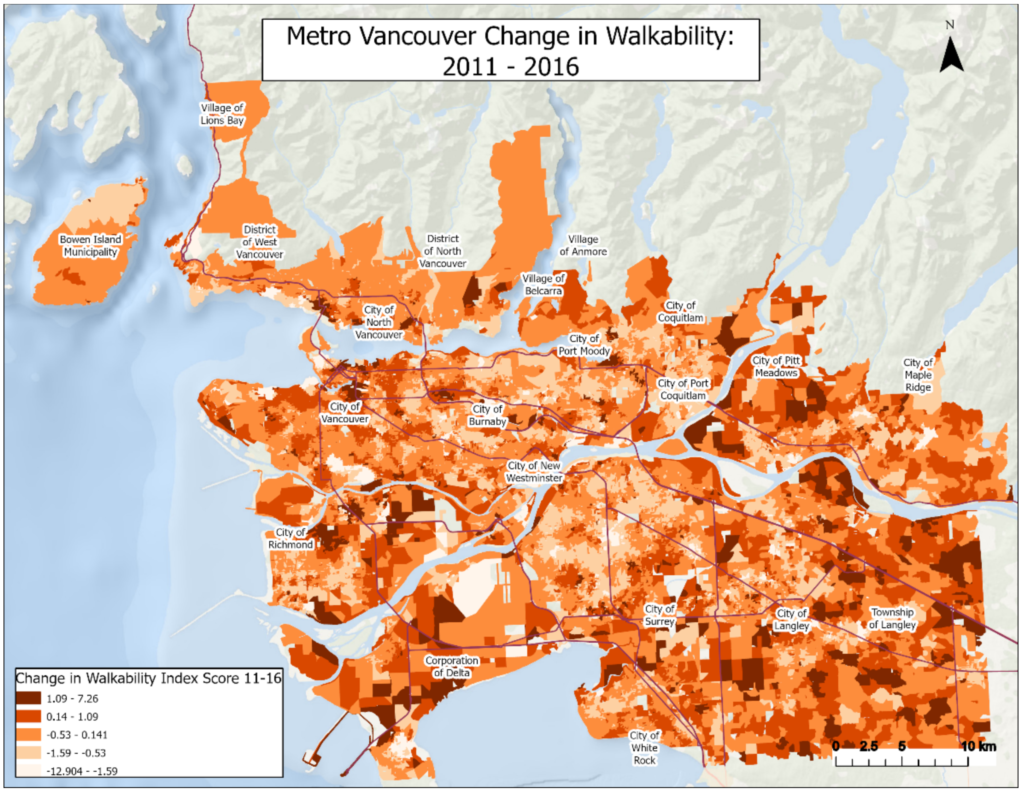


Figure 12-12 Metro Vancouver Change in Walkability Index Score 2011 – 2016

12.1.1. Intersection Density

The road network defines how we navigate the GVRD, what is accessible, and where development is happening. Figure 12-13 illustrates intersection density. The road network in many areas of Metro Vancouver is well-established, gridded and many decades old. However, changes in land use patterns, especially in outlying suburban areas, have spurred changes reducing connectivity in the network structure. Major developments can require new roads to access housing, amenities, and the rest of the region. This is reflected in the changes in intersection density over the 10 years between 2006 and 2016 which have gone from a regional average of 45 intersections per kilometre in 2006 to 65 in 2016.

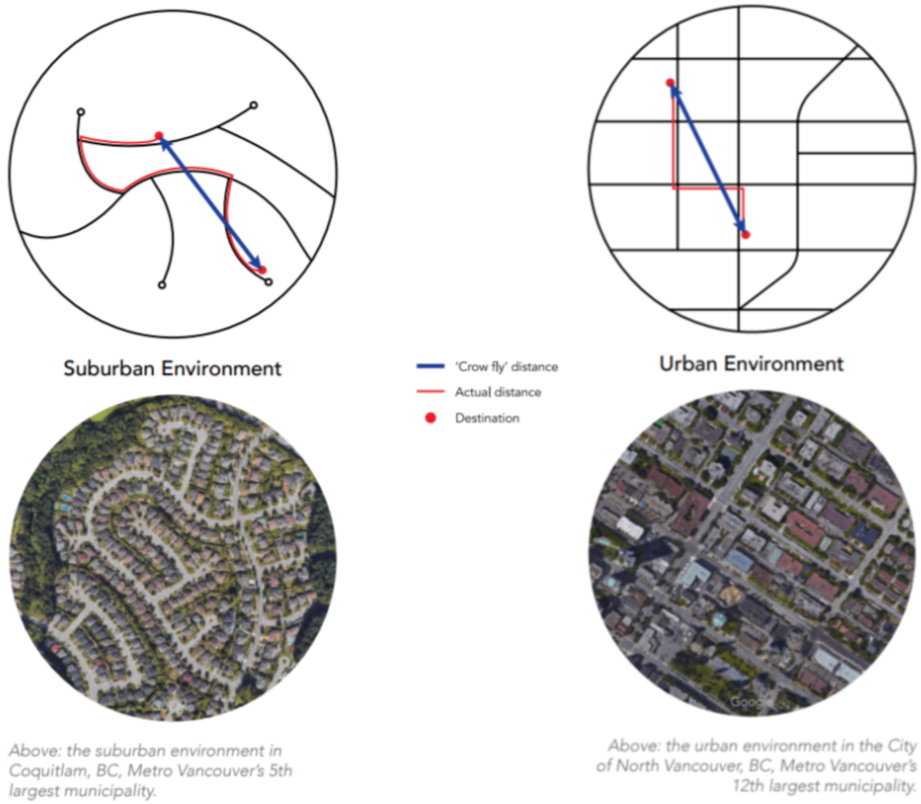


Figure 12-13 Description of Intersection Density

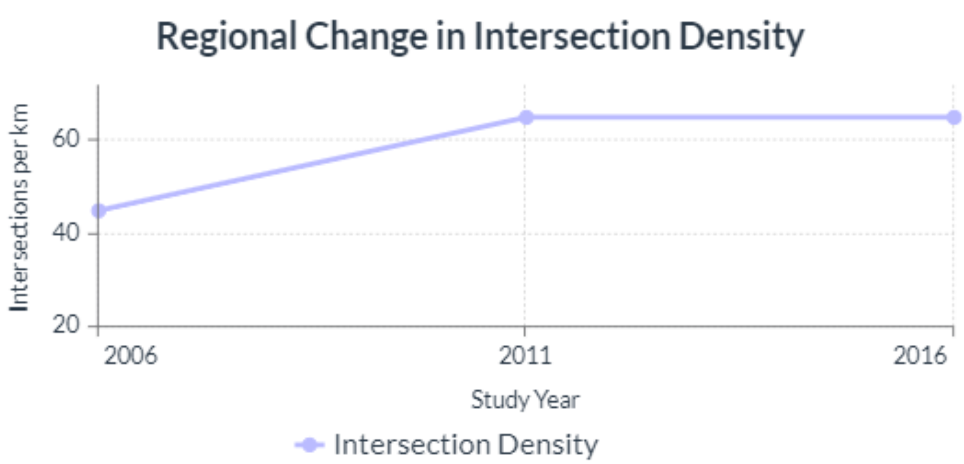


Figure 12-14: Intersection Density 2006-2016

Intersection density (Figure 12-14) is beginning to show a plateauing trend which may be attributed to stagnating greenfield development and new road building in the region. Many of the areas experiencing major development across the region such as Olympic Village and the Cambie corridor are infill or densification projects that require relatively limited changes to the road network. These areas already have a high road connectivity.

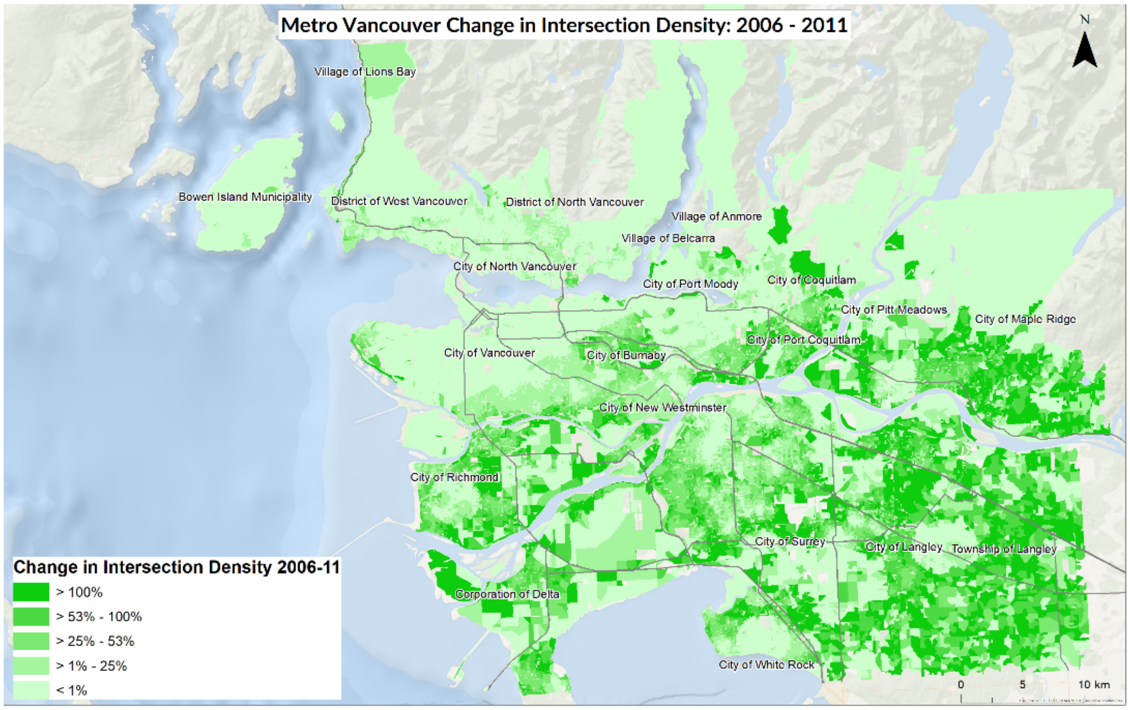


Figure 12-15: Change in Intersection Density 2006-2011

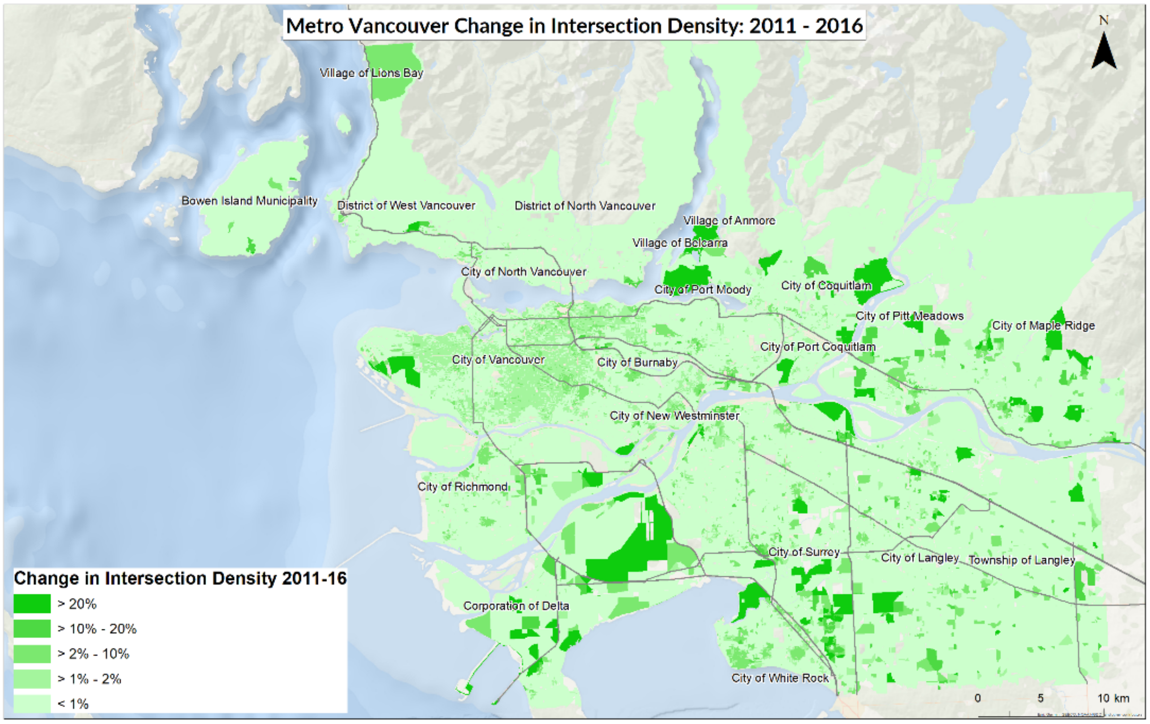


Figure 12-16: Change in Intersection Density 2011-2016

Many of the significant changes in intersection density across Metro Vancouver between 2006 to 2011 are in suburban areas of the region (Figure 12-15). Then from 2011-2016 the map shows that there is far less change across the region, especially in the suburban areas (Figure 12-16). Looking at the differing rates of intersection density change across the member jurisdictions, we can see that the suburban areas have experienced higher increases. Improved intersection density in rural areas may indicate suburban subdivisions which may have low connectivity even if increasing over time. It is also important to remember that some areas of the region, especially those designated for agricultural lands, are not intended for urban development.

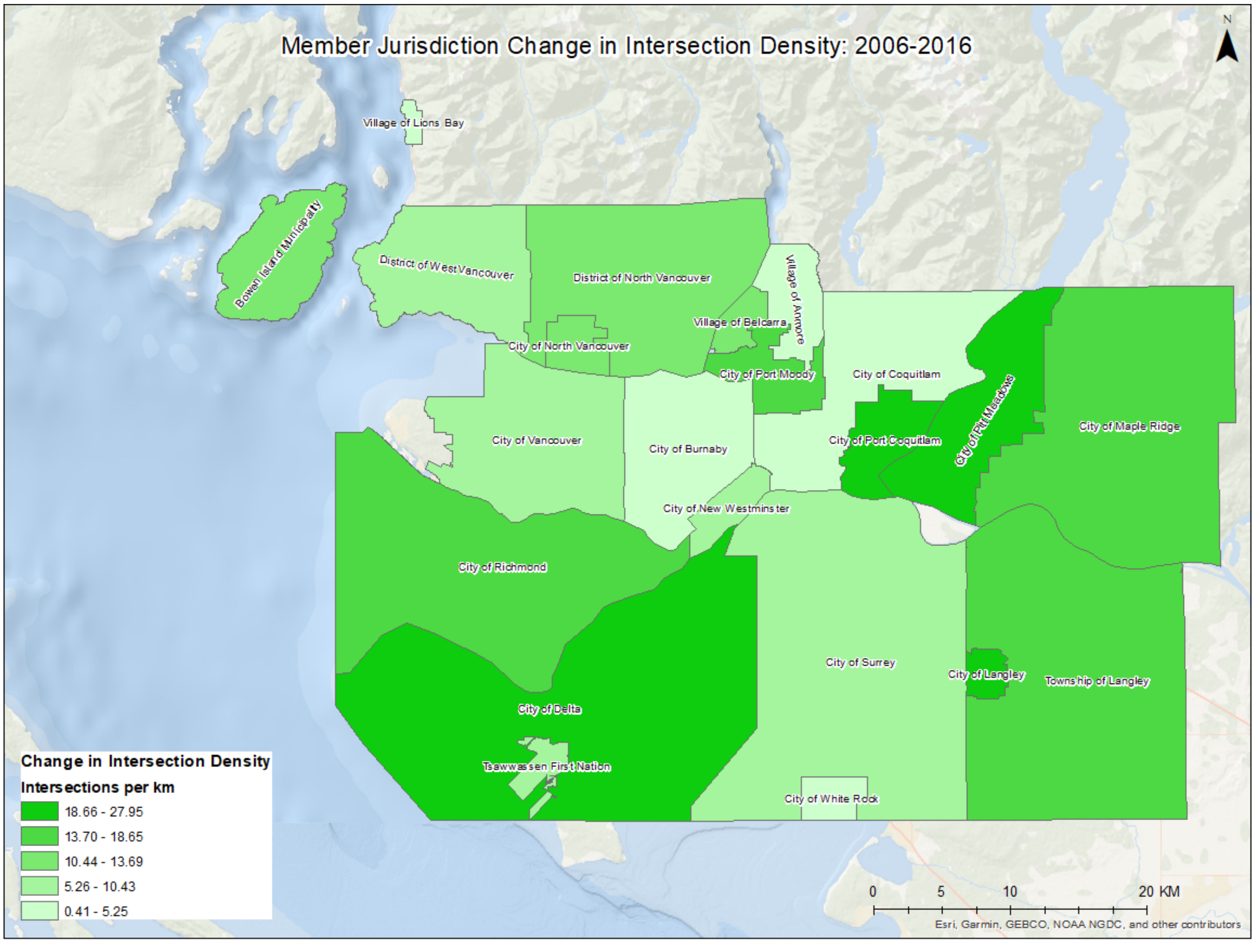
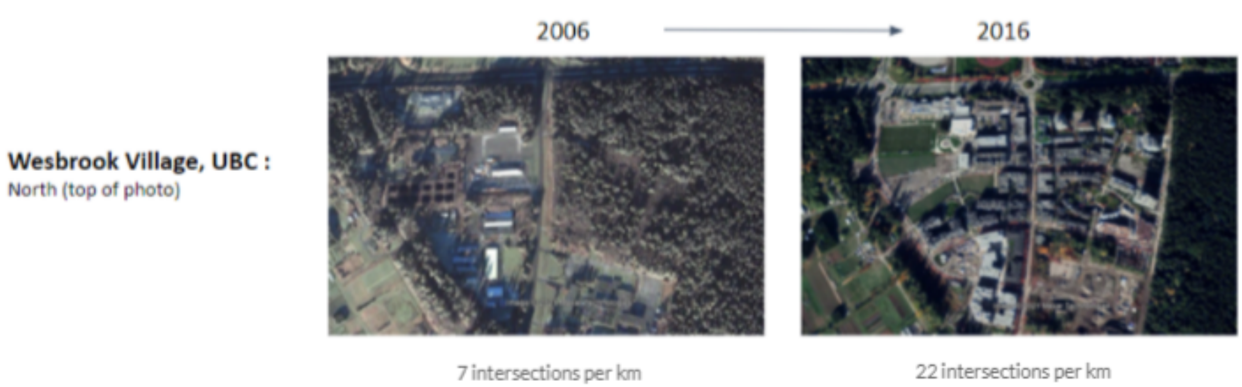


Figure 12-17 Member Jurisdiction Change in Intersection Density: 2006-2016

Changes in intersection density have been most notable where greenfield development has occurred. Shown below are examples of where intersection density has increased between 2006 and 2016.



Wesbrook Village at the south end of the UBC Main Campus has seen a dramatic increase in intersection density spurred by new development of residential and commercial buildings. Similar increases in intersection density have occurred with the development of suburban residential neighbourhoods at the foot of Burke Mountain in the Tri-Cities.

12.1.1. Net Residential Density

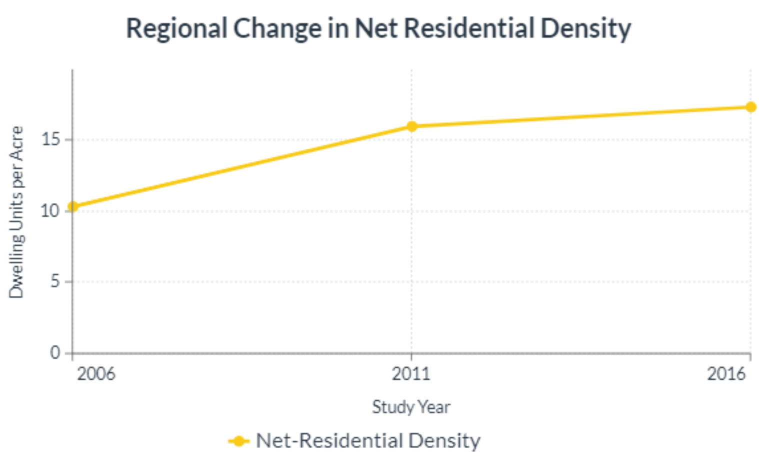
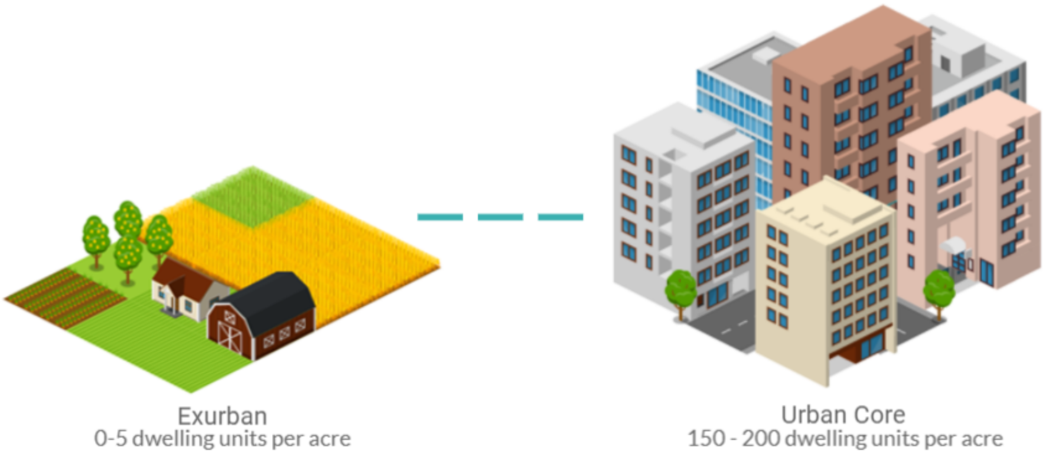


Figure 12-18: Net Residential Density 2006-2016

Residential compactness is one of the hallmarks of urban areas. Dense urban forms allow for more agglomeration of goods and services while facilitating social interaction and well-connected transportation networks.



Net residential density has continued on an upward trajectory from 2006-2016. This can be attributed to increasing density in the urban areas of Metro Vancouver and residential development in the suburbs. Places such as the City of North Vancouver, Port Moody, the UBC Main Campus, Richmond, and Vancouver show some of the highest increases in net residential density from 2006 – 2016 (Figure 12-19 and Figure 12-20).

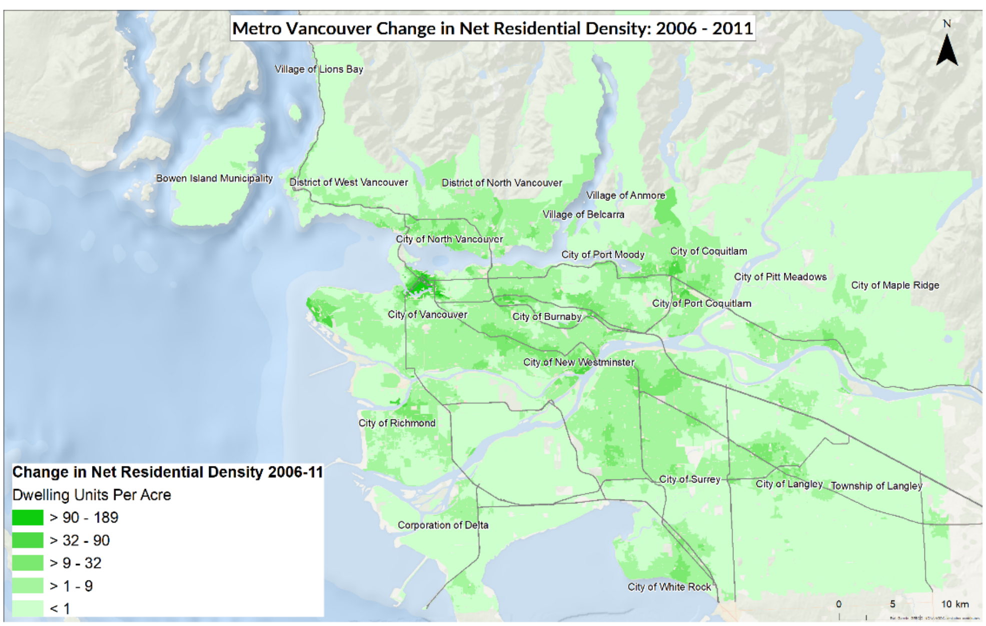


Figure 12-19: Change in Net Residential Density 2006-2011

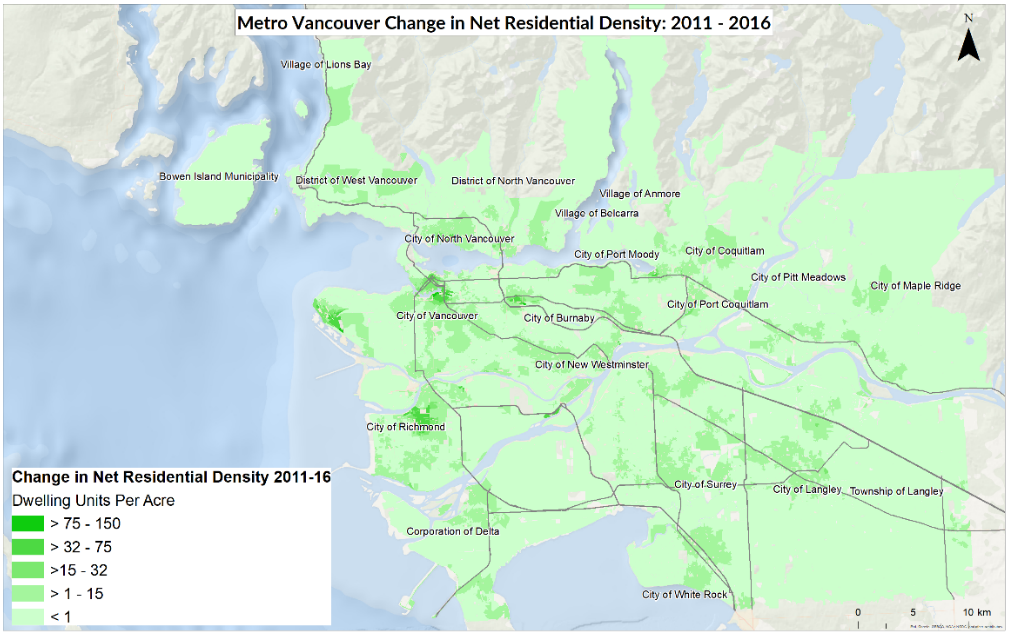


Figure 12-20: Change in Net Residential Density 2011-2016

Across the Member Jurisdictions of Metro Vancouver, Vancouver, the City of North Vancouver, Port Coquitlam, and New Westminster have experienced the largest changes in net residential density.

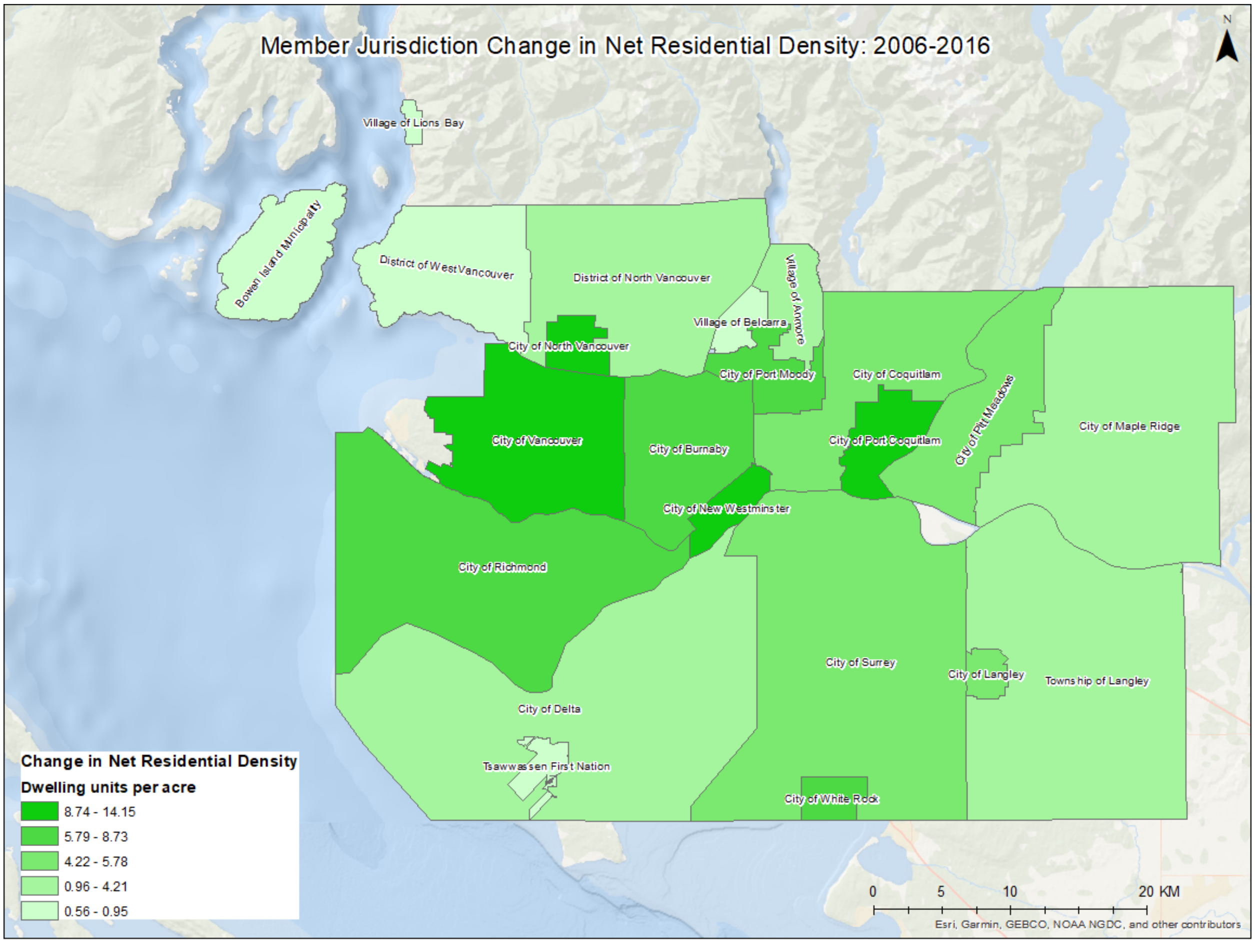


Figure 12-21 Member Jurisdiction Change in Net Residential Density: 2006 - 2016

Examples of dramatic changes in net residential density between 2006 and 2016 are present in Olympic Village in Vancouver and Wesbrook Village at the South end of the UBC campus.

2006 → 2016

Olympic Village, Vancouver:
WB @ Manitoba & 1st

30 Dwelling Units per Acre

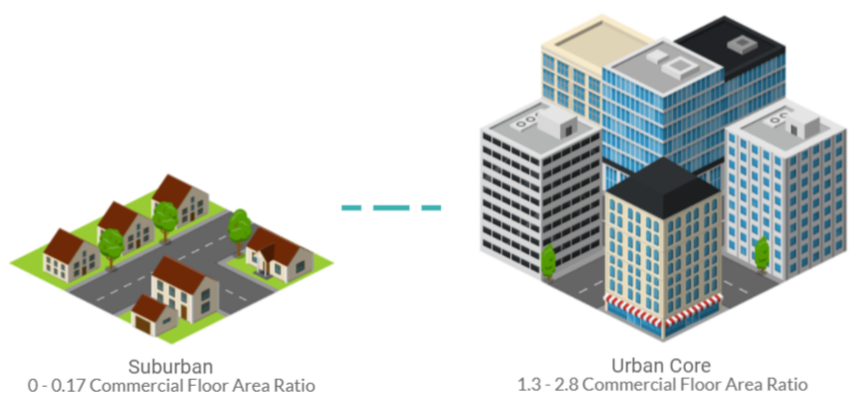
150 Dwelling Units per Acre

Olympic Village experienced a major change in land use from a largely industrial and vacant area to a predominantly residential neighbourhood with a commercial center.

Wesbrook Village transformed from a greenfield site to a bustling commercial and residential community which added much-needed housing to the UBC Main Campus area.

12.1.2. Commercial Floor Area (FAR)

Commercial floor rea ratio (FAR) of a neighbourhood describes the intensity of commercial development. Neighbourhoods with high commercial FAR are generally more urban, have reduced parking and are typically orientated towards more neighbourhood retail allowing residents to easily access goods and amenities.



Regionally, commercial FAR has stayed at a consistent level on average. From 2006 to 2016 it is showing a levelling off trend which could be attributed to widespread increases across the metro region from before 2006 and through to 2011. This indicates that much of the land use that is commercial in the region had been zoned to this use early in the development of the region. From 2006 – 2011 the region experienced the highest rates of change for each component measure, in many of the same areas, which could indicate a period of development in which commercial, residential, and road network development were completed in tandem.

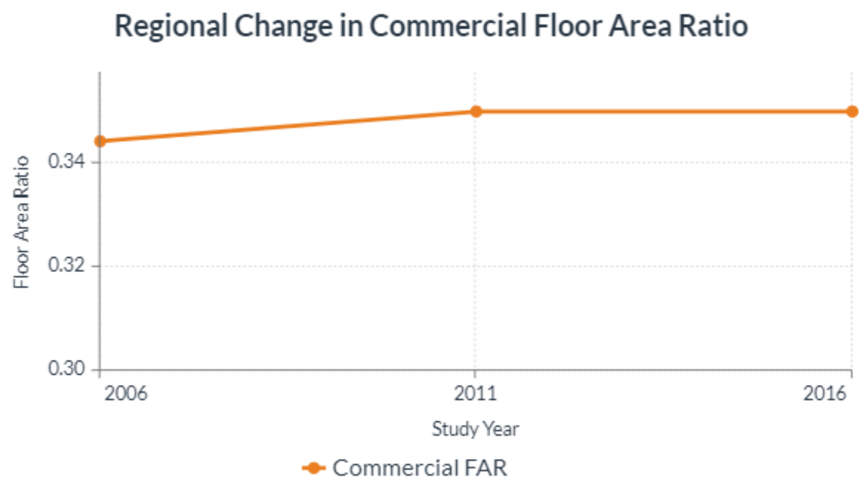


Figure 12-22: Commercial FAR 2006-2016

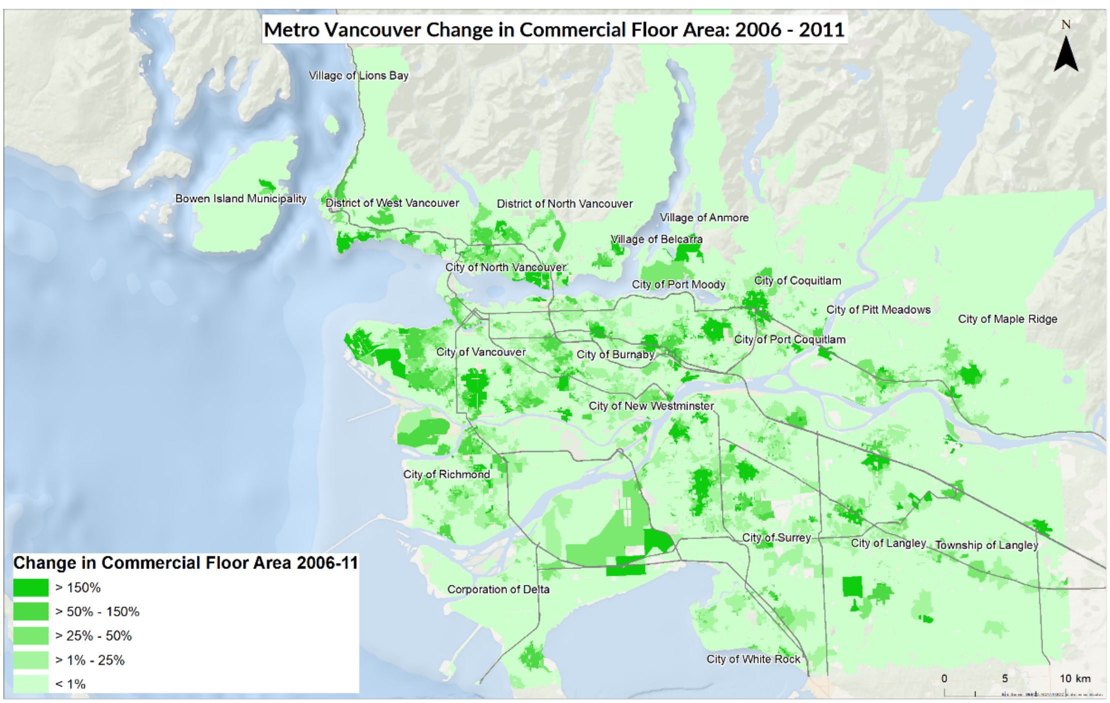


Figure 12-23: Change in Commercial FAR 2006-2011

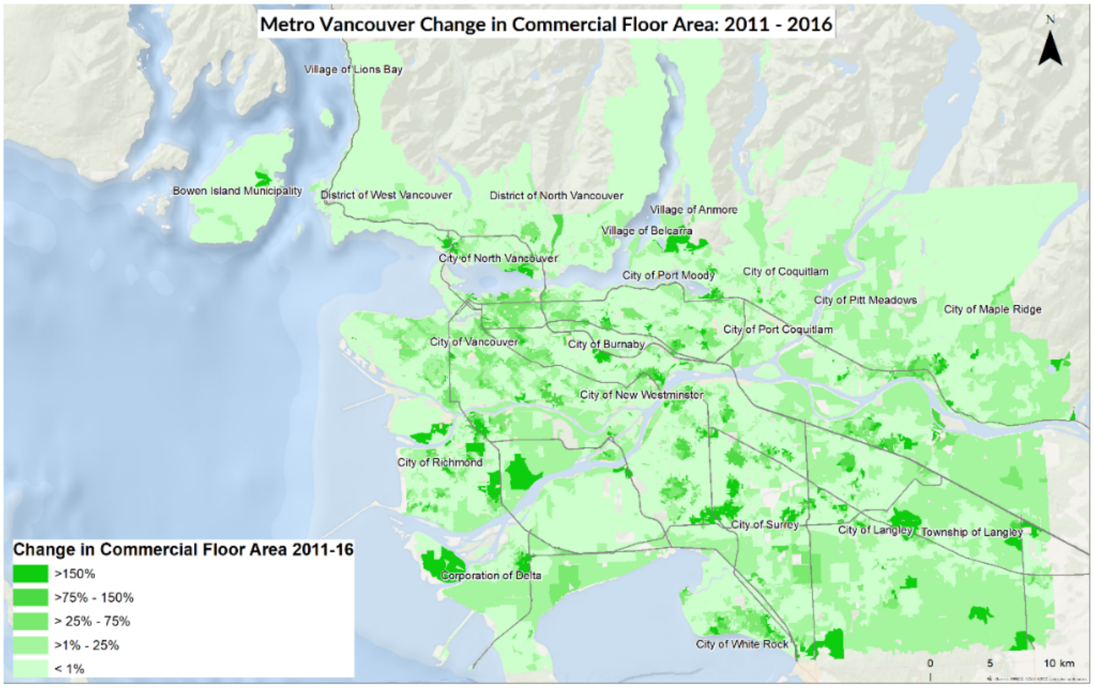


Figure 12-24: Change in Commercial FAR 2011-2016

From 2011-2016, the highest rates of changes in commercial FAR were no longer in the most urban areas of Metro Vancouver. Many of the largest changes were experienced in concentrated areas in Surrey, the City of Langley, Tsawwassen, and the City of North Vancouver. This is reflected when looking at the differing levels of change in the Member Jurisdictions of Metro Vancouver.

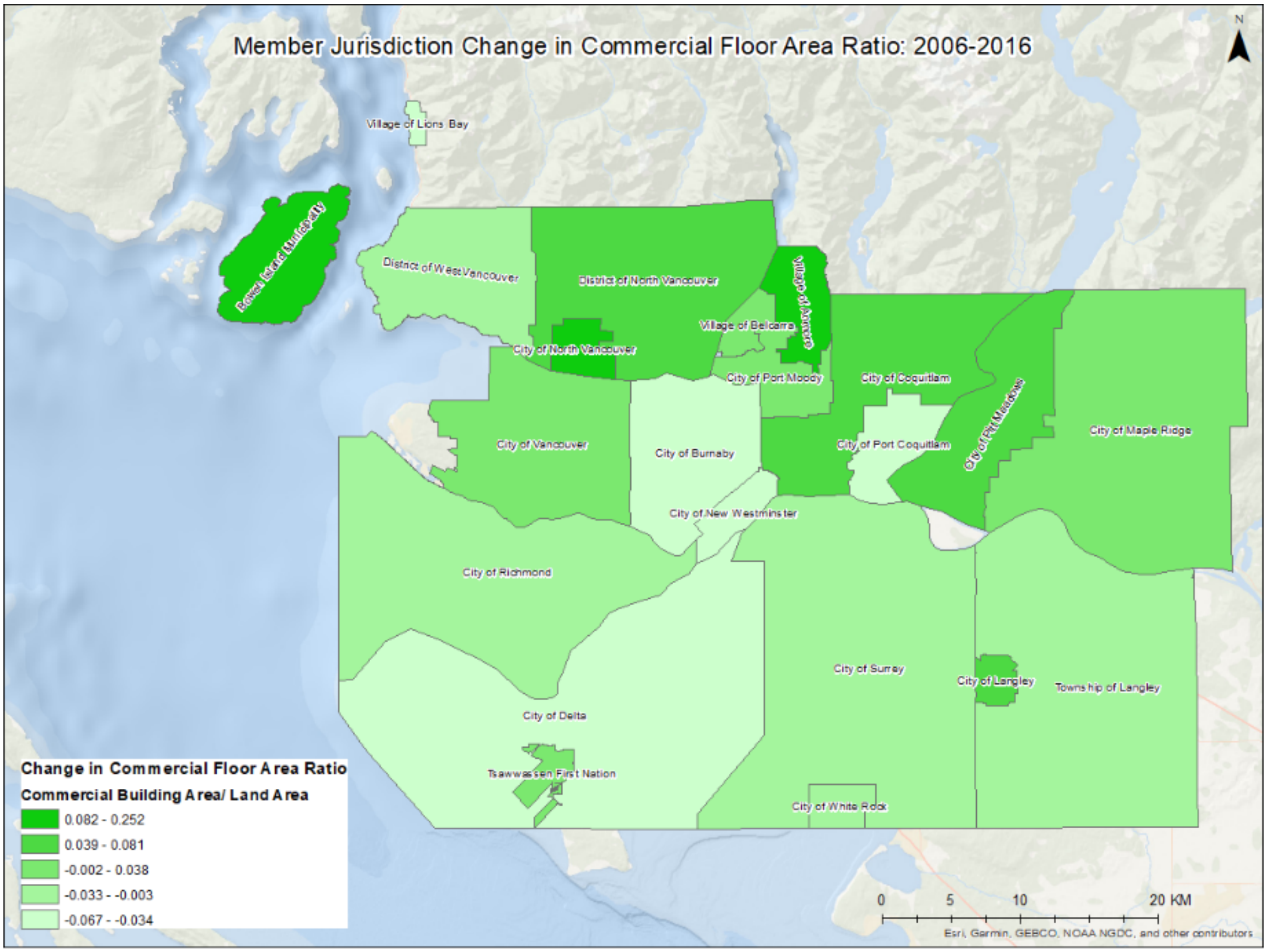


Figure 12-25 Member Jurisdiction Change in Commercial Floor Area Ratio: 2006 - 2016

Areas where significant increases in commercial FAR changed the landscape were, for example, found with the redevelopment of South Dunbar in Vancouver and Park Royal in West Vancouver.

2006 → 2016

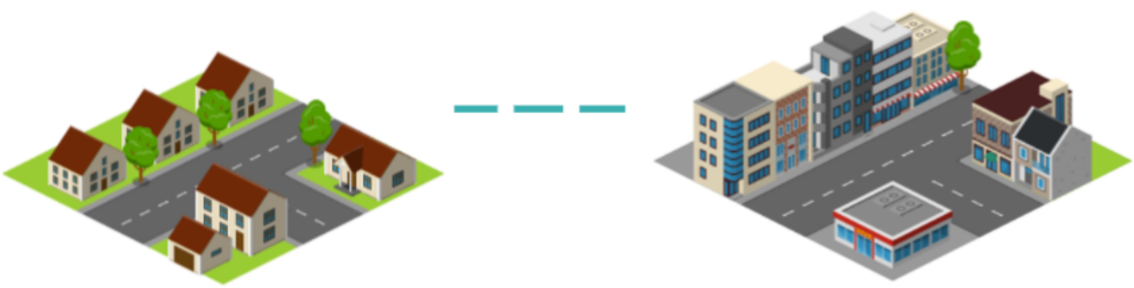
Dunbar, Vancouver:
SB @ Dunbar St.

0.54 Commercial FAR

1.4 Commercial FAR

12.1.3. Land Use Mix

Think of some of your favorite places to visit and walk around. Many of the neighbourhoods you thought of probably have a variety of businesses, amenities, and residences. This is what land use mix measures. Land Use Mix shows the evenness of square footage distribution across residential, commercial (including retail and services), entertainment, and office development within a neighbourhood buffer.



Suburban
0 - 0.12 Land Use Mix

Mixed-use Community
0.62 - 0.96 Land Use Mix

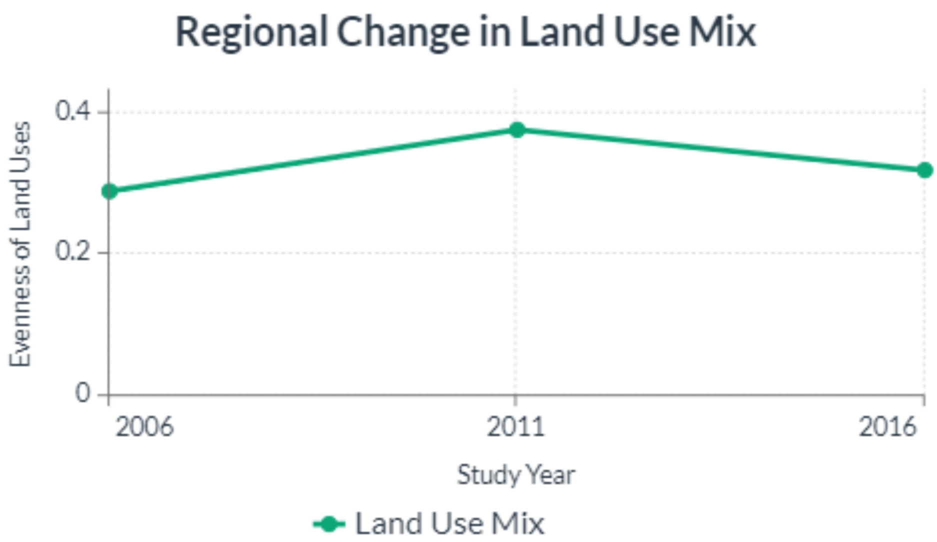


Figure 12-26: Land Use Mix 2006-2016

From 2006 to 2011 the changes in land use mix show that development across the region in these land use types became more balanced. This indicates that within a neighbourhood, new development included retail, residential, office, and entertainment land uses more equally. This can be seen in the trajectory of change in the land use mix measure as well as the consistent upward trend of commercial FAR and net residential density from 2006-2011. The graph above shows that this is the case across the region and the map below shows that there were high changes in land use mix across Metro Vancouver and specifically in smaller urban and suburban areas.

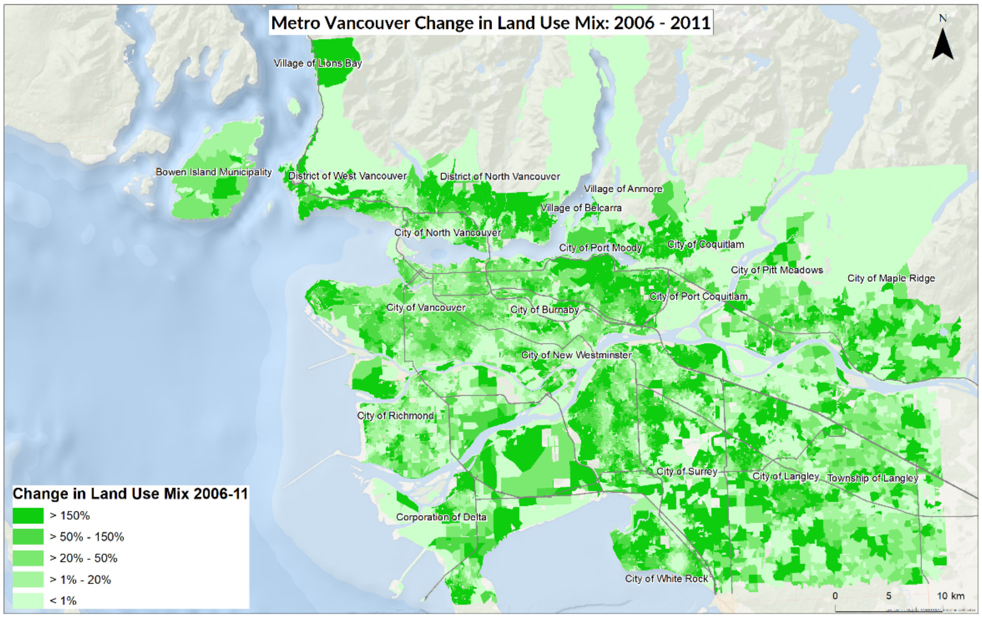


Figure 12-27: Change in Land Use Mix 2006-2011

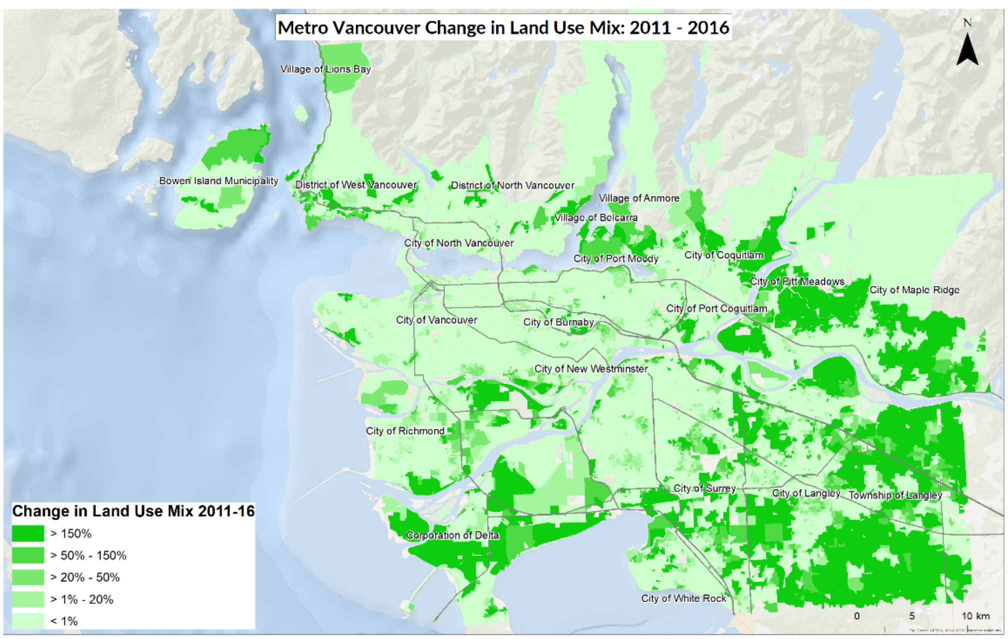


Figure 12-28: Change in Land Use Mix 2011-2016

Figure 12-28 shows that changes in land use mix from 2011 – 2016 have shifted into the southern and easternmost suburban areas where greenfield development of communities is still possible. Elsewhere in the region, changes in net residential density have kept a modest pace while commercial FAR has begun to plateau. This explains the downward trajectory of land use mix from 2011-2016 as the intensification of one land use type over another result in a less even distribution within a neighbourhood buffer. Further, denser urban forms such as apartment buildings with ground-level retail and residences above can result in lower land use mix scores due to the increases in residential density.

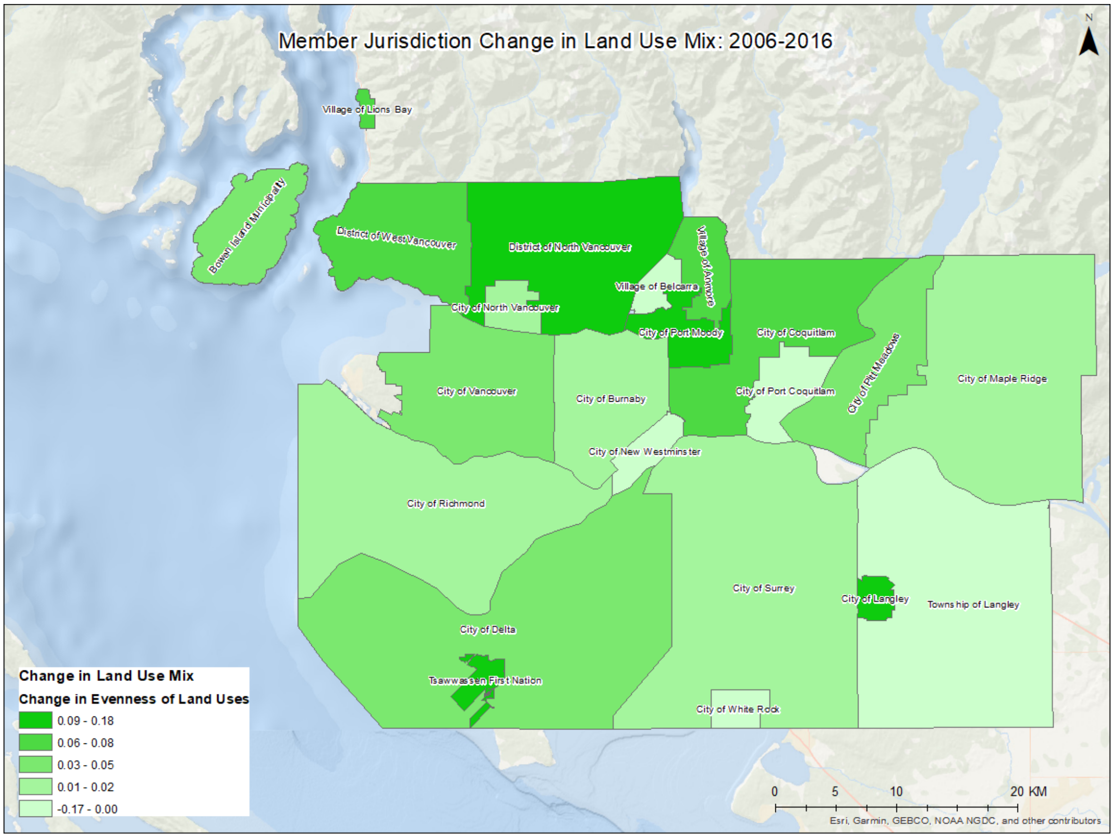


Figure 12-29 Member Jurisdiction Change in Land Use Mix: 2006 - 2016

In the region, many of the Member Jurisdictions that experienced positive changes in land use mix were smaller cities and districts such as Port Moody, Langley, and the District of North Vancouver. Site specific examples where significant changes in land use mix occurred can be found in Vancouver in the Kerrisdale neighbourhood and the District of North Vancouver in Northwoods Village.

On the corner of 57th and Cypress in the neighbourhood of Kerrisdale, we can see an example of how an increase in land use mix contributed to a more even distribution of land use. The corner was upgraded through the renovation of the existing businesses and the addition of apartments on top. This happened to a greater degree in the Northwoods Village area in the District of North Vancouver.

Northwoods Village, North Vancouver:
WB @ Riverside Dr. & Front St.

0.39 Land Use Mix Score   0.84 Land Use Mix Score

The area surrounding Northwoods Village is an example of a medium to low-density residential and industrial area that saw an increase in land use mix and a move towards a more even distribution of land use types with increased construction in both areas.

12.1. Regional Accessibility

The Walkability Index and Change in Walkability Index describe neighbourhood level local accessibility but do not address accessing amenities beyond a 15–20-minute walk. A model describing Regional Accessibility is required to analyze how disparate areas of the region are connected. Using Generalized Transit Feed Specification (GTFS) data from TransLink average travel times for auto and transit at peak AM and mid-day times were determined for the region for 2011 and 2016. These travel times are based on a variety of regional destinations and include Metro Vancouver Regional Growth Strategy destinations, those determined by the Health and Community Design Lab (HCDL), and Metro Vancouver and UBC destinations combined. The additional destinations added by the HCDL were determined based on their importance to regional transportation using criteria such as volume and proximity to regional centers. An example of this is the Commercial Drive Station transportation hub which is one of the most heavily used transit corridors in the region[32]. The destinations are outlined in the tables below.

[32] TransLink. (n.d.). 2019 TSPR - Rail Summaries [Interactive]. Tableau Public. Retrieved August 12, 2021, from https://public.tableau.com/app/profile/translink/viz/2019TSPR-RailSummaries/TableofContents

Figure 12-30 Metro Vancouver Regional Growth Strategy Destinations

#	Destination Name	Municipality	Type
1	Commercial Dr. Station	Vancouver	Transportation Hub
2	Central Broadway	Vancouver	Transportation Hub
3	UBC	UEL	Educational
4	YVR	Richmond	Transportation Hub
5	Clearbrook	Abbotsford	Regional City Centre
6	Cottonwood Centre	Chilliwack	Municipal Town Centre
7	Mission City	Mission	Municipal Town Centre

Figure 12-31 Health and Community Design Lab Determined Destinations

#	Destination Name	Municipality	Type
1	Downtown Vancouver	Vancouver	Metropolitan Core
2	Surrey Centre	Surrey	Suburban Metro Core
3	Oakridge	Vancouver	Municipal Town Centre
4	Metrotown	Burnaby	Regional City Centre
5	Columbia Skytrain	New Westminster	Regional City Centre
6	Richmond Brighouse	Richmond	Regional City Centre
7	Lonsdale Quay	North Vancouver	Regional City Centre
8	Brentwood Town Centre	Burnaby	Municipal Town Centre
9	Lougheed Town Centre	Burnaby	Municipal Town Centre
10	Coquitlam Town Centre	Coquitlam	Regional City Centre
11	Edmonds	Burnaby	Municipal Town Centre
12	Newton	Surrey	Municipal Town Centre
13	Guildford Town Centre	Surrey	Municipal Town Centre
14	Willowbrook Centre	Langley City	Regional City Centre
15	Downtown Port Moody	Port Moody	Municipal Town Centre
16	Downtown Port Coquitlam	Port Coquitlam	Municipal Town Centre
17	Downtown Maple Ridge	Maple Ridge	Regional City Centre
18	Fleetwood	Surrey	Municipal Town Centre
19	Downtown Pitt Meadows	Pitt Meadows	Municipal Town Centre
20	Ambleside	West Vancouver	Municipal Town Centre
21	Lynn Valley Centre	DNV	Municipal Town Centre
22	Semiahmoo Centre	White Rock	Municipal Town Centre
23	Cloverdale	Surrey	Municipal Town Centre
24	Aldergrove Centre Mall	Township of Langley	Municipal Town Centre
25	Ladner	Delta	Municipal Town Centre
26	Willoughby	Township of Langley	Municipal Town Centre

To calculate the travel times for each postal code, travel times acquired from the GTFS data were linked to each postal code based on the traffic analysis zone it falls within. The travel times for each destination were then aggregated and divided by the total number of destinations to arrive at mean AM and mid-day travel times for auto and transit. The resulting travel times for all Metro Vancouver and Health and Community Design Lab destinations are visualized in maps below.

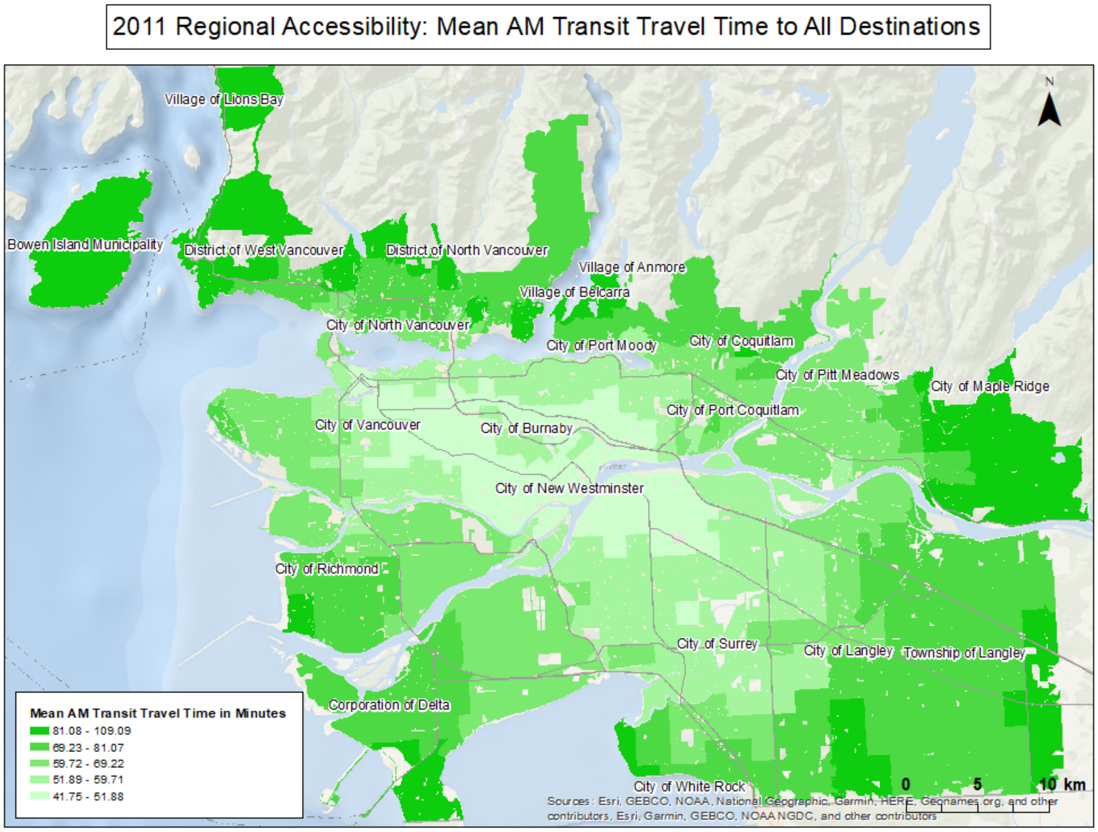


Figure 12-32 Map of 2011 Mean AM Transit Travel Time

2016 Regional Accessibility: Mean AM Transit Travel Time to All Destinations

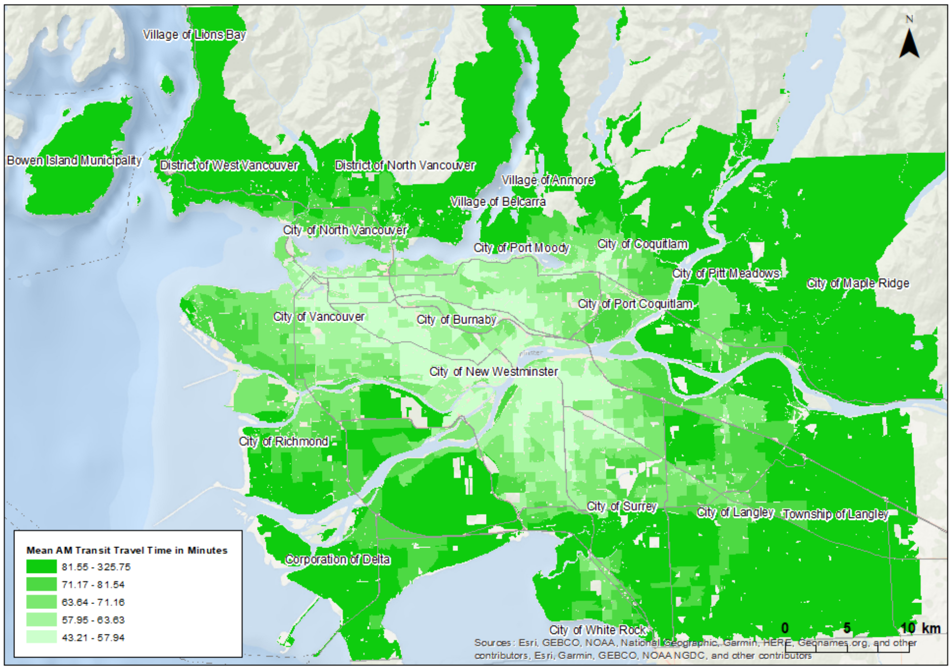


Figure 12-33: Map of 2016 Mean AM Transit Travel Time

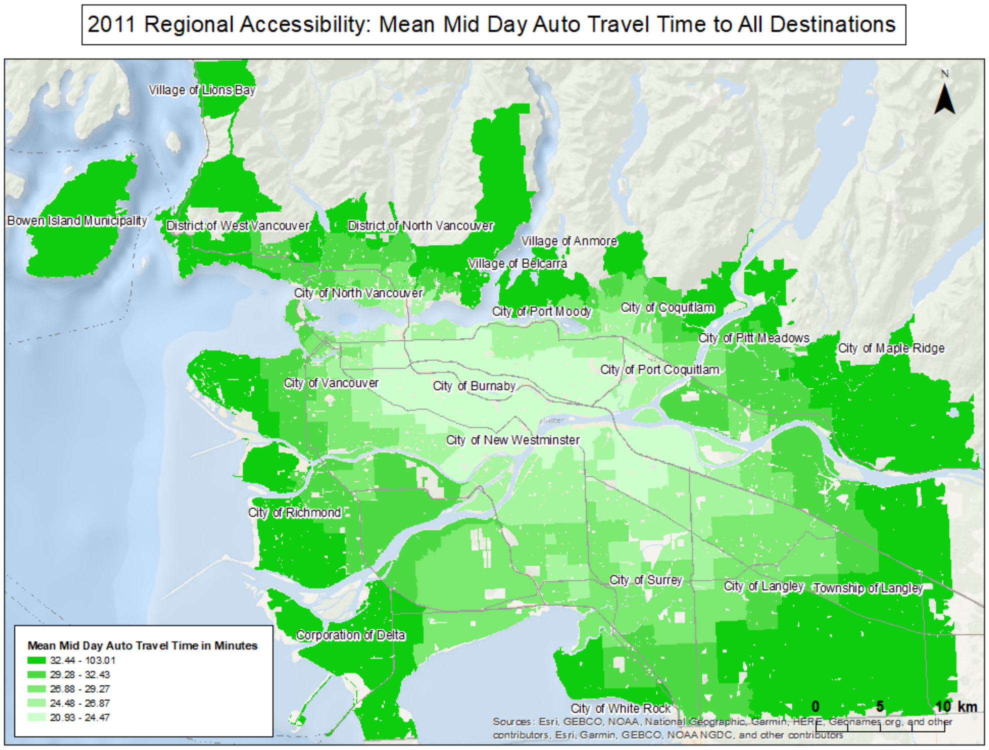


Figure 12-34: Map of 2011 Mean Mid-Day Auto Transit Travel Time

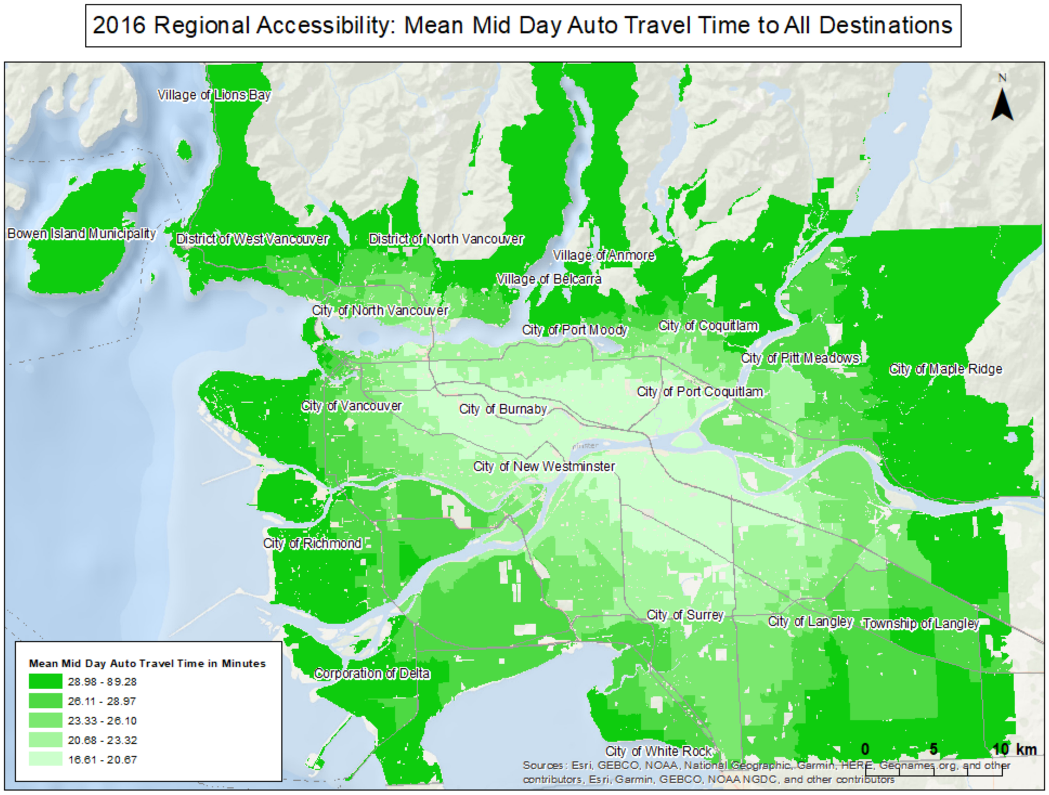


Figure 12-35: Map of 2016 Mean Mid-Day Auto Transit Travel Time

The transit travel time maps consistently show the lowest travel times for transit where transportation is easily accessible. This is apparent on the downtown peninsula of Vancouver, East Vancouver at Commercial Dr. Station, in New Westminster, and areas of Port Moody and Coquitlam where transit is concentrated. Transit travel time increases in car dependent areas with poor transportation connection. This is shown in suburban areas such as Anmore, Belcarra, Maple Ridge, and Lions Bay where transportation investment has historically been low. Auto travel times exhibit similar patterns regionally due to most destinations being closer to the downtown core of Vancouver. Some suburban areas exhibit travel times like those found closer to the downtown core of Vancouver due to transportation design differences. Many suburban areas were built as car dependent enclaves with well-connected highways, while areas within the City of Vancouver have transitioned to more transit and active transportation friendly modes of travel. As transportation policies evolve in the region, we would expect to see transit travel times decrease allowing greener more equitable travel across Metro Vancouver.

12.2. Walkability Summary

The analysis of changes in the component variables which comprise the walkability index allows policy decision makers to examine how changes in the built environment over time shape each neighbourhood and the collective region. These changes show, at the postal code level, the development trajectory of Metro Vancouver with policy relevant measures. When neighbourhood walkability is improved, the culmination of these changes has been shown to be a factor in living healthier more environmentally friendly lifestyles.

12.3. Neighbourhood Change in Metro Vancouver

From 2006 to 2016, some neighbourhoods in Metro Vancouver have undergone extensive change. These changes are reflected in the component variables of net residential density, commercial floor area ratio, land use mix, intersection density, and the walkability index. These neighbourhoods have not only undergone a physical change in the built environment. Along with the processes of densification and upgrading that change the built environment, shifting demographic patterns have occurred resulting in the attraction of new residents and the departure of others. This section describes how changes in walkability and demographic characteristics have interacted from 2006 – 2016. The neighbourhoods in focus are a selection of those that had the highest change in walkability over the study period. Willingdon Heights in Burnaby, Brighouse in Richmond, Morgan Heights in Surrey, and Olympic Village in Vancouver are highlighted in these case studies (Figure 12-36).

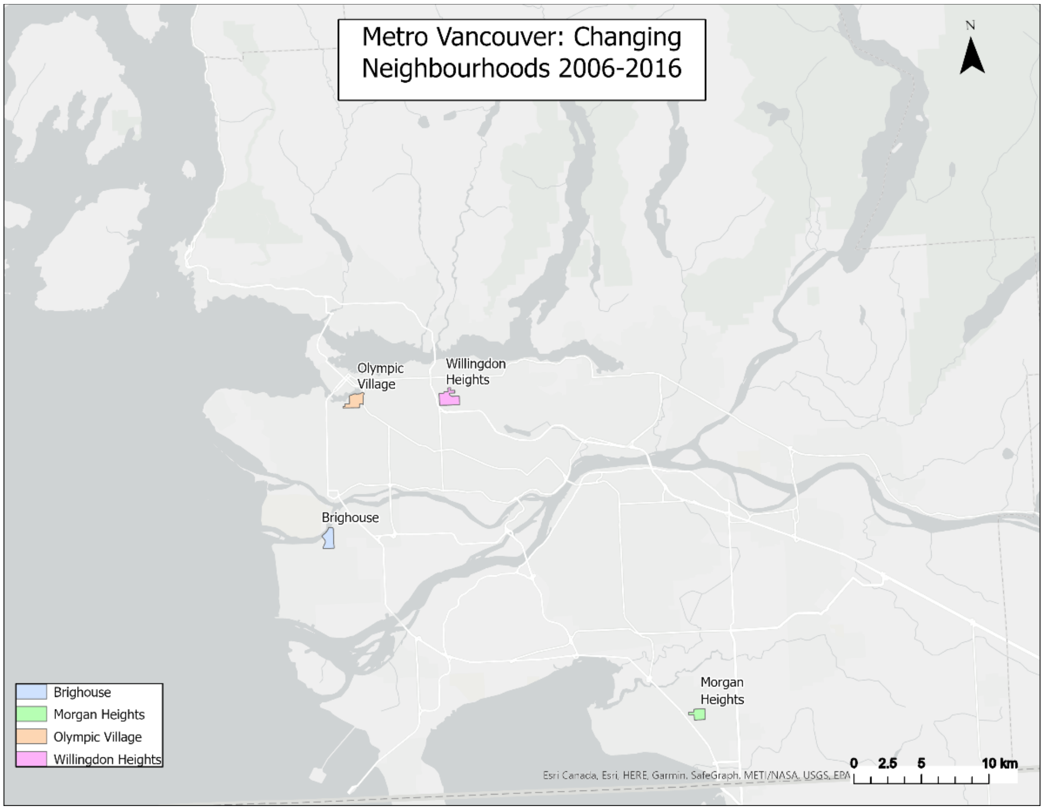
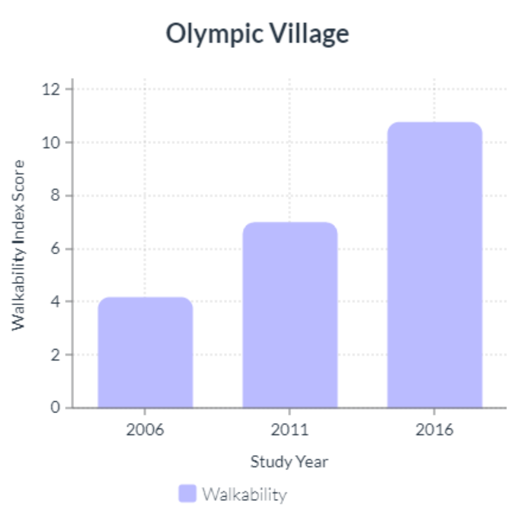


Figure 12-36 Map of Case Study Neighbourhoods

12.3.1. Olympic Village, Vancouver

Olympic Village was constructed for the 2010 Winter Olympics held in Vancouver. It was a major development project that converted largely industrial lands into dense residential



apartment buildings with retail at the bottom. From 2006 to 2016 the walkability index and demographic variables reflect this conversion from a mainly industrial area to a mixed-use residential and retail neighbourhood (Figure 12-37).

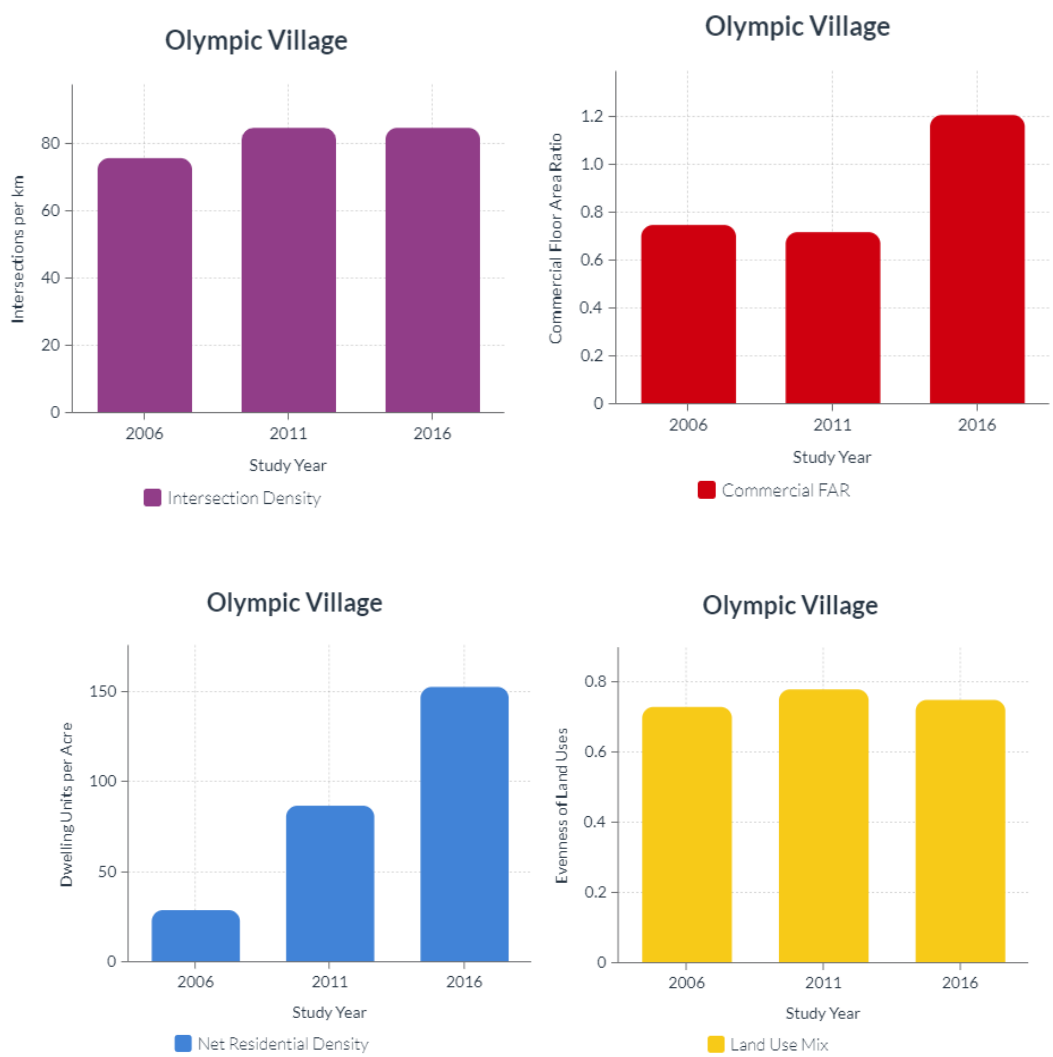


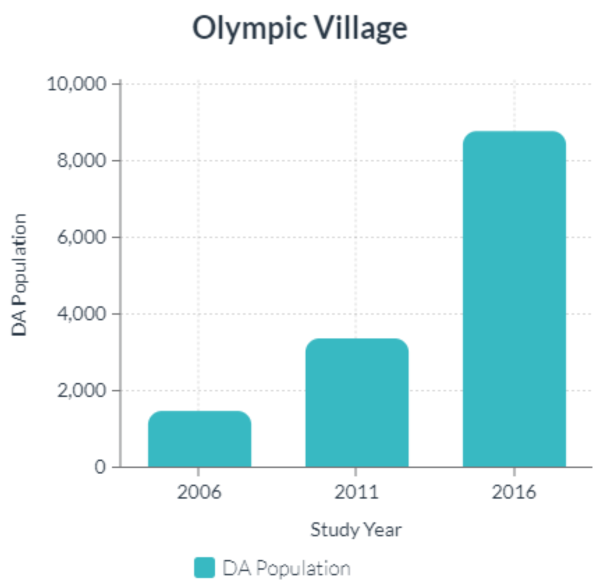
Figure 12-37 Walkability Profile of Olympic Village

From the changes in the walkability index and the component variables, we can see many of the measures increasing resulting in significant changes in the built environment. Through the construction of apartment buildings with retail on the ground floor of many, net residential density and commercial FAR have skyrocketed from 2006 to 2016. There was a dip in commercial FAR in 2011 as the conversion from industrial to mixed-use lands occurred. When Olympic Village was first constructed many of the retail spaces remained vacant for many years.

As residential buildings have been added in the years since Olympic Village's initial construction in 2011, the land use mix has decreased slightly from the intensification of 1 of the 6 land uses used to calculate the measure. The changes in the component measures have interacted to increase walkability in Olympic Village, nearly tripling the index score from 4.2 to 10.8 in 10 years.

Figure 12-38 Olympic Village Changes from 2006 (left) to 2016 (right)

In the photos above (Figure 12-38) you can see the dramatic change in the landscape that has occurred in Olympic Village. The changes shown above have also affected the demographic profile of the area. The graphs presented below outline these shifts in demographics. Over the study period, Olympic Village has continued to become wealthier and more populated. Median annual income rose from $27,000 to $50,000, educational attainment based on those with a Bachelor's degree or higher increase, and the median age of those living in the area was stable at around 35 years old. The changes in these variables indicate that wealthier and younger people have continued to move into the area from 2006 to 2016.


Olympic Village
10,000
8,000
6,000
4,000
2,000
0
DA Population
2006
2011
2016
Study Year
DA Population

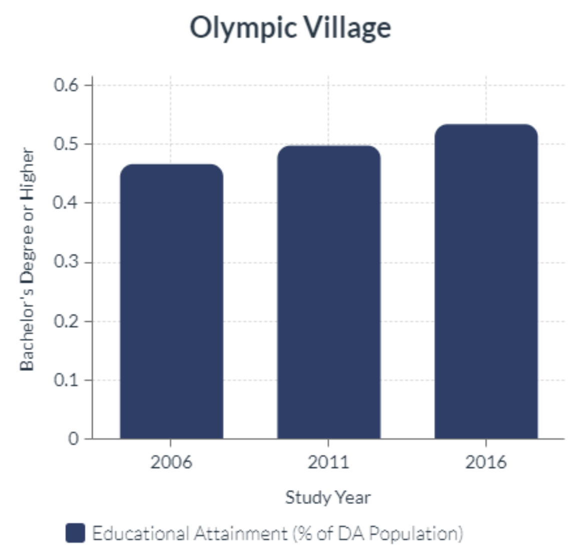

Olympic Village
0.6
0.5
0.4
0.3
0.2
0.1
0
Bachelor's Degree or Higher
2006
2011
2016
Study Year
Educational Attainment (% of DA Population)

Figure 12-39 Demographic Profile of Olympic Village

12.3.2. Willingdon Heights, Burnaby

Located to the east of the City of Vancouver in Burnaby, Willingdon Heights is a neighbourhood named after Willingdon Avenue. The neighbhourhood is well connected to North Burnaby and Metrotown to the south through Kingsway and Willingdon Avenue. It is located close to Brentwood Mall and is connected by transit through the Millenium Line Skytrain at Brentwood Station and several TransLink bus routes.

From 2006 to 2016, areas of Willingdon Heights experienced significant development and densifcatoin throught the constuction of mixed use residential apartment buildings with commercial space on the ground floor. This saw the conversion of industrial, retail, and single family residential land uses converted into much denser urban forms. This is shown through the walkability index and the component measures.

During 2006 to 2016 the neighbourhood experienced a nearly 8-fold increase in net residential density. This was fueld by the densifcation and conversoin of low density land uses into tall residential towers. Further, with ground level retail in many of the residential towers the ratio of commercial lands to commercial floor area remained consistent, even though retail was converted into predominantly residential land use. This contributed to an increasing land use mix over the 10 year period as the neighbourhood developed into a walkable mixed use community. The area changed from an neighbourhood that was below aveage in walkability in 2006 to one that almost 3 times as walkable as the Metro Vancouver average in 2016. The walkability index score changed from -0.12 in 2006 to 2.8 in 2016. During that period regional accessibility, the ease at which resources can be reached within Metro Vancouver, has remained consistent weighted at 45 minutes of travel time to reach all regional destinations.

Figure 12-40 Walkability Profile of Willingdon Heights

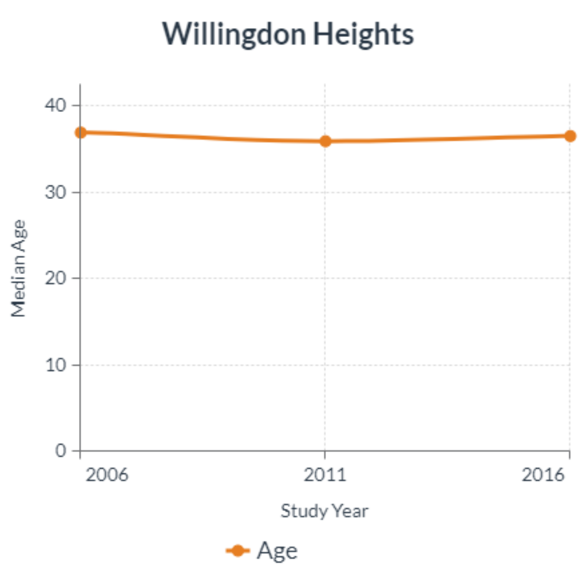
This contributed to an increasing land use mix over the 10 year period as the neighbourhood developed into a walkable mixed use community. The area changed from an neighbourhood that was below aveage in walkability in 2006 to one that almost 3 times as walkable as the Metro Vancouver average in 2016. The walkability index score changed from -0.12 in 2006 to 2.8 in 2016. During that period regional accessibility has remained consistent weighted at 45 minutes of travel time to reach all regional destinations.

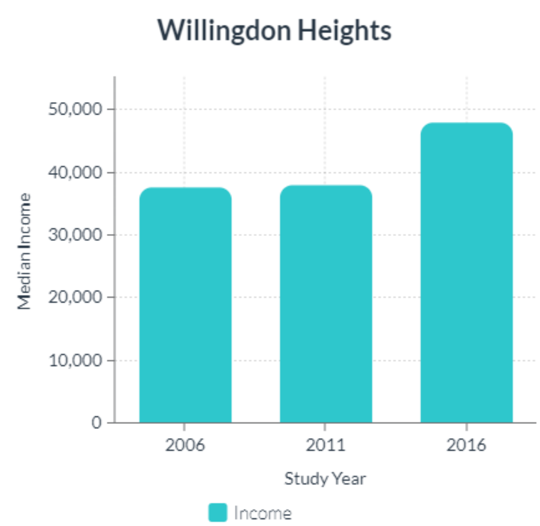
Figure 12-41 Changes in Willingdon Heights from 2006 (left) to 2016 (right)

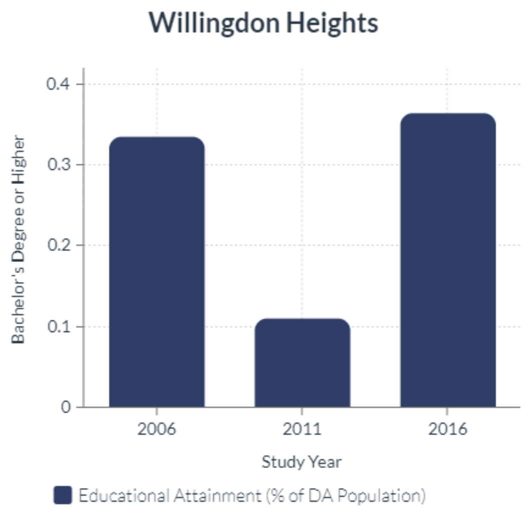
The pictures (Figure 12-41and Figure 12-42) included show the dramatic change in the landscape from the construction of dense residential towers. The transformation of the built environment of Willingdon has also changed who lives in the neighbourhood. With rising housing costs in the City of Vancouver, many younger people are looking towards well connected neighbourhoods like Willingdon Heights that are just outside of the city.

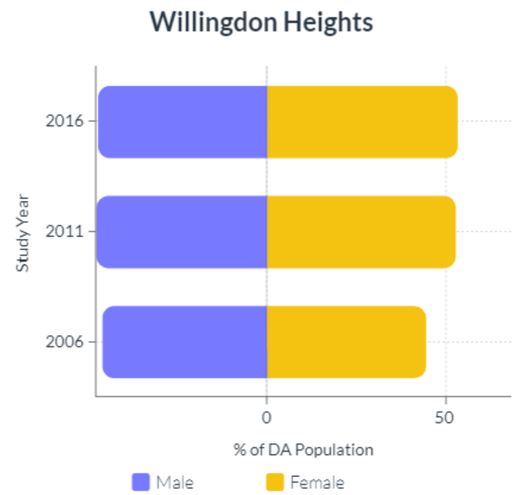
Figure 12-42 Changes in Willingdon Heights from 2006 (top) to 2016 (bottom)

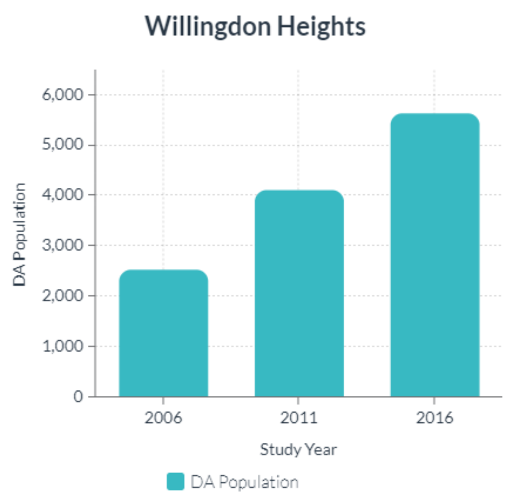
The demographic profile of Willingdon Heights has shifted to be denser, younger, more highly educated, and wealthier as a whole. From 2006 to 2016 the population more than doubled from 2,500 to 5,600. The new people in the neighbourhood tended to be younger as the median age in the area has remained steady at around 36 years old, over the 10 year period. These younger residents buying and renting new apartments had incomes 25% higher than those in 2006. The median income in Willingdon in 2006 was $38,000 and had risen to 47,000 by 2016. The graphs below outline these changes in further detail:

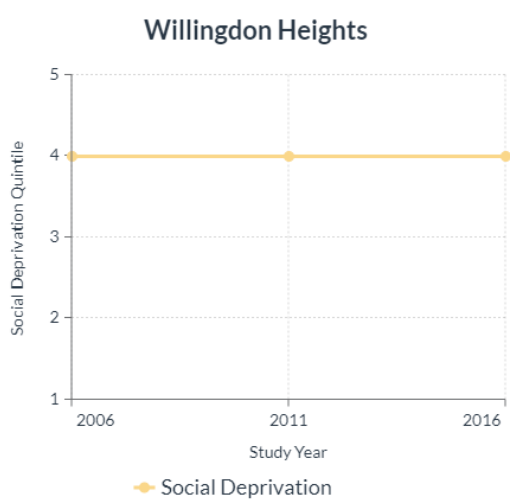












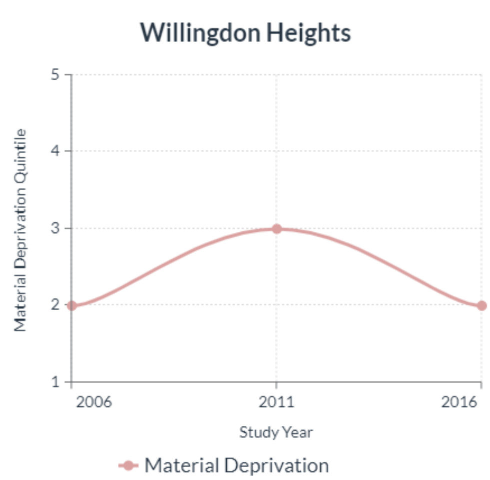
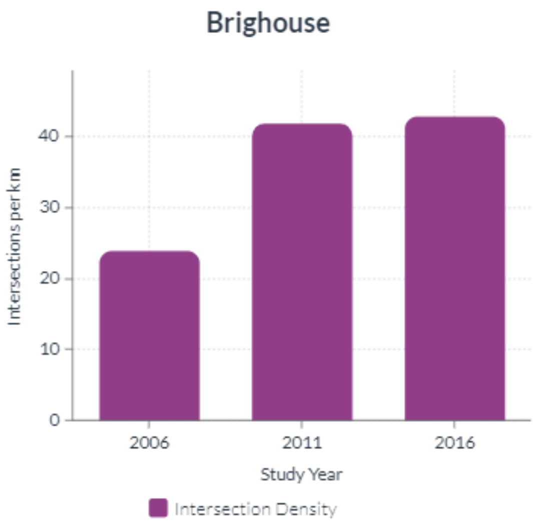
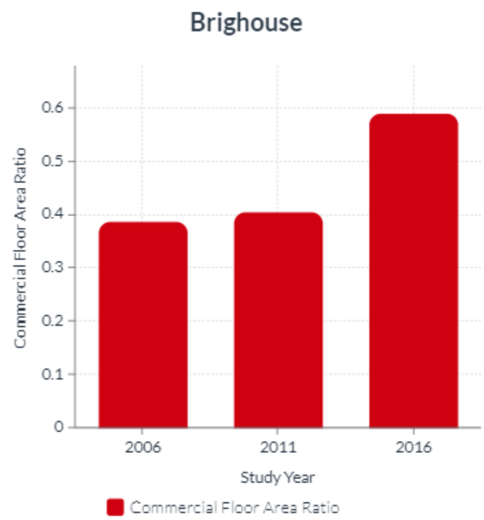


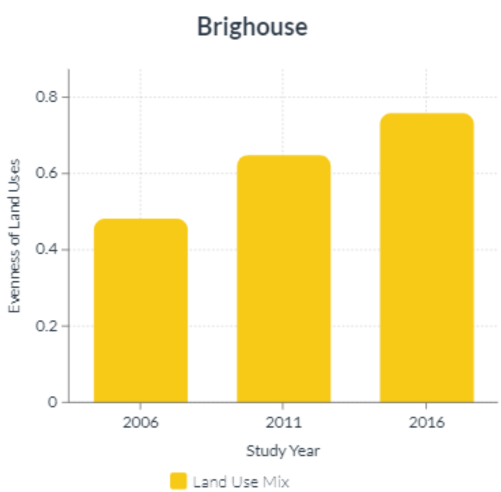
Figure 12-43 Demographic Profile of Willingdon Heights

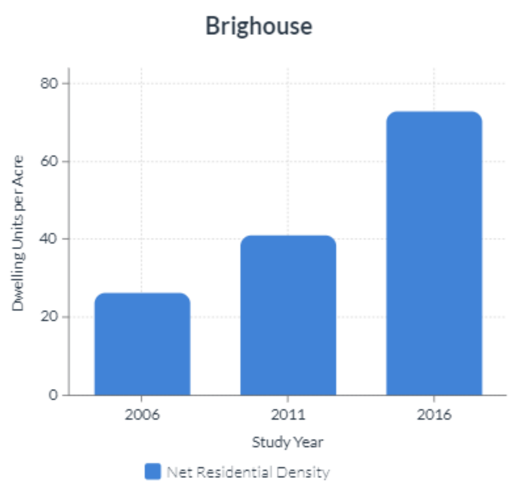
12.3.3. Brighouse, Richmond

Brighouse is a neighbourhood in Richmond which has seen significant development since the turn of millenium. The neighbourhood makes up the majority of the urban core in Richmond and has been the center of densification and development in Richmond since the introduction of the Canada Line to Brighouse station in 2010. The major changes experienced in the Brighouse neighbourhood are reflected in changes in the walkability index, the component measures, and demographic variables.









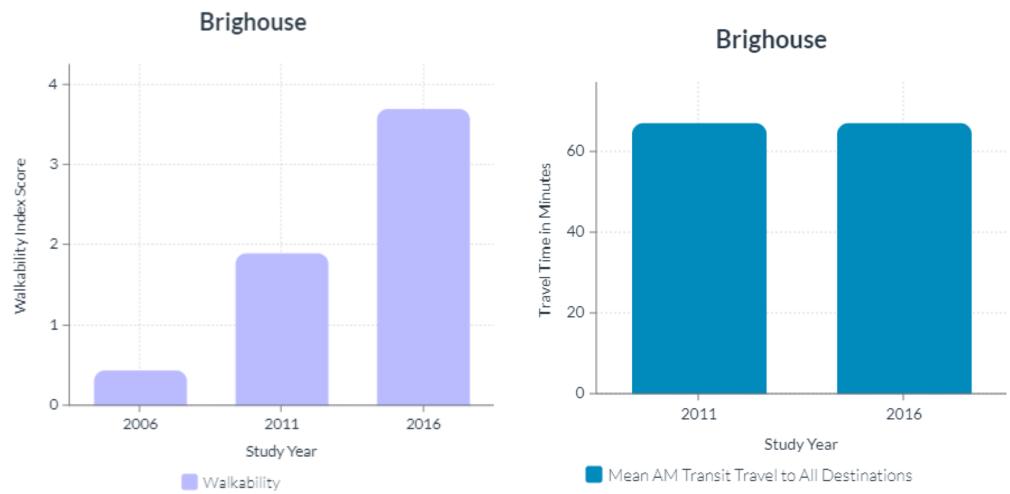


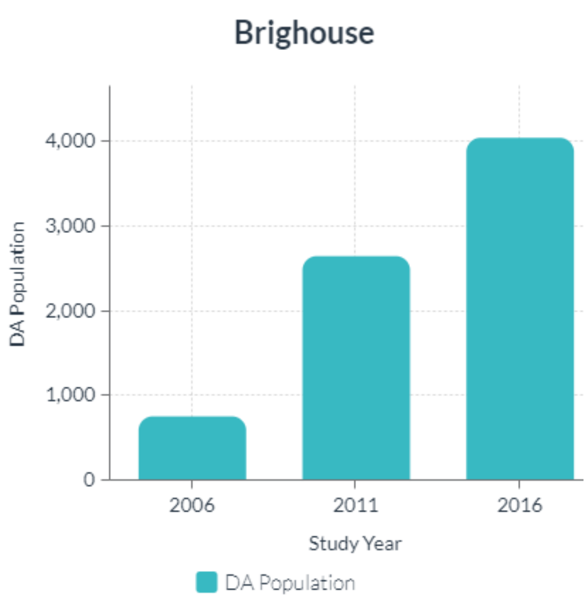
Figure 12-44 Walkability Profile of Brighouse

Brighouse has developed and increased in all component measures of walkability from 2006 to 2016. Each measure saw similar magnitudes of increase throught the period. With the construction of new retail and commercial buildings throughout the neighbourhood, new roads were required to make the new density accessible. During this time intersection density increased from just over 20 intersections per kilometre to 42. The construction of many mid-rise residential towers with commercial podiums in the area catapulted the commercial floor area ratio from 0.39 to 0.59 and the net residential density from 22 to 73 dwelling units per acre. The mixes of land use constructed in the burgeoning area drove an increase in land use mix from 0.48 to 0.76, creating a community with ample residential and commercial spaces. Below are real examples for the development of the neighbourhood. They showcase transit oriented development along the Canada Line and residential buildings with commercial podiums.

Figure 12-45 Changes in Brighouse from 2006 (left) to 2016 (right)

Figure 12-46 Changes in Brighouse from 2006 (left) to 2016 (right)

The changes in the built environment over this time attracted new people to Brighouse. The population of the neighbourhood swelled from 760 in 2006 to 4,000 in 2016. The folks that came to the area in this time were different than those that called the area home before the arrival of the Canada Line and scores of residential apartment buildings.



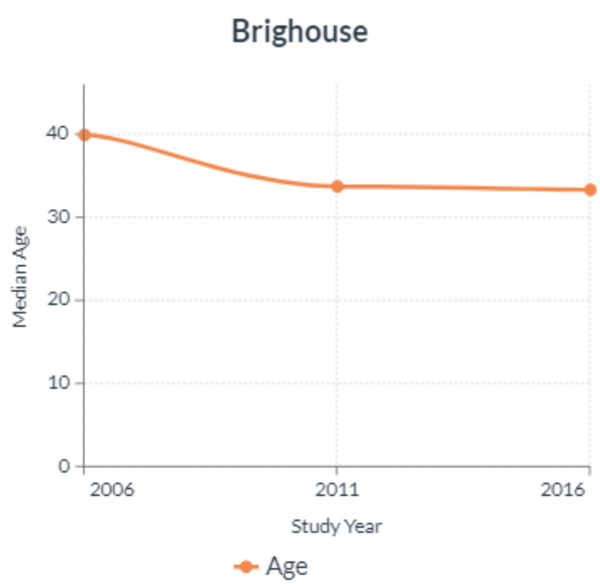


Figure 12-47 Demographic Profile of Brighouse

The trends the demographic variables exhibit is that of younger and wealthier people moving into the Brighouse neighbourhood. From 2006 to 2016 the median age in the area dropped from 40 to 33.4. At the same time, the median income rose from $19,000 to $28,553 and education remained consistent. This trend has been shown in both Olympic Village and Willingdon Heights in which the new housing in each neighbourhood tends to attract younger and wealthier individuals, perhaps escaping the increasingly unaffordable housing prices in the City of Vancouver.

Interestingly, social deprivation increased to a more deprived quintile and material deprivation remained constant over the 10-year period. The change in social deprivation to a more deprived quintile could be due to more individuals living alone. Material deprivation likely remained constant due to the interaction between income and educational attainment that occurred from 2006 to 2016. While income rose more throughout the early part of the decade than in the latter half, education took a big dip in 2011 and returned to a similar level in 2016.

12.3.4. Morgan Heights, Surrey

Morgan Heights is a newly developing suburban community in South Surrey located east of White Rock. Once a predominantly low-density single-family and rural neighbourhood, Morgan Heights has been densifying through the construction of town homes and low to mid rise apartment buildings. These changes have occurred both through largely greenfield development, but the neighbourhood has also experienced some infill development. The addition in residential buildings adds much needed density to an area that from 2006-2011 developed to be well served by amenities. Morgan Heights has schools and retail within walking distance to much of the housing in the neighbourhood. The changes in the built environment can be shown through the walkability index component measures and the overall change in walkability from 2006 to 2016.

Figure 12-48 Walkability Profile of Morgan Heights

As shown through the component measures there was an intense period of development from 2006 to 2011 in which new roads and commercial destinations were built to accommodate the incoming residential density and increased population. This is shown through the increases in intersection density and commercial FAR from 2006-2011. The development resulted in a more even land use mix in 2011 going from 0.041 to 0.59 in 5 years. From 2006 to 2016 there is a large period of residential development reflected in the increase in net residential density. The earlier part of the decade saw an increase from 0.35 dwelling units per acre to 7.25 with the latter half going up to 16.7. Land use mix changed along with these developments in the built environment and settled from 0.59 in 2011 to 0.52 in 2016 after the increase in residential density. The interaction of the changes in the component variables lead to a significant increase in walkability from 2006 to 2011 and continued increases to 2016.

Morgan Heights went from a highly unwalkable neighbourhood that was almost 5 times less walkable than average to an area that is over 2 times more walkable than the regional average. While the neighbourhood is still largely car dependant when accessing the rest of the region, with little transit infrastructure investment as reflected in the stagnant transit travel times, the local accessibility to amenities and housing is high. Some of these changes are ground-truthed in pictures captured by Google street view below:

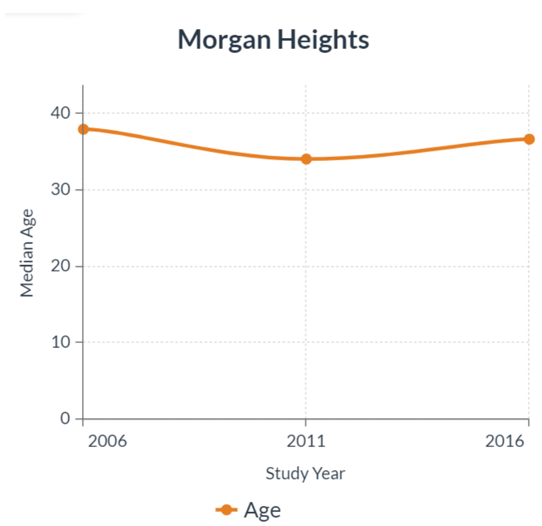
Figure 12-49 Changes in Morgan Heights from 2006 (left) to 2016 (right)

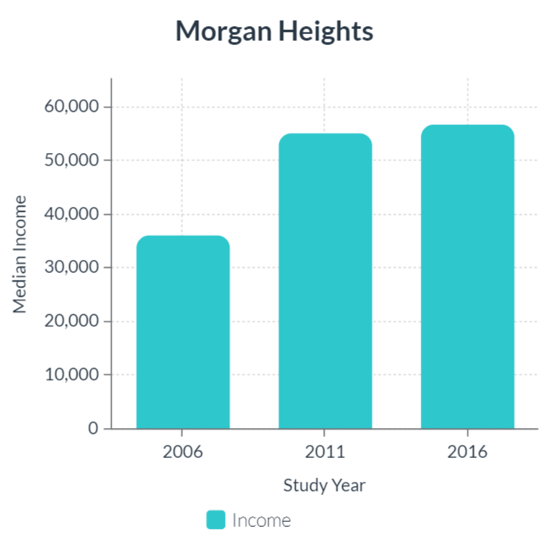
Figure 12-50 Changes in Morgan Heights from 2006 (left) to 2016 (right)

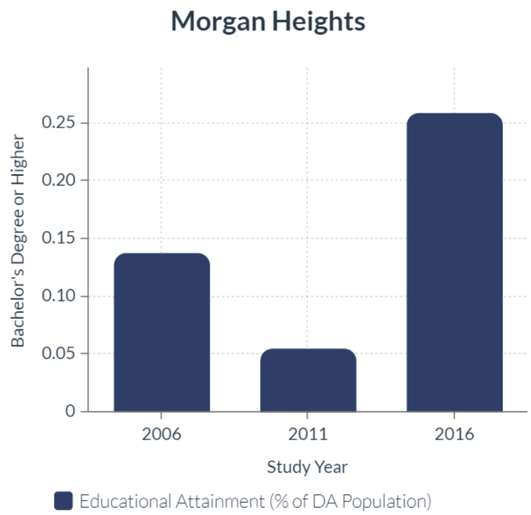
The images show increases in net residential density from the construction of large blocks of townhouses. The new housing developed in the neighbourhood attracted individuals that changed the demographic profile of Morgan Heights.

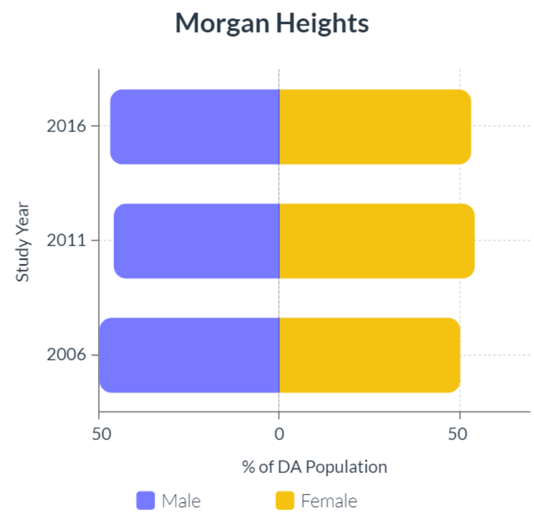
The explosion in population from 2006 to 2016 brought in over 4,000 new residents to Morgan Heights. The difference in median age from 2006 to 2011 signaled the addition of younger and wealthier people to the area. During this time the median age dropped from 38 to 34.1, while median income rose from $36,000 to $55,000. From 2011 to 2016 the population of Morgan Heights continued to increase significantly bringing in a more educated, but largely similar resident with the median age increasing to 36.7 and the median income rising to $57,000. Morgan Heights seems to have become a walkable oasis is suburbia for young families to move to with a proximate school and walkable retail amenities.

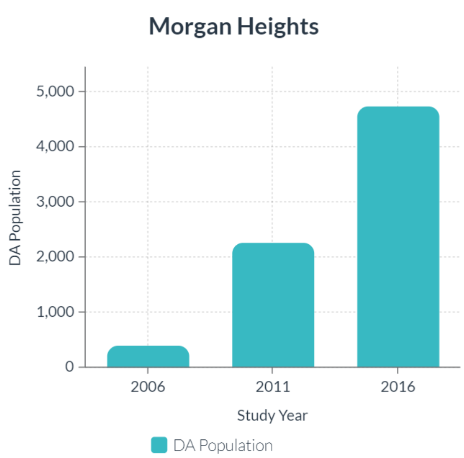
Over the 10 year period in Morgan Heights there were fluctuations in social and material deprivation. The average social deprivation throughout the neighbourhood moved from the lowest quintile to the highest indicating the most socially deprived over the study period. This could be due to more lone parent, divorced, or single individuals moving into the area. Material deprivation exhibited the opposite trend moving from one of the most deprived quintiles to the least. This can likely be attributed to higher levels of education, income, and employment moving into the area with the increase in greenfield development and net residential density.

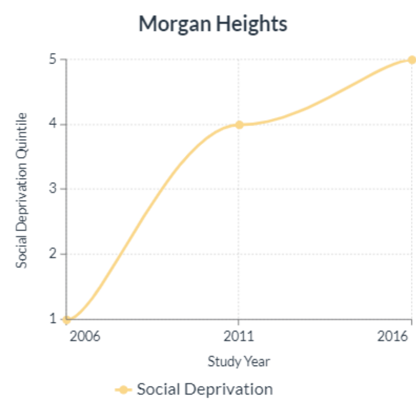





Morgan Heights
Bachelor's Degree or Higher
0.25
0.20
0.15
0.10
0.05
0
2006
2011
2016
Study Year
Educational Attainment (% of DA Population)


Morgan Heights
Study Year
2016
2011
2006
50
0
50
% of DA Population
Male
Female


Morgan Heights
DA Population
5,000
4,000
3,000
2,000
1,000
0
2006
2011
2016
Study Year
DA Population


Morgan Heights
Social Deprivation Quintile
5
4
3
2
1
2006
2011
2016
Study Year
Social Deprivation

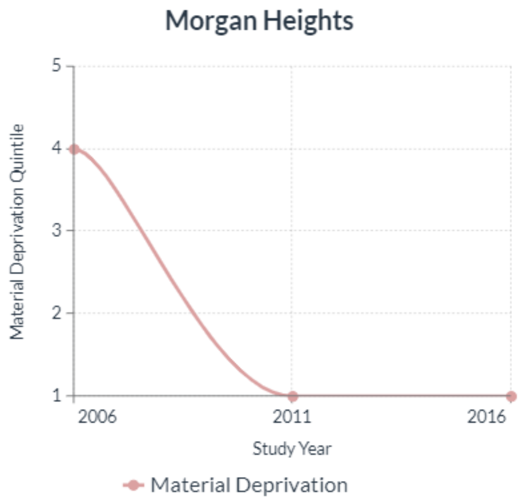


Figure 12-51 Demographic Profile of Morgan Heights

How have patterns of gentrification varied across the region during the study period?

In this section, gentrification patterns across the region from 2006 to 2016 were measuring using both David Ley's Social Status Index as well as individual indicators of change identified through the literature review.

Measuring gentrification using the Social Status Index

First, the Social Status Index for each CT have been calculated and divided into quintiles to illustrate what areas are showing the highest and lowest relative rates of gentrification in the region from 2006 to 2016 (Figure 12-52). Visually inspecting the map, high gentrification neighbourhoods are concentrated on the east side of the City of Vancouver, the City of North Vancouver, and the City of New Westminster. However, there are also more suburban and rural areas showing high relative rates of gentrification, such as Bowen Island and neighbourhoods in Surrey, Maple Ridge, and Pitt Meadows.

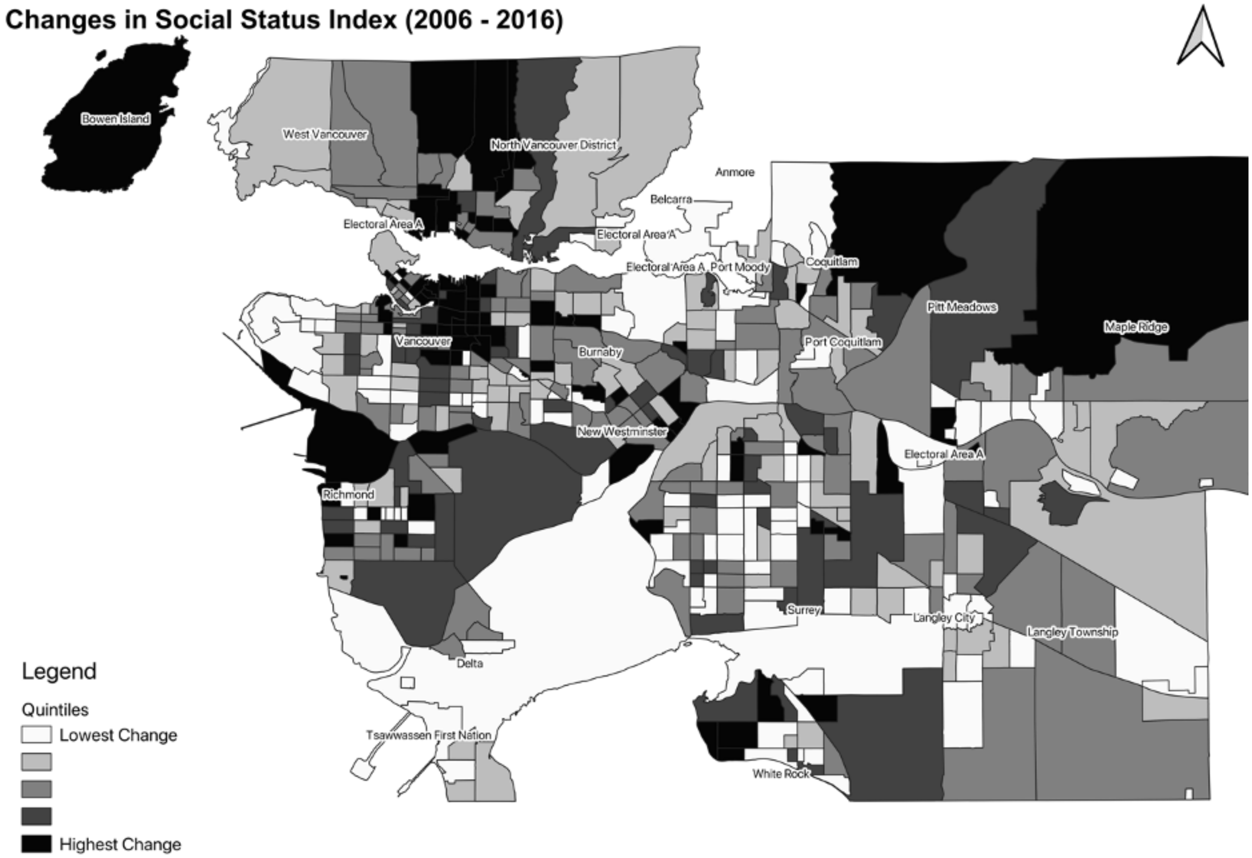


Figure 12-52: Changes in Social Status in Metropolitan Vancouver CTs, 2006 – 2016

Social Status Index scores have also been aggregated at the municipal level to see how each municipality, First Nation and Electoral Area changed relative to each other during the study period. Shown in Table 12-3, it is the rural municipalities of Bowen Island and Pitt Meadows that stand out with the highest increases in social status, which is interesting as both municipalities are relatively small, rural communities far from the urban core. In fact, all other municipalities but one are within +/- 3% of the regional average (**+6%**) change to social status index score. The one exception was the City of Langley, which actually saw a decrease in social status between 2006 and 2016. This is also interesting, as the City of Langley was one of the municipalities with the greatest relative increase in walkability during the study period (Table 12-3).

Table 12-3: Change in Social Status Index in Metropolitan Vancouver by Location, 2006 - 2016

Municipality	% Change in Managerial Profession	% Change in Post Secondary Education	Gentrification Index
Bowen Island	+8	+9	+17
Pitt Meadows	+2	+11	+13
North Vancouver City	+1	+9	+9
Electoral Area A	+3	+6	+9
Vancouver	+1	+7	+8
New Westminster	+0	+8	+8
Port Moody	-1	+8	+7
North Vancouver District	+0	+7	+7
Burnaby	+0	+6	+7
Richmond	-0	+6	+6
Metropolitan Vancouver Region	+0	+6	+6
Maple Ridge	+1	+5	+6
Coquitlam	-0	+6	+6
Surrey	-0	+6	+6
West Vancouver	-1	+6	+5
Langley Township	+1	+5	+5
Port Coquitlam	-1	+5	+4
Delta	-0	+4	+4
Langley City	-2	-1	-3

Exploring the relationship between walkability and neighbourhood change

Regional variations in walkability and neighbourhood change were described in the previous section, and the following section explores the relationships between the two urban processes. To do this, changes in social status index scores as well as individual indicators of neighbourhood change are compared across neighbourhoods that have (1) high and low walkability index scores at the start of the study period, and (2) high and low *changes* in walkability index scores across the study time period.

Baseline Walkability and Social Status Index

In Figure 12-53 the baseline walkability index scores from Table 12-1 have been compared against the Social Status Index scores from Table 12-3 to see where gentrification is occurring relative to the walkability of each neighbourhood. Neighbourhoods have been ranked and divided into deciles based on their 2006 Walkability Index scores and Social Status Index scores, with the corresponding ranges representing “high walkability”, “low walkability”, “high neighbourhood change” and “low neighbourhood change”. To create separation between low and high change neighbourhoods, the fourth, fifth and sixth deciles were omitted from analysis.

Red neighbourhoods are those with high baseline walkability and high increases in social status. On visual inspection, high-high neighbourhoods are concentrated around the City of Vancouver downtown core and the neighbourhoods immediately east of the downtown core. There are also some concentrations of high-high neighbourhoods in North Vancouver and the City of New Westminster where high-high neighbourhoods are also concentrated.

Orange neighbourhoods are those with high baseline walkability and low relative rates of gentrification. These neighbourhoods are primarily located in the City of Vancouver. There is some concentration of these neighbourhoods in the district of West Vancouver, which could be explained as these are historically affluent neighbourhoods and changes in social status likely happened in decades prior to the beginning of the study period. The concentration in the south-east of Vancouver does not have an immediately obvious explanation and is interesting because it is fairly close to two major urban centers (City of Vancouver and City of New Westminster) and is in an area well served by transit (the Expo SkyTrain Line).

Green neighbourhoods are those with low walkability and high increases in social status. These low-high neighbourhoods are generally on the urban periphery. This suggests is that there might be similar patterns of gentrification occurring in the most urban (and walkable) neighbourhoods as well as the most rural (least walkable) in the region; however, patterns of gentrification occurring in high and low walkability neighbourhoods are examined further in the following section.

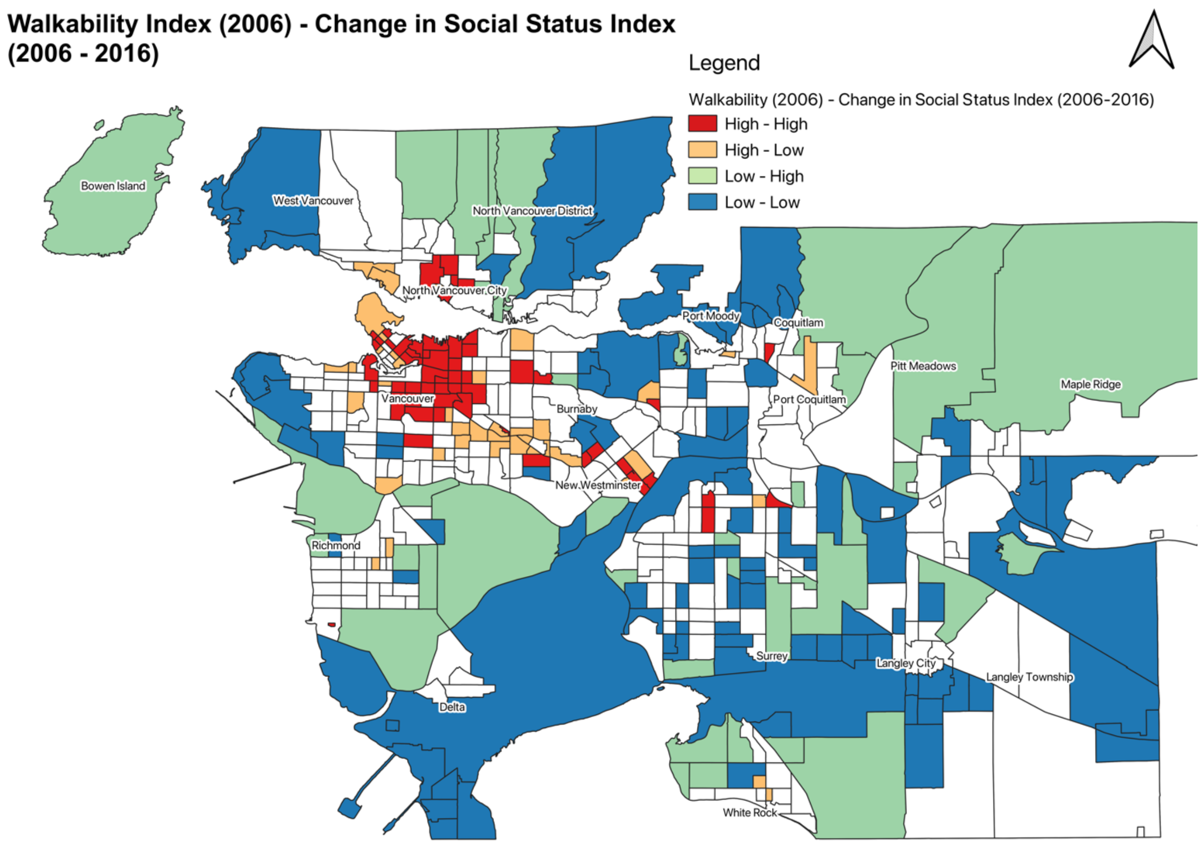


Figure 12-53: Distribution of Baseline Walkability Index Score (2006) and Social Status Index Changes (2006-2016)

Baseline Walkability and Changes in Individual Indicators of Gentrification

To understand if there are certain indicators of neighbourhood change that are more closely related with walkability than others, changes in individual measures have also been calculated for neighbourhoods of high and low baseline walkability in Table 12-4. Walkability index scores have been categorized using deciles, with high walkability defined as having a walkability index score in the top three deciles, and low walkability as having a score in the bottom three.

The findings in Table 12-4 do suggest that some social, economic, and demographic indicators are more associated with high/low walkability than others. For instance, during the study period, high walkability neighbourhoods had a greater increase in the proportion persons aged 25-25 years (+11%), while changes in low walkability neighbourhoods were consistent with regional averages (+7%). High walkability neighbourhoods had less of an increase in population 65 years and older than the regional average (+15% vs +22%), and low walkability neighbourhoods had a higher proportion than the regional average (+29%). The proportion of immigrants decreased in high walkability neighbourhoods (-3%), despite the regional proportion of immigrant population growing by +3%. For employment indicators, high walkability neighbourhoods saw much higher increases in proportion of some occupations (such as management and health occupations) and low walkability and the region, and less of an increase than the region in others (education, government service and social science occupations). The two indicators that comprise the Social Status Index were also included in individual indicators. Interestingly, proportion of managerial employment has a stronger relationship with walkability than education, which was nearly consistent across high, low and control neighbourhoods.

What these findings suggest is that some indicators of change do likely have a stronger relationship with walkability than others, across the individual indicators as well as the two that comprise the social status index. What can be drawn from these findings is that selecting different indicators of change (and gentrification) would lead to different results. For instance, while education is a very common indicator of gentrification across the literature, there is no strong differentiation in education rates across high and low walkability neighbourhoods in this comparative analysis. If education was swapped with a different indicator that is positively associated with neighbourhood change in the social status index, perhaps the results would not show similar gentrification patterns in urban and rural settings.

Table 12-4: Changes in Individual Indicators of Neighbourhood Change for Neighbourhoods with High and Low Walkability Index Scores

	2006 - 2016		
Population Indicators	**Metro Vancouver (Control)**	**High Walkability CTs**	**Low Walkability CTs**
% Change total pop	**+17**	**+16**	**+24**
% Change pop. 25 - 34 years	**+8**	**+11**	**+7**
% Change pop. 65+ years	**+22**	**+15**	**+29**
% Change Pop. Immigrants	**+3**	**-3**	**+9**
Employment Indicators			
% Change management occupations	**+4**	**+12**	**+1**
% Change business, finance and administration occupations	**-12**	**-9**	**-14**
% Change natural and applied sciences and related occupations	**+3**	**+2**	**+6**
% Change health occupations	**+16**	**+23**	**+15**
% Change education, government service, social science occupations	**+30**	**+23**	**+37**
% Change art, culture, recreation, sport occupations	**+12**	**+16**	**+6**
% Change sales and service occupations	**-2**	**-3**	**-2**
% Change trades, transport, equipment occupations	**-3**	**-12**	**+0**
% Change agriculture and primary industry occupations	**-25**	**-14**	**-33**
% Change processing, manufacturing, utilities occupations	**-27**	**-40**	**-19**
Socioeconomic Indicators			
% Change population 15 years and older university educated	**+24**	**+27**	**+25**

Differences in gentrification in high and low walkability neighbourhoods

What is clear from the analysis of individual indicators of neighbourhood change is that gentrification (defined using the Social Status Index) is that some form of gentrification occurring in both urban and suburban/rural areas of Metro Vancouver, and the index suggested higher rates of gentrification were occurring in rural settings (such as Bowen Island and Pitt Meadows). It is important to emphasize that while the findings suggest that gentrification is occurring in both high and low walkability settings, the David Ley Social Status Index is just one measure of gentrification. Many processes of gentrification can be occurring at any one time to different degrees in one place, and these cannot be captured or described using a two-indicator index of change.

PCA has been used to create principal components from the common indicators of gentrification in Table 12-4 to understand associations differ between individual indicators in high and low walkability areas. The purpose of this exercise is to see how gentrification as a process may be occurring differently in high and low walkability places (despite both high and low walkability places scoring high on the social status index).

Comparing the biplots of high gentrification and high walkability (high-high) and high gentrification/low walkability (high-low) neighbourhoods in Figure 12-54 can show how the principal components and relationships between variables differ in high and low walkability areas. Despite both high and low walkability neighbourhoods considered gentrifying, relationships between changes in individual measures are inconsistent between the two settings. For instance, the biplots show increases in immigrant population to be negatively associated with gentrification high walkability neighbourhoods, but positively associated with gentrification in low walkability neighbourhoods. Increases in arts, culture, recreation, and sports occupations are positively associated with gentrification in high walkability neighbourhoods, but negatively associated with gentrification in low walkability neighbourhoods. The loading factors of the first principal component of both high and low walkability neighbourhoods experiencing high rates of gentrification are compared in Table 12-5.

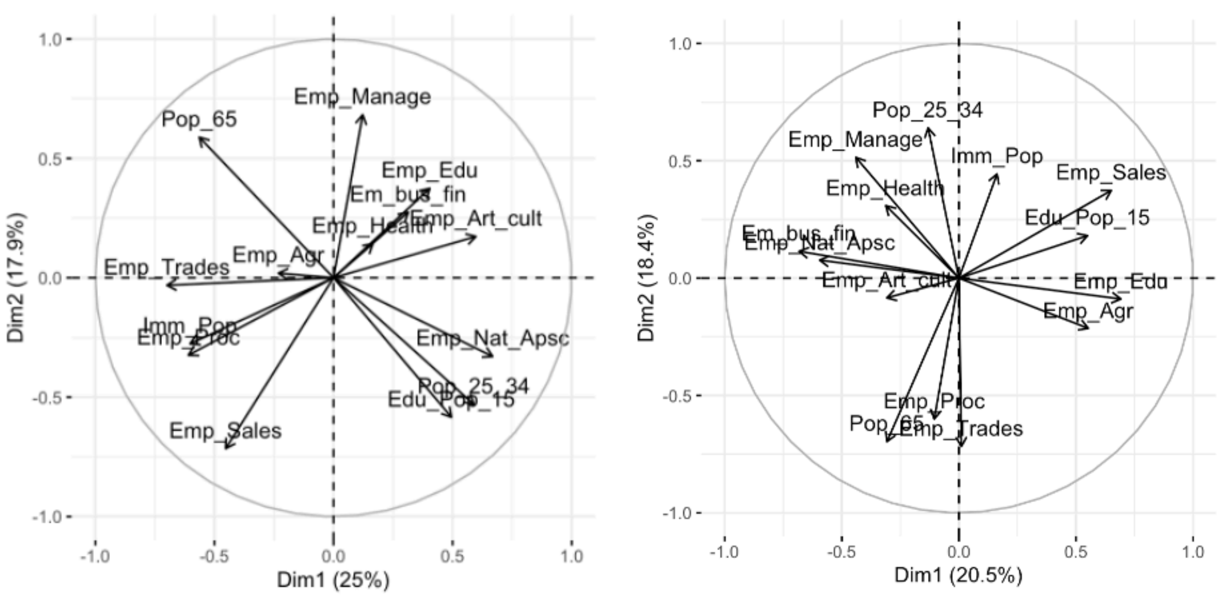


Figure 12-54: Principal Component Loading Matrix of High-High CTs (Left) and High-Low CTs (Right)

Table 12-5: Loading Factors of First Principal Component of High-High and High-Low CTs

	Principal Component 1 Factor Loadings	
Indicators	High Gentrification, High Walkability CTs	High Gentrification, Low Walkability CTs
% Change pop. 25 - 34 years	0.31	-0.08
% Change pop. 65+ years	-0.30	-0.18
% Change Pop. Immigrants	-0.32	0.10
% Change management occupations	0.07	-0.26
% Change business, finance and administration occupations	0.17	-0.40
% Change natural and applied sciences and related occupations	0.36	-0.35
% Change health occupations	0.09	-0.18
% Change education, government service, social science occupations	0.22	0.41
% Change art, culture, recreation, sport occupations	0.32	-0.18
% Change sales and service occupations	-0.24	0.38
% Change trades, transport, equipment occupations	-0.37	0.01
% Change agriculture and primary industry occupations	-0.12	0.33
% Change processing, manufacturing, utilities occupations	-0.33	-0.06
% Change population 15 years and older university educated	0.26	0.32

How are changes in walkability associated with neighbourhood change?

The paper also tried to explore the relationship between changes in neighbourhood walkability and neighbourhood change by comparing the changes in the walkability index scores Table 12-2 and changes in both the social status index (Figure 12-52) and individual indicators (Table 12-4**).** In summary, a relationship could not be found between the two processes using the visual and comparative analysis methods.

Another potential limitation for identifying relationships between changes in walkability and neighbourhood change is the temporal scope. This exercise compares two processes of change over the same (relatively short) time period. What this does not consider is that one process may lag behind the other, with built form changing first and neighbourhood change taking place in later time periods (or even vice vera). A further analysis could try comparing changes in walkability between an initial time point, such as 2006 to 2011, to gentrification trends at a later time point, to see if the processes are occurring during different periods.

12.4. Discussion

When comparing common indicators of neighbourhood change over the study period to the walkability of the neighbourhoods at baseline, there are some distinct patterns. The findings in Table 12-4 suggest that younger people tend to live in more walkable neighbourhoods, while a disproportionate percentage of immigrants and seniors live in neighbourhoods with the lowest walkability. Visually comparing the walkability of neighbourhoods to changes in social status index over the study period (Figure 12-52), neighbourhoods that are highly walkable at the start of the analysis period also saw higher increases in social status. However, many suburban and rural areas with low walkability also saw increases in social status index scores. The highest changes to social status index scores were found to be in two of the most rural municipalities in the region, Bowen Island and Pitt Meadows.

When comparing changes in neighbourhood walkability and other aspects of neighbourhood change, patterns are less distinct. Comparing changes in individual indicators of neighbourhood change in neighbourhoods with high and low changes in walkability, results for both categories are nearly identical to regional patterns. Visually inspecting the distribution of neighbourhoods with high and low changes in walkability and social status index, neighbourhoods that had high instances of both (red) were dispersed throughout the region, while neighbourhoods with low changes in walkability but high changes in social status (green) were concentrated around urban centers, despite some of them having high baseline walkability (City of Vancouver) and others low (Pitt Meadows and Maple Ridge). Other regions saw high changes in walkability but low changes in social status. For example, the City of Langley saw the second highest increase in walkability index score during the study period (see Table 12-2), but it was the only city to have a negative change in social status index score (Table 12-3).

The analysis results suggest there is a stronger relationship between baseline walkability of a neighbourhood and gentrification than changes in walkability and gentrification. The findings of this analysis did not find a strong relationship between changes in walkability and other aspects of neighbourhood change, however, there may be a relationship that could be found through other analysis methods and more granular data, such as regression modelling. Using visual inspection methods and calculating changes at relatively coarse level (CTs and Municipalities) is a way to identify preliminary trends and patterns, but data at the DA level along with more rigorous ways of measuring spatial correlation could be an area of further research. Measuring data at the dissemination area was initially considered as it would be a more granular analysis and may be easier to interpret a relationship between neighbourhood change and walkability (which is measured at the census block level), but there were several issues with data suppression for some of the variables at this scale. If another method for measuring neighbourhood change other than the social status index or individual indicators, analysis at the DA level could reveal some spatial patterns not apparent at the CT level.

Gentrification can often be understood as multiple overlapping processes taking place over both the short and long term. One limitation of this analysis is that it considers both processes of urban physical change (walkability) and neighbourhood change (gentrification) over the same time period, where this may not be the case. One process may be taking place before the other, and some may be taking place over a much longer period than the 10 years analyzed.

12.5. Conclusion

The purpose of this paper is to explore the relationship between walkability and neighbourhood social change. Using longitudinal walkability data and Metropolitan Vancouver as a case study, this project sought to investigate how walkability has changed in Metro Vancouver between the study period (2006-2016), how socioeconomic and sociodemographic characteristics of neighbourhoods have changed during the same time period, and what the relationship is between the two.

At the start of the analysis period (2006), walkable neighbourhoods were generally concentrated within the City of Vancouver near the downtown core, with walkability decreasing radially from there. While the City of the Vancouver was the most walkable municipality in 2006, it was more suburban and rural areas that saw the greatest increases in walkability during the study period, and the Capilano 5 First Nation Reserve surpassed Vancouver as the most walkable in the region by 2016, largely spurred by high density development.

The findings of analysis did find a relationship between walkability and certain indicators of neighbourhood change, such as younger persons tending to live in more walkable neighbourhoods and a disproportionate number of immigrants living in low walkability neighbourhoods in the region. The greatest increases in social status index scores were also concentrated in high walkability neighbourhoods, and with the greatest changes concentrated near urban cores. However, there were also several low walkability neighbourhoods that stood out with the highest increase in social status index scores during the study period. On closer investigation, it was found that while high relative rates of gentrification (defined by the social status index) were taking place in high and low walkability neighbourhoods, there were stark differences in the processes and their associated social, economic and demographic shifts. For instance, gentrification was more associated with young persons (25-35 years) in high walkability areas, but older persons (65+) in low walkability neighbourhoods. These findings suggest that there is opportunity to examine the relationship between walkability and various individual indicators of neighbourhood change, possibly developing a better method than the social status index to differentiate between urban and rural processes.

A relationship between changes in walkability and neighbourhood change was harder to discern. Neighbourhoods that experienced high (and low) rates of each phenomena were dispersed throughout the region, and reviewing changes in individual indicators didn't show much differentiation between neighbourhoods with high or low changes in walkability.

12.5.1. Limitations and Future Research

This exercise was exploratory, relying on visual analysis and data aggregated at a relatively coarse level (census tracts and municipality) to draw conclusions. The temporal scope of the study was relatively short (10 years), and future research that measures longitudinal change over a longer duration and multiple (3+) time points might yield important findings.

With regards to measuring change in walkability, this analysis was a first attempt that made assumptions about the preferred method. Further research could involve testing and validating various methods to measure change in walkability against actual travel behavior.

One of the most important findings of this analysis was that findings on gentrification and the conclusions that drawn were largely dictated by how it is defined. It is important to carefully consider the conclusions that can be drawn from findings, and how they might be limited by the methods used to analyze the phenomenon. This study found that some indicators of change were more closely associated with walkability than others, and further research could investigate the various processes of urban change occurring in high and low walkability neighbourhoods and see how gentrification patterns differ in these contexts.

While a relationship between change in walkability and neighbourhood change wasn't found using these analysis methods, using more granular data and quantitative analysis methods such as regression modelling would be the next step in identifying patterns in neighbourhood change and walkability change. Further research could also include investigating the relationship between the individual measures that make up the walkability index (intersection density, net residential density, retail floor area, land-use mix), to understand if certain measures are more or less associated with gentrification patterns through a correlation matrix.

Evaluating the influence of built environment changes on neighbourhood social trajectories can help us understand why some neighbourhoods experience change while others remain stable, and potentially help identify predictors of future processes of gentrification. Further research could also include investigating policy or contextual reasons that some walkable neighbourhoods are rapidly gentrifying in Vancouver, while some have remained relatively stable.

Quantified research can indicate general trends in the way that the social and the built form are connected. This paper demonstrates how longitudinal walkability data can be used to understand regional variations in macro-level neighbourhood walkability over time, which is important for regional authorities like Metro Vancouver that are committed to growth plans that emphasize walkable communities but have no jurisdiction over land use decisions. While walkability indices do not capture many important measures of walkability like road safety and vibrancy, using them to measure how large areas are changing over time could be used to understand how municipal development patterns are tracking towards broader regional policy goals, and investigate the social implications of those policy goals.

Walkability is an essential resource for many persons with mobility issues or those who do not have access to a car. The findings of this paper suggest that walkable neighbourhoods are a resource that is not equally accessible by all residents, that people who might need walkable environments the most might have unequal access to them. In addition to being a spatial justice issue, gentrification of highly walkable areas may diminish the benefits of walkable neighbourhoods if the persons moving into them have the means and desire to continue to travel by car, while those who benefit the most from walkable neighbourhoods become increasingly unable to afford to live in them and must instead relocate to the car-dependent suburbs.

Understanding how social and physical aspects of the built environment influence each other is important, especially in a region facing an enduring affordability crisis. The Metro Vancouver region and many of its member municipalities are emphasizing walkable neighbourhoods on their urban planning agendas as a means of meeting congestion and air quality targets, and densification is essential in accommodating the additional 1 million new residents the region it is expected to welcome over the next three decades. As the Metro Vancouver region continues to invest in walkable communities, it is important to consider whether the strategies deployed to operationalize the region's policy goals are serving the regions diverse populations and how changes in built and social neighbourhood trajectories are connected.

13. Appendix C: Community Design Characteristics – Greenspace: How Does Neighbourhood Walkability Relate to Greenspace Exposure, Park Access, and Social and Material Deprivation?

13.1.1. Introduction

Neighbourhood factors do not act independently; rather, they all affect one another collectively impacting residents. There is extensive literature examining the impacts of the built and natural environment on engaging in health behaviours and human health outcomes. Along with other environmental exposures, neighbourhood walkability, and greenspace exposure and access have been linked to many health behaviours and health outcomes (Frank et al., 2010; Glazier et al., 2014; Kardan et al., 2015; Markevych et al., 2017; Twohig-Bennett & Jones, 2018). Several pathways have been proposed to explain the positive impact of access and exposure to greenspace, such as mitigation of harmful exposures (e.g., noise, air pollution and heat), providing increased restoration, and by increasing health promoting behaviours (e.g., social interaction and physical activity) (Markevych et al., 2017). The predominant pathway by which neighbourhood walkability is theorized to improve human health and wellbeing, is through increasing physical activity and reducing sedentary time (Frank et al., 2007). Adjusting for socioeconomic factors in this analysis is important since those effects can modify health outcomes in relation to greenspace accessibility.

Several previous studies have looked at both neigbourhood walkability and greenspace exposure. In general, neighbourhoods which are highly walkable tend to have a lower overall exposure to greenspace (typically measured by NDVI). This pattern may be due, at least in part, by the fact that the characteristics of a walkability area (e.g., sidewalk network, intersection density and building density – for residential units, commercial land uses and land use mix) require land to be developed, and therefore often reduce the maximum amount of vegetation possible in the area. On the other hand, park count (e.g., the number of parks which are present and/or accessible in an area) tends to be the greenspace metric which more closely relates to walkability (Shuvo et al., 2021).

There are also a number of mutual confounding factors which complicate the relationship between green and walkable neighbourhoods and health, specifically neighbourhood self-selection and household socio-economic status (SES). Individuals who place a greater importance on engaging in outdoor activities, such as leisure and transport walking, may forgo other housing criteria to live in walkable areas with greater access to greenspace (Dendup et al., 2019; Heinen et al., 2018). In addition, residential areas with desirable amenities, such as access to greenspace and increased walkability tend to be associated with higher housing costs. Therefore, it is vital to acknowledge and attempt to consider household SES, as this may otherwise distort the apparent relationship between positive neighbourhood characteristics and improved individual health outcomes (Adler & Ostrove, 1999).

Previous work has examined both the relationship between neigbourhood level deprivation and health, and the spatial relationship of built and natural environment (specifically walkability and NDVI) in high and low material deprivation neighbourhoods. However, to date, less work has looked at how other greenspace metrics relate to walkability, and how these neighbourhood characteristics are associated with both social and material deprivation in Metro Vancouver.

13.1.2. Material and Social Deprivation Index

Local area deprivation was measured using the 2016 Material and Social Deprivation Index (MSDI) using data collected from the Canadian National Household Survey (NHS). The NHS replaced the long form census in 2011, to collect more comprehensive data on Canadian citizens and has been sent to 30% of Canadian household every 5 years to correspond with the short form census. This index uses a total of 6 measures to quantify the material and social deprivation at the dissemination area geographic level. Social deprivation is comprised of three measures of the population aged 15 and older: the proportion of individuals living alone, proportion of lone parent families, and proportion of separated, divorced, or widowed individuals. Material deprivation is also comprised of three measures: average income, the proportion of individuals without a high school diploma, and the proportion of employed individuals (Institut National de Sante Publique du Quebec, 2017).

13.1.3. Statistical Analysis

To measure correlations, each greenspace metric, walkability, and social and material deprivation variables outlined above were joined by unique 6-digit postal code. The values were then compared at the 400m and 1000m distances for both the circular and network buffers. Correlation matrices were created, for the 400m and 1000m circular and network buffers, using the “Hmisc” package (Harrell Jr, 2021). To display the series of relationships heatmap visualizations were created using the “corrplot” package (Wei & Simko, 2021). All analysis were preformed using R version 3.6.1 (R Core Team, 2019).

13.2. Results

13.2.1. Comparison of Walkability and Greenspace Metrics

The same general patterns emerged at both the 1000m and 400m buffers sizes (apart from the relationship between park count and walkability), but with stronger relationships found in the 1000m buffers compared to 400m. Walkability was negatively associated (from weak to moderate) with postal-code level proportion of total green land cover type (400m r = -0.43; 1000m r = -0.55; p < .01), NDVI (400m r = -0.21; 1000m r = -0.47, p < .01), and tree canopy (400m r = -0.27; 1000m r = -0.33, p < .01) . The relationship between park count and walkability shifted from weakly negative (400m r = -0.04, p < .01) to weakly positive (1000m r = 0.07, p < .01).

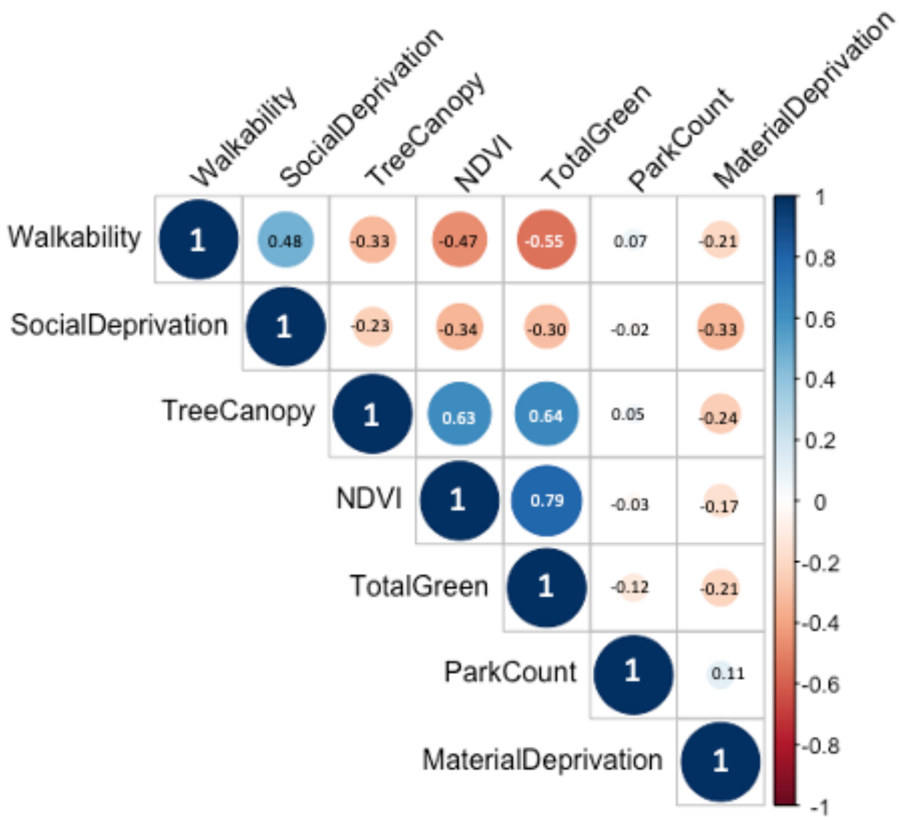


Figure 13-1: Pearson correlation coefficients between walkability and greenspace metrics for 1000m network buffers

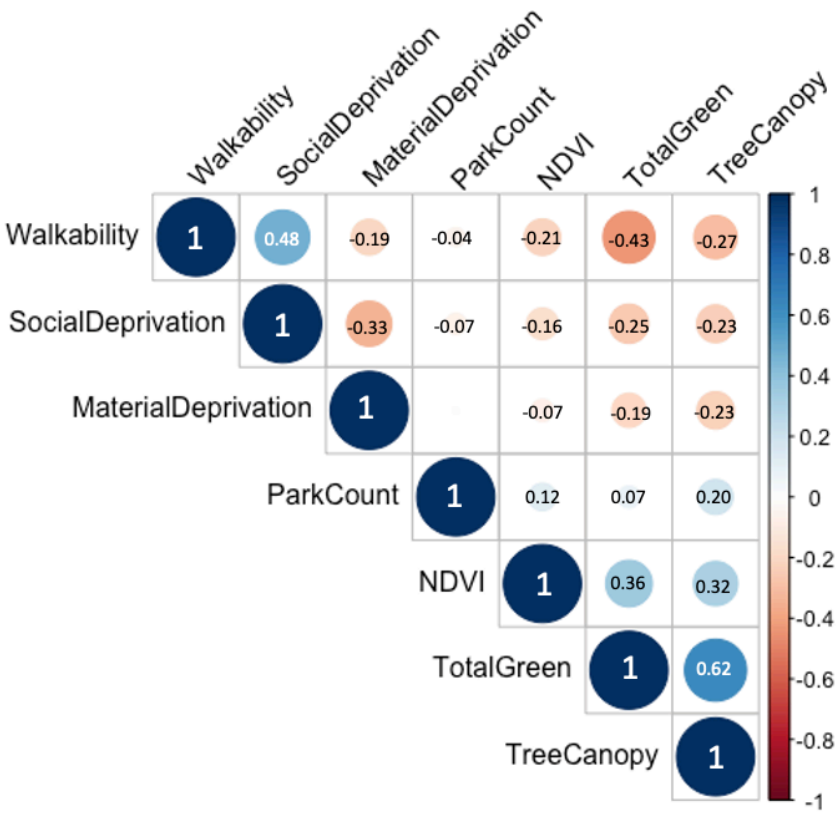


Figure 13-2: Pearson correlation coefficients between walkability and greenspace relationships for 400m network buffers

13.2.2. Neighbourhood Social and Material Deprivation, Walkability and Tree Canopy

Social and material deprivation were negatively correlated (1000m r = -0.33; 400m r = -0.33, p < .01). Walkability was positively associated with social deprivation (1000m r = 0.48; 400m r = 0.48, p < .01), while walkability has a weak inverse relationship with material deprivation (1000m r = -0.21, p < .01). Tree canopy was negatively related to both social (1000m r = -0.23, 400m r = -0.23, p < .01) and material deprivation (1000m r = -0.24, 400m r = -0.23, p < .01).

13.3. Discussion

Park count was weakly associated with walkability, with this negative association (r = -0.04, $p < .01$) at the 400m buffer distance, shifting to a positive relationship at the 1000m buffer distance (r = 0.07, $p < .01$). All other measures of greenspace (total green land cover, NDVI and tree canopy cover) were negatively associated with walkability. In this study area, social and material deprivation were moderately negatively associated, which supports previous research suggesting that these two measures should be considered separately rather than as a composite "deprivation" index (Pampalon et al., 2012). Walkability was positively correlated with social deprivation, indicating that neighbourhoods with greater social deprivation tended to be more walkable in this study area. All greenspace metrics were negatively correlated with both social and material deprivation (except for no statistically significant relationship between park count and material deprivation at the 400m distance, and a weak positive correlation between these two variables at the 1000m distance), indicating that in general neighbourhoods with more social and material deprivation also tended to have less greenspace. The relationship between park count and social and material deprivation was weak, indicating that the number of parks in an neighbourhood was not strongly related to the level of deprivation. Yet, these more deprived areas may be less green overall.

These findings are consistent with previous works, which found that overall greenspace and walkability tend to have a moderate negative relationship. Previous work has found that neighbourhoods with the highest NDVI values tended to be more car-dependent, whereas the most walkable neighbourhoods have lower average NDVI (Shuvo et al., 2021). Similar relationships (-0.6) between walkability and NDVI were seen previously in Vancouver, and negative correlations (-0.2 to -0.6) have been reported in other US cities (San Diego and Seattle) and in other Canadian cities (Clark et al., 2017; Marquet et al., 2020; Shuvo et al., 2021).

The use of multiple greenspace metrics to determine associations between walkability and greenspace in this paper is novel, as typically only NDVI and/or park count have been used. In addition, this work compares four commonly used greenspace metrics, a walkability index, and social and material deprivation calculated from data collected in either 2014 or 2016, reducing temporal mismatch which may otherwise influence the association between these measures.

Due to the scope of this analysis, no health outcome data has been included, which would allow for a richer analysis of how these neighbourhood built and natural environment and local area social and material deprivation related to health outcomes. Additionally, longitudinal data on these neighbourhood features would allow for analysis of whether changes to the built and natural environment (e.g., additional greenspace or improved walkability) would in turn impact the local area social and material deprivation. This current descriptive cross-sectional analysis only suggests relationships between these variables.

A larger limitation inherent in the study of neighbourhood characteristics and health, is the potentially confounding effect of individual income or wealth. Although local area or individual income, or other measures of material deprivation or affluence, can be controlled, it is virtually impossible to disentangle these variables from other desirable built and natural environment features which tend to be represented in wealthier neighbourhoods. Individuals with higher incomes or more wealth, are more able to self-select their residential neighbourhood, based upon factors other than just housing costs.

13.4. Implications

Future work should consider how postal-code level walkability, greenspace exposure and deprivation relate to health outcomes. Additionally, these measures can be tracked longitudinally to better understand potential causal relationships. The finding that areas with greater social and material deprivation tend to be associated with lower greenspace, indicate that these areas may benefit from investments in additional greenspaces. The identification of neighbourhoods with higher material deprivation, low walkability, and low greenspace, should be prioritized by urban planners and decision makers as possible locations for additional greenspace allocation. In already developed areas where adding large park spaces or dramatically altering the build environment may be impossible to quickly implement, more micro-scale pedestrian and green infrastructure investments may be more feasible. In areas with greater material deprivation and limited greenspace, it may also be important to consider the potential impacts on land values associated with incorporating additional greenspaces, and to attempt to reduce any displacement of existing residents. Future work may also strive to better understand the role of smaller scale greenspace investments and the associated impacts of resident health, which may support decision makers in determining how to best allocate greenspace throughout a city or region.

14. Appendix D: Health Impacts - Full Article - Longitudinal Associations Between Walkability and Incident Obesity, Hypertension, and Type 2 Diabetes Among Adults in Vancouver, Canada

14.1. Background

Obesity and related diseases continue to adversely impact health and economic indicators across low, middle, and high income countries (Shekar & Popkin, 2020; World Health Organization (WHO), 2016). The prevalence of obesity worldwide has tripled in the last 50 years and is responsible for nearly 3 million premature deaths annually (World Health Organization (WHO), n.d.). Overweight and obesity are linked to increased risk of numerous chronic conditions including type 2 diabetes mellitus (T2DM) and high blood pressure (HBP), which are leading causes of cardiovascular disease and premature mortality globally (Leon & Maddox, 2015; Mills et al., 2020).

Insufficient physical activity (PA) is one of the primary causes of these preventable diseases (*Facts about Physical Activity| CDC*, n.d.) and the prevalence of adults who do not meet physical activity guidelines remain low despite concerted global public health efforts (World Health Organization (WHO), 2022). The World Health Organization's Global Action Plan on Physical Activity recommends policies and infrastructure to encourage active (i.e. non-motorized vehicle) modes of travel for everyday trips, which has been highlighted as one of the best investments to meaningfully increase population-level PA (Giles-Corti et al., 2016; Global Advocacy for Physical Activity (GAPA) the Advocacy Council of the International Society for Physical Activity and Health (ISPAH), 2011; World Health Organization (WHO), 2018, 2022).

Living in walkable environments has been linked to significantly higher levels of PA and active travel across multiple age groups (Carlson et al., 2017; Cerin et al., 2017; L. Frank et al., 2016; Grasser et al., 2012; J. Sallis et al., 2016). Research has shown several macro-level, built environment features support walkability including, having a mix of land uses in close proximity (i.e. destination diversity), greater residential density, retail floor area ratio, and a highly connected road network (L. D. Frank et al., 2005; Saelens & Handy, 2008). Among adults, there is growing evidence linking GIS-measured walkability to lower prevalence of obesity and metabolic disorders. Several recent reviews show generally consistent inverse relationships between walkability and body weight or obesity, hypertension and diabetes (S. Barbosa et al., 2019; Chandrabose, Cerin, et al., 2019; L. D. Frank et al., 2022; Jones et al., 2021; J. Sallis et al., 2016; Tarlov et al., 2020a), though findings have been mixed. Obesity is by far the most studied of these outcomes and most research to date has been cross-sectional. Longitudinal studies have commonly utilized a single baseline walkability measure with repeated health measures over time. This paper aims to contribute to our understanding of temporal relationships between longitudinal, objectively measured walkability and reported health outcomes.

Using data from an observational, longitudinal cohort in Canada, this study investigated associations between change in objectively-measured walkability and incident obesity, HBP, and T2DM. We hypothesized that walkability would be inversely related to odds of becoming obese or starting treatment for HBP or T2DM at follow up. In secondary analyses, we additionally studied whether relationships differed across demographic characteristics, including sex, age, and income.

14.2. Methods

14.2.1. Analytic sample

The current study used data from the British Columbia Generations Project (BCGP), the largest health study in British Columbia. Details have been published elsewhere but, in brief, BCGP prospectively follows a cohort of nearly 30,000 adults from 35 to 69 years of age (Dhalla et al., 2019). This analysis includes data only from participants residing in the Metro Vancouver and Fraser Valley Regional Districts to maximize potential change in walkability over time (n=12,181). Between 2009 and 2013, participants were recruited to complete baseline questionnaires on health, lifestyle factors and medical histories and roughly half of the full sample had physiological measures collected in person at an assessment center. From 2016 to 2019, participants were invited to complete follow-up surveys on health and lifestyle factors, with approximately three-quarters of the original sample contributing data. The Behavioral Research Ethics Board of the University of British Columbia approved this study (H17-00648).

14.2.2. Exposure variable

GIS-based walkability index: Participant-level walkability was assessed using a validated composite index which includes four built environment features: land use mix ((LUM) diversity of destinations), intersection density ((IDENS) street connectivity), net residential density ((NRD) housing density), and commercial floor-to-area ratio ((CFAR) ratio of floor area to lot size) (L. D. Frank et al., 2010a). A walkability score was created for each postal code which, on average, covers roughly 19 Canadian households and has been shown to provide acceptable positional accuracy, especially in urban areas (Khan et al., 2018; Pinault et al., 2020). The index was applied to a 1km road network buffer from participants' postal code centroid. Participants provided their residential history since childhood. An average of each walkability component feature was calculated for participants' residential locations from 2000-2006 (baseline) and 2012-2016 (follow up). We created the baseline and follow up walkability indices by calculating z-scores for each of the 4 components (LUM, IDENS, NRD, CFAR) using 2006 mean and standard deviations for the Vancouver population center to exclude rural hinterlands (*Statistics Canada*, n.d.). Standardizing to baseline regional walkability provides a measure of how individuals' walkability compares to the region and how it has changed over time. Change in walkability was the sum of zCFAR + zLUM + zIDENS + zNRD at follow up minus the sum in baseline. We additionally quintiled the change in walkability score to explore the relationship between walkability and the outcomes of interest in more depth.

14.2.3. Outcome Variables

Obesity: At baseline, a subset of participants (n=8,100) had height and weight measured at an assessment center, otherwise, self-reported height and weight from the health questionnaire were used (n=3,696). At follow up, all data were self-reported. BMI was calculated as the weight in kilograms divided by the height in metres squared and a binary obesity variable was created (BMI ≥30 or BMI <30). Incident obesity was defined as shifting from not obese at baseline to obese at follow up.

Hypertension: At both baseline and follow up, participants were considered to have prevalent hypertension if they reported currently being treated for high blood pressure or hypertension. Those not treated for hypertension at baseline and treated at follow up were considered to have incident hypertension.

Diabetes: At baseline, participants were considered to have type 2 diabetes if they reported being currently under treatment for diabetes and having been diagnosed with type 2 diabetes. At follow up, participants reported whether they were currently under treatment for type 2 diabetes. Incident T2DM was defined as a change from not being treated at baseline to currently being treated for at follow up.

14.2.4. Covariates

Participant demographics were collected through the health and lifestyle questionnaire and included age, male/female sex. Racial and ethnic descent was classified as "White or European", "Some other descent", or "Unknown". Baseline income was dichotomized into "≤74,999" or "≥$75,999", to approximate above or below median income in the Vancouver area during baseline data collection. We also adjusted models for the length of time (in years) between the baseline and follow up assessment.

14.2.5. Statistical analysis

Descriptive statistics compared baseline participant characteristics across change in walkability quintiles using ANOVA for continuous and χ^2 for categorical variables. We used mixed effects regression models to assess associations between change in walkability (as a continuous variable) with binary incident obesity, T2DM, and HBP status, in separate models. We also modeled change in obesity status by quintiled change in walkability. Mixed model analyses allow for missing observations in studies with repeated measures, avoiding bias associated with complete case analysis (Gabrio et al., 2022). To account for non-independence of repeated measures, we included participant ID as a random effect. We assessed clustering by Forward Sortation Area (the geographical unit designated by the first 3 digits in Canadian postal codes) and found it accounted for less than 1% of total variance so did not include it in models. All models adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments. We conducted a sensitivity analysis including only those with self-reported height and weight data at both assessments to test the robustness of results. We additionally explored associations within individual subgroups, including sex (female/male), age (above/below 60 years), and baseline income (above/below $75,000). All analyses were conducted in Stata Version 16.1 (StataCorp, College Station, TX).

14.3. Results

14.3.1. Descriptive statistics

We included those participants with walkability data at both time points (N=9,932). The time between study assessments ranged from 2.7 to 9.3 years, with a mean 5.5 years. At baseline, participants were on average 55 years of age, and nearly 70% were female. The majority (80%) were White or of European descent, and roughly 60% had an income over $75,000 CAD. Approximately 16% of the sample were obese, and 12% and 2% were being treated for hypertension and T2DM at baseline, respectively. There were differences in age, length of follow up and education level across change in walkability quintiles, though no obvious pattern was discernible. We did not observe any differences in baseline obesity, HBP or T2DM across change in walkability groups. As expected, those living in the most walkable neighourhoods at baseline had the least change in walkability between study assessments.

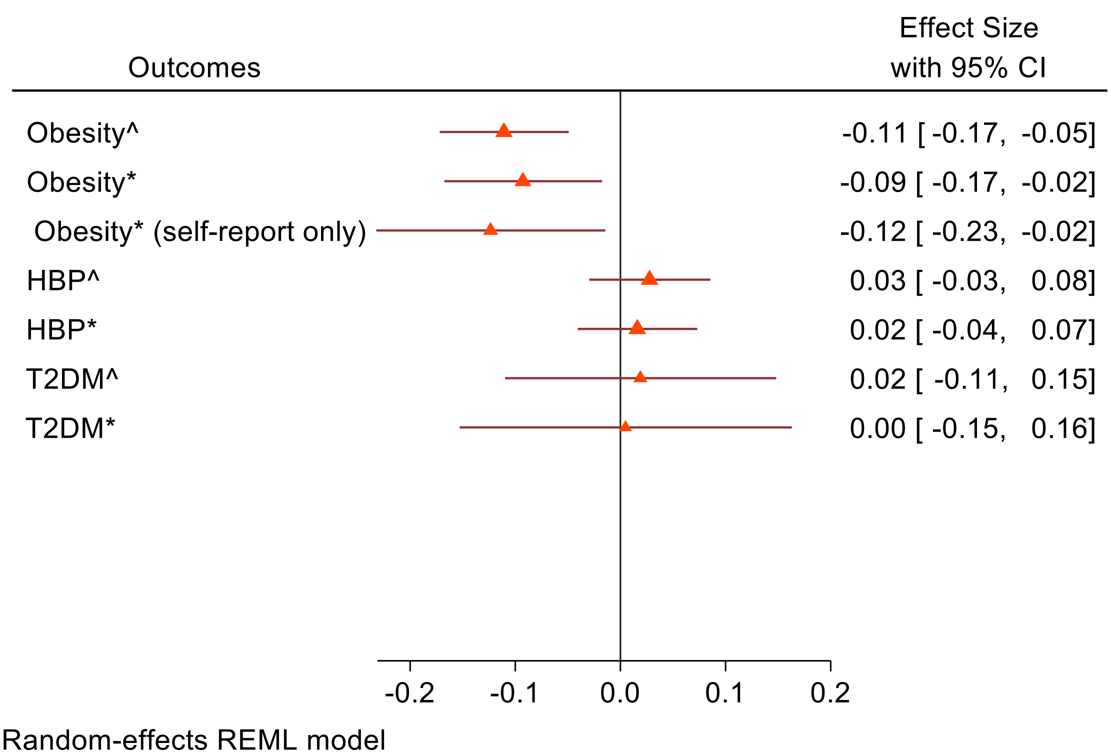
Table. 1 Baseline characteristics of the study sample by change in walkability quintiles

Baseline Descriptives	Total Sample	Change in walkability index from 2006 to 2016 (quintiles)					p-value
	N=9,932	Q1 n=1,987	Q2 n=1,986	Q3 n=1,987	Q4 n=1,986	Q5 n=1,986	
	n(%) or mean(SD)						
Length of follow up (years)	5.5 (1.2)	5.66 (1.27)	5.51 (1.19)	5.52 (1.18)	5.43 (1.20)	5.61 (1.23)	**0.00**
Age (years)	55.0 (9.0)	52.2 (9.5)	55.00 (8.8)	56.30 (8.6)	56.20 (8.4)	55.40 (8.9)	**0.00**
Female	8,456 (69.4)	1,373 (69.1)	1,362 (68.6)	1,389 (69.9)	1,371 (69,0)	1,381 (69.5)	0.92
White/European descent	7,902 (79.6)	1,597 (80.4)	1,542 (77.6)	1,595 (80.3)	1,604 (80.8)	1,564 (78.8)	0.04
Bachelor's degree or above	4,821 (48.8)	1,053(53.3)	962 (48.7)	945 (47.8)	890 (45.1)	971 (49.1)	**0.00**
Income >=$75,000	5,631 (60.9)	1,165 (61.7)	1,153 (62.8)	1,095 (59.6)	1,124 (61.4)	1,094 (58.9)	0.09
Obese (BMI ≥30)	1,530 (15.9)	307 (16.0)	283 (14.7)	315 (16.4)	322 (16.8)	303 (15.7)	0.45
Currently treated for hypertension	436 (12.2)	84 (10.4)	81 (11.8)	87 (13.0)	83 (13.2)	101 (13.1)	0.40
Currently treated for diabetes	74 (2.1)	17 (2.1)	10 (1.5)	10 (1.5)	14 (2.2)	23 (3.0)	0.24
Baseline walkability index (z-scores)	0.8 (3.2)	3.1 (3.3)	0.6 (2.8)	0.1 (2.8)	-0.10 (2.7)	0.1 (3.1)	**0.00**

14.3.2. Model Results

Odds ratios and confidence intervals for all models are presented in Table 2, whereas the figures show the effect size and 95% CIs. Change in walkability was inversely associated with incident obesity in both unadjusted and adjusted models (Figure 1). In adjusted analyses, a 1-unit increase in the walkability change score was associated with an 9% reduction in odds of becoming obese (OR=0.91, 95% CI 0.85, 0.98). In those with self-reported height and weight data only, there was a slightly larger decrease in odds of incident obesity (OR 0.88, 95% CI 0.79,0.98). Change in walkability was not associated with incident HBP or T2DM in unadjusted or adjusted models.

Figure 1. Incident obesity, HBP and T2DM

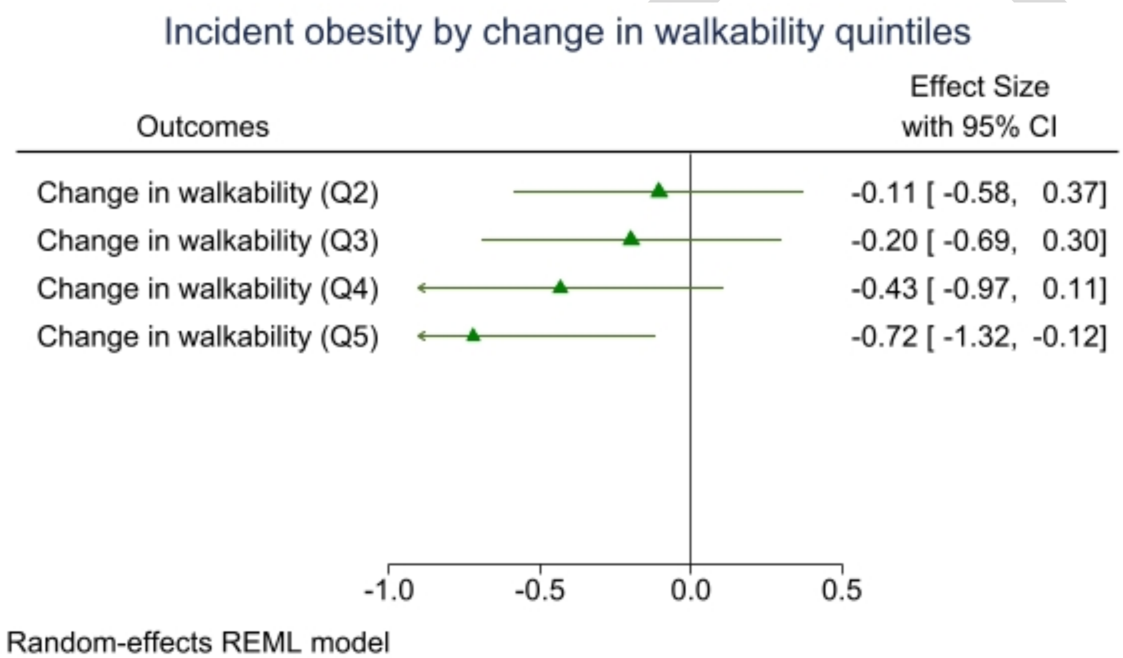


^Unadjusted models

*Adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments.

Figure 2 shows the association between change in walkability quintiles and incident obesity. Compared to quintile 1, those in quintile 5 had a 51% reduction in odds of becoming obese (OR=0.49, 95% CI 0.27, 0.88). Confidence intervals overlapped the null value for other quintiles, though the reduction in odds of incident obesity suggested a graded inverse association with greater change in walkability.

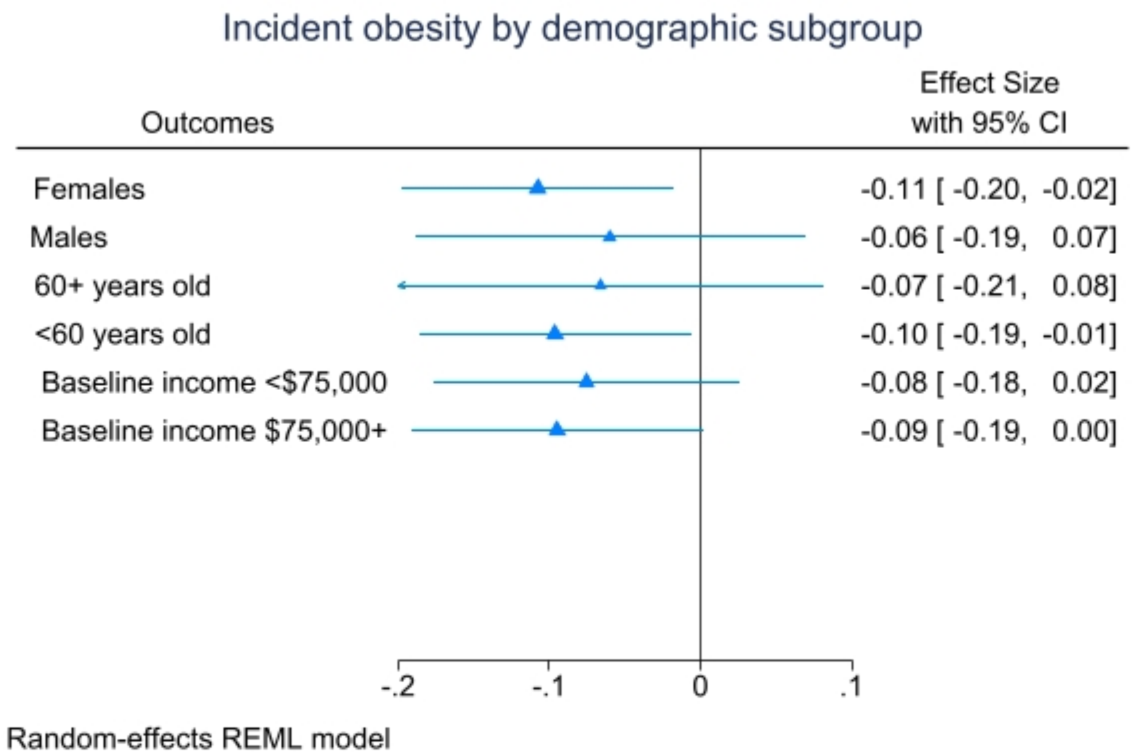
Figure 2. Incident obesity by change in walkability quintiles



All models adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments.

Change in walkability was associated with an 10% reduction in the odds of becoming obese in females (OR=0.90, 95% CI 0.82,0.98) , while results among males were imprecise (Figure 3). A similar reduction in odds of obesity at follow up was observed among those who were less than 60 years old at baseline (OR=0.91, 95% CI 0.83,0.99), while this relationship was imprecise in older adults. Results by income were imprecise though suggestive that higher household income was associated with a slightly greater reduction in odds of obesity (OR=0.91, 95% CI 0.83, 1.0) compared to the lower income group.

Figure 3. Incident obesity by demographic subgroups



All models adjusted for sex, age, racial/ethnic descent, baseline income, and length of time between assessments.

Table 2. Odds ratios, p-values, and 95% confidence intervals for models

	Odds Ratio	p-value	95% CI	95% CI
Becoming obese^{+}	**0.895**	**0.000**	**0.843**	**0.951**
Becoming obese*	**0.911**	**0.014**	**0.847**	**0.981**
Becoming obese (self-report only)*	0.884	0.025	0.794	0.984
Treated for HBP^{+}	1.028		0.972	1.088
Treated for HBP*	1.016	0.571	0.961	1.074
Treated for T2 Diabetes^{+}	1.019	0.771	0.897	1.158
Treated for T2 Diabetes*	**1.005**	0.952	0.859	1.175
Incident obesity by change in walkability quintiles				
Quintile 2	0.899	0.663	0.558	1.449
Quintile 3	0.820	0.431	0.500	1.344
Quintile 4	0.649	0.115	0.379	1.111
Quintile 5	**0.486**	**0.018**	**0.268**	**0.884**
Incident obesity by age				
60 and over	0.936	0.377	0.809	1.084
Under 60	**0.908**	**0.035**	**0.830**	**0.993**
Incident obesity by sex				
Female	**0.898**	**0.019**	**0.821**	**0.982**
Male	0.942	0.360	0.828	1.071
Incident obesity by income				
Baseline income <$75,000	0.927	0.141	0.839	1.025
Baseline income $75,000+	**0.910**	**0.052**	**0.827**	**1.001**

14.4. Discussion

We found change in walkability was associated with reduced odds of incident obesity in both unadjusted and adjusted models. The inverse relationship was strongest among women, adults 60 years and younger, and those with higher incomes. The odds of becoming obese decreased with greater change in walkability over time. While estimates were imprecise except for comparisons between the largest and smallest change in walkability quintiles, the pattern was suggestive of an inverse, dose response relationship with obesity. We did not observe a relationship between walkability and incident HBP or T2DM. The follow up period may have been insufficient to observe changes in these longer-term, chronic disease outcomes. Much of the research on walkability and health outcomes has been cross-sectional or utilized a single baseline measure of walkability with repeated health outcomes (Chandrabose, Rachele, et al., 2019a; Lai et al., 2023). The current study expands the longitudinal evidence supporting urban design as an effective approach to reducing the significant public health burden of obesity and obesity-related conditions.

Our longitudinal analyses builds on a prior cross-sectional study of this BCGP cohort which found those living in the most walkable neighourhoods had significantly lower odds of obesity compared to those living in the least walkable neighourhoods (L. D. Frank et al., 2022). Research evidence generally supports an inverse relationship between GIS walkability factors and indices with obesity (S. Barbosa et al., 2019; Chandrabose, Rachele, et al., 2019b; Fazeli Dehkordi et al., 2022; Zhang et al., 2023), though inconsistencies have been documented (Grasser et al., 2013; Mackenbach et al., 2014). Studies are largely cross-sectional (J. P. D. A. S. Barbosa et al., 2019; Mackenbach et al., 2014) or rely on a single walkability measure (Chandrabose, Rachele, et al., 2019a). Neither the CARDIA nor SOF studies, both of which used longitudinal measures of walkability, found associations with BMI or obesity risk (Braun et al., 2016; Michael et al., 2013). An analysis of participants who relocated in the MESA study reported a small decrease in BMI among those moving to a more walkable neighourhood (as measured by Walk Score), though no relationships with BMI categories (Hirsch et al., 2014). Tarlov et al., had similar findings to ours with an inverse relationship between walkability and weight outcomes in younger age groups (Tarlov et al., 2020b). However, King et al. found living in more walkable neighourhoods to be associated with lower BMI in older adults over the age of 65 (King et al., 2011b). Other health and mobility factors are likely to play a role in physical activity and weight status in older adults that may explain mixed results with walkability in this age group. There is an established inverse association between income and body weight and some evidence that income may modify the impact of walkability on weight outcomes (T. J. Kim & Von Dem Knesebeck, 2018; J. F. Sallis et al., 2009). The longitudinal REGARDS study found duration weighted Walk Score was associated with lower odds of obesity though they didn’t find significant interaction by neighourhood socioeconomic status (I. M. Lang et al., 2022). This difference could be due to use of census versus individually reported income data used in the present study.

Our null findings for hypertension and T2DM deviate from most prior research. Reductions in odds of T2DM of from 12% to 20% have been reported (DenBraver et al., 2018; Dendup et al., 2018; Zhang et al., 2023). A large population study of adults in Sweden reported greater walkability decreased risk of objectively measured T2DM after 4 years of follow up, though associations were no longer significant after adjustment for individual factors as done in the current study (Sundquist et al., 2015). A meta-analysis of studies with longitudinal, objectively measured outcomes found strong evidence of a relationship between walkability and decreased incidence of T2DM and HBP (Chandrabose, Rachele, et al., 2019a). Of note, the strength of the relationship with these outcomes was attenuated when using objective, GIS measures of walkability, rather than perceived environmental measures. A systematic review by Lai et al., found protective effects of walkability and objectively measured blood pressure outcomes in cross-sectional studies, though the results were mixed in studies with longitudinal design (Lai et al., 2023). Our study differs from those reported by Braun et al. where increased walkability after residential relocation was associated with reductions in systolic blood pressure, though not with BMI (Braun et al., 2016). Participants in this study were younger, on average, than the current study and it may be that younger groups may be more susceptible to change from environmental factors and have less medication-controlled conditions. Similar to our findings, analyses of older adults in the MESA study found relationships between walkability and weight in the expected direction, but not with other cardiometabolic risk factors, including blood pressure.

14.4.1. Strengths and Limitations

This study had a large sample size and participants' residential history allowing for longitudinal assessment of GIS-based walkability indicators with an average of 6 years between baseline and follow up assessments. Our walkability index averaged 6 years of residential location data at each time point, thus should give an accurate estimate of participants' walkability exposure. We utilized a street network buffer to define walkability, which is preferable to radial buffers utilized in many studies (REF). The association of walkability with obesity but not with T2DM or HBP may indicate the follow up time was insufficient to detect these longer-term outcomes, though our time in study was similar to studies reporting significant associations. We did not have follow up physical activity data so were unable to assess the impact of walkability on this mediating variable. We were not able to control for residential self-selection, which may be related to both the exposure and outcomes studied (L. D. Frank et al., 2007). A further limitation with this study was the use of self-reported data for health outcomes which could result in misclassification. While self-report is a reasonable indicator among those under treatment for these conditions, some in the population may be undiagnosed (Burvill et al., 2022; Ng et al., 2013). Studies with both objective and self-reported outcomes have found protective results with HBP and T2DM. While the longitudinal walkability data are useful in exploring causal relationships with health outcomes, interpretation is challenging. Our exposure measure was somewhat imprecise in that a similar lack of change would apply equally to those who remained in highly walkable or unwalkable neighbourhoods.

14.5. Conclusions

This study provides longitudinal evidence on the benefits of neighbourhood walkability on reduced incidence of obesity in urban dwelling adults. Our findings do not support relationships with downstream health outcomes, though results may be limited by self-reported blood pressure and diabetes data and insufficient follow up. Longer monitoring would help elucidate this relationship and the length of exposure required to modify risk. As obesity remains a significant public health concern, policies and investments to support walkable communities are justified.

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15. Appendix E: Health Impacts - Full Article - Multifaceted Impacts of Green Space and Walkability on Mental Health: Depression and Anxiety in Focus

15.1. Background

Mental health refers to the overall state of an individual's well-being and their capacity to positively impact the community, while effectively managing the everyday challenges of stress ((WHO), 2022). The term "mental health conditions" encompasses mental disorders, psychosocial disabilities, and other mental states characterized by considerable distress, impaired functioning, or a potential risk of self-harm (Perrino et al., 2019). Mental disorders have a significant impact on the global burden of disease, affecting communities and people of all ages in both high and low-income countries (WHO (World Health Organization), 2018).

15.1.1. Problem statement:

The World Health Organization (WHO) states that one out of every four individuals will encounter a mental health issue at some stage during their lifetime (Sayers, 2001). During 2019, approximately 970 million individuals, which accounts for 1 in every 8 people worldwide, were experiencing a mental disorder, with anxiety and depressive disorders being the most prevalent conditions (Núñez-González et al., 2020). Mental health is a matter of concern for a substantial number of Canadians as well, as it is estimated that 1 in 5 Canadians will experience some sort of mental health condition during their lifetime (Lesage et al., 2012) and the prevalence of Canadian individuals living with mental illness is expected to rise by 31% in the next three decades (Smetanin et al., 2011).

Mental disorders not only compromise individual well-being but also have substantial socio-economic repercussions, including increased healthcare costs and loss of productivity (Kessler et al., 2009; WHO (World Health Organization), 2017). Research indicates that mental illness ranks among the most expensive health conditions in Canada (Smetanin et al., 2011). Approximately $14.3 billion of public funds were allocated to mental health services and supports in 2007-2008, constituting 7.2% of the overall government health expenditure (Jacobs et al., 2010). The global cost of mental disorders was estimated to be 2.5 trillion USD in 2010, and these costs could rise to six trillion USD by 2030 (Bloom et al., 2012).

Depression stands as a significant public health issue affecting 344 million individuals globally in 2019 ("GBD Mental Disorders Collaborators. Global, Regional, and National Burden of 12 Mental Disorders in 204 Countries and Territories, 1990–2019: A Systematic Analysis for the Global Burden of Disease Study 2019," 2022). Based on the 2012 Canadian Community Health Survey (CCHS), approximately 4.7% of Canadians aged 15 and above exhibited symptoms consistent with a diagnosis of major depression (C. Pearson et al., 2013a). The research indicates that depression is estimated to affect approximately 10.8% of the global population throughout their lifetime (Lim et al., 2018). While it is estimated that about 11.3% of Canadians experienced a major depressive episode at some point in their lives (C. Pearson et al., 2013b).

Depression is identified by symptoms such as a loss of interest or enjoyment in activities, decreased energy levels, and depressed mood (World Health Organization, 2017) (2). Depression differs from normal mood fluctuations and daily emotional responses. During a depressive episode, individuals experience persistent feelings of sadness, irritability, or emptiness, along with reduced interest in activities, lasting for most of the day, nearly every day, for at least two weeks. Additional symptoms include difficulty concentrating, overwhelming guilt or low self-esteem, a sense of hopelessness about the future, thoughts of death or suicide, disrupted sleep, appetite changes, and persistent fatigue (Perrino et al., 2019).

Anxiety disorders stand as the second most common mental disorders globally, affecting approximately 301 million individuals in 2019 (Núñez-González et al., 2020). These disorders are characterized by intense feelings of fear and worry, accompanied by associated behavioral disturbances. The severity of these symptoms is significant enough to cause either notable distress or substantial impairment in daily functioning (Perrino et al., 2019). In the Canadian context, the prevalence of diagnosed mood and anxiety disorders has shown a notable increase. In 2019, it was estimated that about 4.4 million Canadians, or 14% of those aged 12 and older residing in the provinces, had a diagnosed mood or anxiety disorder. This shows an increase from 3.7 million individuals, or 12%, in

2015. Importantly, this rise has been particularly significant among young adults aged 18 to 34, where the prevalence increased from 13% in 2015 to 17% in 2019 (“Statistics Canada. Canadian Community Health Survey, 2019: Mental HealthStatistics. Canada Catalogue No. 11–001-X,” 2020).

Mental health is influenced by a multifaceted interplay of factors, extending beyond individual characteristics to encompass a range of health determinants. These include elements at the individual, family, community, and structural levels, all of which can either bolster or compromise mental well-being (Perrino et al., 2019; Shen, 2014; *World Health Organization (WHO). Mental Health Action Plan 2013–2020*, 2013). Hirschfeld and Weismann (2002) identified several risk factors for depression, such as being female, having medical illnesses, experiencing early-life trauma, and facing adverse life events. These risk factors encompass various individual-level attributes, underscoring the significance of investigating environmental risk factors as well in understanding this major public health concern (Hirschfeld & Weissman, 2002).

The built environment encompasses the human-made infrastructure and arrangement, which includes urban green spaces, road and pedestrian networks, as well as residential and commercial establishments (J. F. Sallis et al., 2012). It plays a role in influencing health through factors such as dietary choices, physical activity, circadian rhythm, hormonal changes, air pollution, and other environmental exposures (Bird et al., 2018; L. D. Frank et al., 2019; Koren & Butler, 2006). One review revealed that higher population density, greater land-use mix, and increased availability of retail goods were associated with higher depressive symptoms, while walking-friendly neighbourhoods were linked to lower depressive symptoms in adults 65 years old or above (Julien et al., 2012). On the other hand, another review found that measures of the built environment showed more consistent associations with depression compared to socio-economic factors (Mair et al., 2008). Renalds and colleagues further argued that the built environment could be a fundamental asset in promoting general health and wellness (Renalds et al., 2010).

Among the various built environment factors, walkability has been hypothesized to have a considerable impact on mental health outcomes (Sugiyama et al., 2008). Walkability refers to the convenience and attractiveness of walking in a given environment, often assessed through a Walkability Index that includes parameters such as street connectivity, density, and land-use mix (L. D. Frank et al., 2019). Walkability indices have been found to be linked with physical activity (Camhi et al., 2019; Twardzik et al., 2019).

Nevertheless, there have been limited studies examining the relationship between walkability and depression or anxiety, and the results have been inconclusive.

Multiple research studies have indicated that besides built environment, components of natural environment such as green spaces have the potential to enhance overall well-being (Grant et al., 2012), self-assessed health status (Maas et al., 2008; R. Mitchell & Popham, 2007), promote increased physical activity levels (Mytton et al., 2012; Toftager et al., 2011), reduce morbidity, and increase life expectancy (Maas et al., 2009). Moreover, access to green areas has been associated with greater satisfaction regarding housing, jobs, and life perspectives (Kaplan & Kaplan, 1989). Furthermore, access to green areas is a factor that has been gaining attention for its potential impact on mental health and well-being too (Beyer et al., 2014; Hartig, 2008; R. J. Mitchell et al., 2015). Studies have linked environmental greenness to reduced symptoms of depression, stress, and anxiety in adult populations (Beyer et al., 2014; Groenewegen et al., 2006; Roe et al., 2013). The underlying mechanisms for these effects include attention restoration, reduced rumination, stress reduction, increased physical activity, and improved social contact and support (Bratman et al., 2015; Y. Fan et al., 2011; Roe et al., 2013; Van den Berg et al., 2010). Notably, Mitchell et al. proposed that greater exposure to green spaces could mitigate the negative impacts of income disparities on mental health and mortality, suggesting a viable strategy for tackling health inequalities (R. J. Mitchell et al., 2015; R. Mitchell & Popham, 2008).

The association of built and natural environment with mental health remains an underexplored domain. While some studies have found a positive correlation between increased walkability or green space and reduced levels of depression and anxiety (Beyer et al., 2014; Hartig et al., 2014), the relationships are often not straightforward, and the mechanisms underlying these associations are not fully understood (McCormack & Shiell, 2011). The findings from this study could guide urban planning efforts to focus on the mental health of residents. Given the ongoing global shift towards city living (*United Nations (UN). World Urbanization Prospects 2018*, 2018), using evidence-based strategies to improve mental well-being through changes in the environment is both relevant and crucial.

The primary objective of this study is to investigate the relationship between key elements of the urban environment—specifically, walkability and green space—and clinically diagnosed depression and anxiety. Complementing this, the secondary objective aims to delve into the underlying mechanisms that drive these associations. To accomplish this, we explore how varying levels of walkability and green space correlate with specific symptoms characteristic of depression (e.g., little interest or pleasure in doing things, sleep disturbances) and anxiety (e.g., nervousness, restlessness).

15.2. Methods

15.2.1. Data sources:

The study integrated data from three sources: BC Generations Project (BCGP) (BCGP, 2019), the Canadian Urban Environmental Health Research Consortium (CANUE) (CANUE, n.d.), and the Where Matters: Health & Economic Benefits Study (*Where Matters: Health & Economic Benefits Study*, n.d.). This analysis involve secondary data analysis of the mental health variables from BC Generations Project (BCGP) (BCGP, 2019), along with environmental measures associated with these cohorts from The Canadian Urban Environmental Health Research Consortium (CANUE) (CANUE, n.d.) and the Where Matters project (*Where Matters: Health & Economic Benefits Study*, n.d.).

15.2.2. Green space assessment:

The normalized difference vegetation index (NDVI) is a widely used measure to assess the the health and density of vegetation in an area, and it is derived from satellite imagery. In plants, chlorophyll efficiently absorbs visible light (0.4–0.7 μm) for photosynthesis, while leaves reflect near-infrared light (0.7–1.1 μm). NDVI is calculated by taking the ratio of the difference between reflectance values of near-infrared wavelength and red wavelength of light to the sum of these two measures (Weier & Herring, n.d.). NDVI values fall within the range of -1 to 1, where higher positive values indicate a denser and healthier presence of vegetation (Fong et al., 2018). The NDVI for the residential neighbourhood is derived from the CANUE dataset. The categories applied for NDVI as a categorical variable is obtained from NDVI quintiles. The NDVI levels used are as follow: very low – 1^{st} quintile (0.22,0.316], low – 2^{nd} quintile (0.316,0.39], medium - 3^{rd} quintile (0.316,0.39], high - 4^{th} quintile (0.39,0.48], very high - 5^{th} quintile (0.48,0.81].

15.2.3. Walkability assessment:

The Where Matters Study (*Where Matters: Health & Economic Benefits Study*, n.d.) constructed a walkability index for the Greater Vancouver region in British Columbia, utilizing postal codes. This index was developed by integrating data from different sources, including Statistics Canada (StatsCan, n.d.) and CanMap (*DMTISpatial. CanMap® GIS Data for GIS Mapping Software - DMTI Spatial.*, n.d.), and it is specifically linked to the BCGP cohort, focusing on residential postal codes. In comparison to the CANUE walkability index, the Where Matters index incorporates extra factors to evaluate walkability and has been established for the years 2006, 2011, and 2016, utilizing the following measures:

a) Residential Density: The number of residential units per acre within a neighbourhood.

b) Commercial Density: The area designated for commercial use within a neighbourhood.

c) Land use mix: A measure of the different purposes of land use in a neighbourhood. A higher value indicates even distribution between purposes of land use such as residential, commercial, entertainment, and office development.

d) Street Connectivity: The number of street intersections in a neighbourhood. A larger number of intersections would lead to increased connectivity and movement.

The walkability index used in the current study is the sample standardized walkability index. The categories applied for walkability index as a categorical variable is obtained from walkability index quintiles. The walkability index levels used in the analysis are as follow: very low – 1^{st} quintile [-6.1,-1.86], low – 2^{nd} quintile (-1.86,-0.363], medium - 3^{rd} quintile (-0.363,1.25], high - 4^{th} quintile (1.25,3.03], very high - 5^{th} quintile (3.03,13.8].

Depression and anxiety were evaluated separately as both continuous variables and categorical variables, utilizing a cutoff score of 10 to distinguish between different levels.

Descriptive statistics was used to summarize the characteristics of the study sample, including demographics and relevant variables. Univariate descriptive analysis was conducted to assess the distribution of variables of interest, which includes exposure variables (i.e., NDVI and walkability index), outcome variables (i.e., depression and anxiety), and covariates (i.e., income, education, marital status, health perception, alcohol, smoking, sleep duration, activity category). Continuous variables were analyzed to reveal means, standard deviations, and interquartile ranges, while categorical variables were presented in terms of frequencies.

The study employed bivariate analysis to examine the relationships between exposure and outcome variables, as well as the associations between covariates and both exposure and outcome variables. The selection of appropriate statistical tests, such as the chi-square test, independent samples t-test, or Pearson's correlation, were determined based on the characteristics of the variables under investigation. Complete case analysis was utilized for the statistical analysis. All statistical computations were performed using R version 4.2.2 ((2023), 2019) with a significance level set at $p < 0.05$ for all tests.

We employed generalized linear models for our multivariable analysis. We examined the relationship between green space and depression, as well as anxiety, and also looked at how walkability correlates with these mental health conditions. Logistic regression was used for analyzing relationships with categorical mental health outcomes, while linear regression was applied for continuous mental health scores. This included overall scores as well as individual components of depression and anxiety questionnaires.

as which controls for confounders and risk factors. First, the logistic regression assumptions was checked for separately for each relationship and further considerations made to address possible issues. Second, an unadjusted model was fitted to analyze the relationship of interest. Currently the following potential adjustment variables or risk factors for the outcome variables are identified based on the literature: age, sex, education level, occupation, income, physical activity, sleep pattern, dietary intake, smoking habits, and alcohol intake. Thus, the hypothesized adjustment variables were included in the DAG and the minimal adjustment set was identified. The variables to be adjusted for in the model were selected by backward selection using the Akaike Information Criteria (AIC). Afterwards, a logistic model was fitted and adjusted for the detected adjustment variables and the unadjusted and adjusted odds ratio with 95% confidence intervals were reported. Additionally, the model's goodness of fit was assessed by Area Under the Curve (AUC) from Receiver Operating Characteristics (ROC). A sensitivity analysis was performed to compare the participants with complete data and participants with missing values.

15.3. Results

The characteristics of participants stratified by depression is presented in Table 1. The initial sample collected in this study was 9,238. After removing the participants with missing data, a total of 5,085 participants with complete information were considered for the analysis, of which 213 (4.1%) were categorized as depressed, and 4872 (95.8%) as depressed. The mean age of the overall sample was 60.72 years (SD = 9.08).

The distribution of various sociodemographic, behavioral, and environmental factors was examined between the two groups. The sample was predominantly female, with 67.5% females and 32.5% males. There were no significant gender differences between the two groups in terms of depression ($p = 0.081$). However, marital status showed a significant difference; a higher percentage of depressed individuals were single or separated (32.9%) compared to non-depressed participants (24.8%; $p = 0.010$).

Regarding educational attainment, a higher percentage of depressed participants had education level of equal or below bachelor's degree compared to non-depressed participants (84.5% vs. 77.3%) while non-depressed participants had higher percentage of graduate studies (22.7% vs. 15.5). In terms of income distribution, a significantly higher percentage of depressed participants (27.7%) were in the lowest income bracket compared to non-depressed participants (17.3% vs. 17.3%; $p < 0.001$).

Health perception also differed significantly between the groups. Interestingly, a higher percentage of depressed participants compared to the non-depressed group rated their health excellent (6.6% vs. 1.0%), very good (17.4% vs. 5.0%), good (43.2% vs. 25.3%), and fair (28.6% vs. 45.0%) ($p < 0.001$). Moreover, 37.1% of depressed participants had history of depression compared to 5.0% of non-depressed participants. In terms of alcohol consumption, depressed individuals were more likely to be never drinker (8.9% vs. 5.0%) and former drinker (10.8% vs. 4.6%). In terms of smoking status, depressed participants were more likely to be former (39.4% vs. 36.4%) or current smoker (7.0% vs. 2.6%) compared to non-depressed participants.

Significant differences were also found in sleep duration and physical activity levels. Over half of (52.6%) depressed participants reported getting insufficient sleep (less than 7 hours per day), compared to 27.5% in the non-depressed group. Depressed participants were also less active, with 20.2% falling into the lowest activity category, compared to 11.3% for non-depressed individuals ($p < 0.001$).

The characteristics of participants stratified by anxiety is also presented in Table 1. The mean age differed between the two groups, with participants with anxiety being younger (58.08 ± 9.64 years) compared to participants without anxiety (60.84 ± 9.04 years). Gender distribution also varied significantly between the groups, with a higher percentage of females in anxiety group (76.3%) compared to females without anxiety (67.1%), p = 0.005. Marital status, education, and income did not show significant differences between the two groups.

Similar to depressed participants, participants in anxiety group had better health perceptions than those in non-anxiety group, as evidenced by significant differences across the health perception excellent, very good and good categories (p < 0.001). History of depression was significantly more common in participants with anxiety (32.5%) compared to participants without anxiety (5.1%), p < 0.001. Alcohol consumption and smoking habits were also significantly different between the groups, with a lower number of current drinkers (82.5% vs. 90.3%) and higher number of current smokers (6.1% vs. 2.6%) observed in participants with anxiety.

Sleep duration differed dramatically between the groups, with 52.2% of anxiety group sleeping less than 7 hours per day compared to only 27.5% in non-anxiety group, p < 0.001.

A higher percentage of anxiety group reported lower activity levels (18.0%) compared to non-anxiety group (11.4%), and this was statistically significant (p = 0.009).

Table 1- Characteristics of the study participants (n=5085)

	Level	**Overall**	**Depression**			**Anxiety**		
			No	**Yes**	**p-value**	**No**	**Yes**	**p-value**
N (%)		5085	4872 (95.8)	213 (4.1)		4857 (95.5)	228 (4.5)	

Age (mean (SD))		60.72 (9.08)	60.81 (9.06)	58.58 (9.31)	**<0.001**	60.84 (9.04)	58.08 (9.64)	**<0.001**
Sex (%)	Male	1651 (32.5)	1594 (32.7)	57 (26.8)	0.081	1597 (32.9)	54 (23.7)	**0.005**
	Female	3434 (67.5)	3278 (67.3)	156 (73.2)		3260 (67.1)	174 (76.3)	
Marital_status (%)	Single or separated	1277 (25.1)	1207 (24.8)	70 (32.9)	**0.010**	1213 (25.0)	64 (28.1)	0.329
	Married or living with partner	3808 (74.9)	3665 (75.2)	143 (67.1)		3644 (75.0)	164 (71.9)	
Education (%)	Less than college	683 (13.4)	648 (13.3)	35 (16.4)	**0.035**	645 (13.3)	38 (16.7)	0.138
	College or bachelor's degree	3265 (64.2)	3120 (64.0)	145 (68.1)		3116 (64.2)	149 (65.4)	
	Master's degree or higher	1137 (22.4)	1104 (22.7)	33 (15.5)		1096 (22.6)	41 (18.0)	
Income (%)	< 50K	901 (17.7)	842 (17.3)	59 (27.7)	**<0.001**	851 (17.5)	50 (21.9)	0.223
	(50k - 70k]	951 (18.7)	914 (18.8)	37 (17.4)		912 (18.8)	39 (17.1)	
	(75k-100k]	945 (18.6)	902 (18.5)	43 (20.2)		898 (18.5)	47 (20.6)	
	>= 100k	2288 (45.0)	2214 (45.4)	74 (34.7)		2196 (45.2)	92 (40.4)	
Health_Perception (%)	Excellent	64 (1.3)	50 (1.0)	14 (6.6)	**<0.001**	55 (1.1)	9 (3.9)	**<0.001**
	Very good	281 (5.5)	244 (5.0)	37 (17.4)		248 (5.1)	33 (14.5)	
	Good	1325 (26.1)	1233 (25.3)	92 (43.2)		1236 (25.4)	89 (39.0)	

	Fair	2253 (44.3)	2192 (45.0)	61 (28.6)		2181 (44.9)	72 (31.6)	
	Poor	1162 (22.9)	1153 (23.7)	9 (4.2)		1137 (23.4)	25 (11.0)	
History of major depression (%)	No	4763 (93.7)	4629 (95.0)	134 (62.9)	**<0.001**	4609 (94.9)	154 (67.5)	**<0.001**
	Yes	322 (6.3)	243 (5.0)	79 (37.1)		248 (5.1)	74 (32.5)	
Alcohol (%)	Never	262 (5.2)	243 (5.0)	19 (8.9)	**<0.001**	243 (5.0)	19 (8.3)	**<0.001**
	Former	249 (4.9)	226 (4.6)	23 (10.8)		228 (4.7)	21 (9.2)	
	Current	4574 (90.0)	4403 (90.4)	171 (80.3)		4386 (90.3)	188 (82.5)	
Smoking (%)	Never	3087 (60.7)	2973 (61.0)	114 (53.5)	**<0.001**	2955 (60.8)	132 (57.9)	**0.006**
	Former	1858 (36.5)	1774 (36.4)	84 (39.4)		1776 (36.6)	82 (36.0)	
	Current	140 (2.8)	125 (2.6)	15 (7.0)		126 (2.6)	14 (6.1)	
Sleep_hr (%)	<= 7 hours	1454 (28.6)	1342 (27.5)	112 (52.6)	**<0.001**	1335 (27.5)	119 (52.2)	**<0.001**
	7 - 9 hours	3570 (70.2)	3480 (71.4)	90 (42.3)		3470 (71.4)	100 (43.9)	
	>= 9 hours	61 (1.2)	50 (1.0)	11 (5.2)		52 (1.1)	9 (3.9)	
Race (%)	White	4289 (84.3)	4111 (84.4)	178 (83.6)	0.824	4101 (84.4)	188 (82.5)	0.477
	Others	796 (15.7)	761 (15.6)	35 (16.4)		756 (15.6)	40 (17.5)	

Activity_category (%)	Low Activity	595 (11.7)	552 (11.3)	43 (20.2)	**<0.001**	554 (11.4)	41 (18.0)	**0.009**
	Moderate Activity	2410 (47.4)	2318 (47.6)	92 (43.2)		2306 (47.5)	104 (45.6)	
	High Activity	2080 (40.9)	2002 (41.1)	78 (36.6)		1997 (41.1)	83 (36.4)	
Walkability index (mean (SD))	N/A	0.72 (3.00)	0.71 (2.99)	1.02 (3.10)	0.141	0.70 (2.99)	1.13 (3.17)	**0.034**
Walkability index quartiles (%)	[-6.1,-1.86]	1053 (20.7)	1013 (20.8)	40 (18.8)	0.419	1015 (20.9)	38 (16.7)	0.179
	(-1.86,-0.363)	989 (19.4)	950 (19.5)	39 (18.3)		944 (19.4)	45 (19.7)	
	(-0.363,1.25)	1023 (20.1)	987 (20.3)	36 (16.9)		977 (20.1)	46 (20.2)	
	(1.25,3.03]	1016 (20.0)	967 (19.8)	49 (23.0)		975 (20.1)	41 (18.0)	
	(3.03,13.8]	1004 (19.7)	955 (19.6)	49 (23.0)		946 (19.5)	58 (25.4)	
NDVI (mean (SD))	N/A	0.35 (0.15)	0.35 (0.15)	0.34 (0.14)	0.374	0.35 (0.15)	0.33 (0.15)	**0.018**
NDVI quartiles (%)	[-0.17, 0.22]	1060 (20.8%)	1017 (20.9%)	43 (20.2%)	0.314	1003 (20.7)	57 (25.0)	0.262
	(0.22, 0.316]	955 (18.8%)	913 (18.7%)	42 (19.7%)		907 (18.7)	48 (21.1)	
	(0.316, 0.39]	1042 (20.5%)	997 (20.5%)	45 (21.1%)		1000 (20.6)	42 (18.4)	
	(0.39, 0.48]	1086 (21.4%)	1032 (21.2%)	54 (25.4%)		1038 (21.4)	48 (21.1)	
	(0.48, 0.81]	942 (18.5%)	913 (18.7%)	29 (13.6%)		909 (18.7)	33 (14.5)	

Table 2.a presents the unadjusted, minimally adjusted, and fully adjusted logistic regression models assessing the association between walkability index levels and the likelihood of depression as categorical variable (n=5085). No significant associations were observed between various levels of walkability and the occurrence of depression in either the unadjusted or adjusted models.

Table 2.b provides the linear regression models evaluating the impact of walkability index levels on the total score of depression among the complete cases (n=5085). The unadjusted model showed a significant association between high walkability and increased total score of depression ($\beta = 0.31$, $p=0.02$) as well as very high walkability ($\beta = 0.45$, $p < 0.001$). However, these associations were not maintained after adjustments for confounding variables in both minimally and fully adjusted models.

Table 2.c presents the linear regression models evaluating the relationship between different levels of walkability and component scores of depression in unadjusted, minimally adjusted, and fully adjusted analyses. In the unadjusted analysis, significant associations were observed for 'High' and 'Very High' walkability levels across multiple depression components. For example, 'High' walkability was significantly associated with interest ($\beta = 0.06$, $p < 0.01$), feeling depressed ($\beta = 0.05$, $p = 0.03$), confidence ($\beta = 0.06$, $p < 0.01$), ability to concentrate ($\beta = 0.04$, $p = 0.04$), and suicidal thoughts ($\beta = 0.02$, $p = 0.03$). 'Very High' walkability showed similar significant associations with interest, feeling depressed, confidence, and ability to concentrate ($p < 0.001$ for all). In the minimally adjusted model, only 'Low' walkability showed a significant association with ability to concentrate ($\beta = 0.05$, $p = 0.02$). 'Very High' walkability remained significant in multiple components including interest ($\beta = 0.05$, $p = 0.02$), feeling depressed ($\beta = 0.05$, $p = 0.02$), confidence ($\beta = 0.05$, $p = 0.04$), and ability to concentrate ($\beta = 0.05$, $p = 0.01$). In the fully adjusted model, no significant associations were observed between walkability levels and any of the depression components.

Table 3.a presents the univariable and multivariable logistic regression analyses exploring the association between the walkability index and anxiety condition using complete cases (n=5085). In the unadjusted model, compared to areas with very low walkability, areas with very high walkability showed a statistically significant increased

odds of anxiety with an odds ratio (OR) of 1.74 (95% CI: 1.16–2.64). This association remained significant in both the minimally adjusted model (OR=1.35, 95% CI: 1.00–1.84) and the fully adjusted model (OR=1.43, 95% CI: 1.03–1.98), suggesting that people living in areas with very high walkability had increased odds of experiencing anxiety, even after adjusting for demographic, lifestyle, and health-related variables.

Table 3.b demonstrates the linear regression analyses on the relationship between walkability index and the total score of anxiety. The unadjusted and fully adjusted models revealed that individuals in areas with very high walkability had a statistically significant increase in the total anxiety score ($\beta=0.46$, $p<0.001$; $\beta=0.36$, $p<0.01$, respectively). This trend remained even after adjusting for confounding variables, indicating a strong positive association between high walkability and anxiety scores.

Table 3.c displays the results from the linear regression analyses exploring the relationship between walkability index and individual components of anxiety. For areas with very high walkability, the unadjusted analysis showed a statistically significant positive association across multiple components, such as 'Nervous' ($\beta=0.11$, $p<0.0001$), 'Worrying1' ($\beta=0.08$, $p<0.001$), and 'Afraid' ($\beta=0.05$, $p=0.01$). This relationship generally held in the minimally and fully adjusted models, particularly for the components 'Nervous' and 'Worrying1' ($p<0.01$).

Table 4.a presents the results from logistic regression analyses examining the association between green space (as measured by NDVI) and depression condition. In the unadjusted model, compared to the reference category of "very low" NDVI, those living in areas with "very high" NDVI showed a reduced odds ratio (OR) of 0.72 (95% CI: 0.47 – 1.10). However, this association was not statistically significant. After adjusting for age, sex, and income in the minimally adjusted model, the OR changed to 0.82 (95% CI: 0.60 – 1.12), still not reaching statistical significance. Finally, in the fully adjusted model, which controlled for additional variables like education, health perception, history of depression, alcohol consumption, smoking, and sleep duration, the OR for the "very high" NDVI category was 0.97 (95% CI: 0.62 – 1.51), indicating no significant relationship between high levels of green space and depression condition.

Table 4.b demonstrates the results from linear regression analyses. In the unadjusted model, a "very high" NDVI was significantly associated with a lower total depression score ($\beta = -0.39$, $p < 0.01$). However, the significance disappeared when adjusting for covariates

in both the minimally and fully adjusted models (β = -0.05, p = 0.64 in the fully adjusted model).

Table 4.c shows the linear regression outcomes for individual components of depression. In the unadjusted model, higher NDVI was significantly associated with lower scores in multiple components, including feeling "depressed" (β = -0.05, p < 0.01), "tired" (β = -0.05, p = 0.08), and "eating" (β = -0.05, p = 0.04). After adjusting for covariates in the minimally and fully adjusted models, most of these significant associations were attenuated, and only a few remained significant, such as an increase in "sleeping" scores (β = 0.08, p = 0.02) and a decrease in "concentrate" scores (β = -0.05, p = 0.01) in the "very high" NDVI category in the fully adjusted model.

In Table 5.a, logistic regression models assessed the association between varying levels of green space (NDVI) and the likelihood of experiencing an anxiety condition. In the unadjusted model, medium (OR: 0.62, 95% CI: 0.41–0.92) and very high (OR: 0.60, 95% CI: 0.39–0.90) levels of NDVI were significantly associated with lower odds of anxiety. However, this association attenuated after adjusting in the minimally adjusted model and further variables in the fully adjusted model (age, sex, income, education, health perception, alcohol, smoking, and sleep duration). In the fully adjusted model, none of the NDVI categories were significantly associated with anxiety (e.g., Medium NDVI OR: 0.92, 95% CI: 0.68–1.23).

Table 5.b presented linear regression models to quantify the association between NDVI and the total anxiety score. In the unadjusted model, higher levels of green space tended to be associated with lower total anxiety scores, although the results were not statistically significant (e.g., High NDVI β: -0.16, p-value: 0.20). This non-significant trend persisted in the minimally and fully adjusted models (e.g., High NDVI in fully adjusted model β: -0.03, p-value: 0.81).

Table 5.c showed the relationship between NDVI and individual components of anxiety. In the unadjusted model, the "Very high" level of NDVI was significantly associated with lower scores in the "Relax" component (β: -0.06, p-value: 0.01). This relationship remained significant in the minimally adjusted model (β: -0.05, p-value: 0.03) but lost significance in the fully adjusted model (β: -0.05, p-value: 0.07). No other significant associations were found between NDVI levels and individual components of anxiety in any of the models.

Table 2.a – Unadjusted, minimally adjusted and fully adjusted logistic regression models using complete cases (n=5085) for the relationship between walkability index and depression condition

Outcome: Depression (No / Yes)			
	Unadjusted model	**Minimally adjusted model[a]**	**Fully adjusted model[b]**
Independent variable	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
Walkability index			
Very low	Ref	Ref	Ref
Low	1.08 (0.70 – 1.67)	1.11 (0.81 - 1.54)	0.97 (0.61 – 1.53)
Medium	1.07 (0.69 – 1.65)	1.08 (0.78 - 1.49)	0.94 (0.59 – 1.49)
High	1.42 (0.95 – 2.15)	1.23 (0.90 - 1.69)	1.17 (0.76 – 1.83)
Very high	1.37 (0.91 – 2.08)	1.17 (0.86 - 1.61)	1.05 (0.67 – 1.63)

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, history of depression, alcohol, smoking, and sleep duration

Table 2.b - Univariable and multivariable linear regression using complete cases (n=5085) for the relationship between walkability index and the total score of depression

Outcome: Depression total score						
	Unadjusted model		**Minimally adjusted model[a]**		**Fully adjusted model[b]**	
Independent variable	**β**	**p-value**	**β**	**p-value**	**β**	**p-value**
Walkability index						
Very low	Ref		Ref		Ref	
Low	0.12	0.36	0.06	0.68	0.06	0.60
Medium	0.20	0.13	0.06	0.65	-0.01	0.94

High	**0.31**	**0.02 ***	0.16	0.25	0.10	0.41
Very high	**0.45**	**<0.001 ***	0.25	0.06	0.14	0.24

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, history of depression, alcohol, smoking, and sleep duration

Table 2.c – Unadjusted, minimally adjusted and fully adjusted linear regression using complete cases (n=5085) for the relationship between walkability index and the scores of depression components separately.

Outcome: Depression component scores									
				Unadjusted analysis					
	interest	**depressed**	**sleeping**	**tired**	**eating**	**confidence**	**concentrate**	**move**	**suicidal**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index									
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.04 (1.68)	0.02 (0.24)	-0.02 (0.49)	0.01 (0.83)	0.01 (0.62)	0.01 (0.56)	0.04 (0.05)	0.01 (0.77)	0.00 (0.93)
Medium	0.03 (0.13)	0.01 (0.49)	0.01 (.81)	0.03 (0.23)	0.02 (0.51)	0.03 (0.17)	**0.04 (0.03*)**	0.02 (0.14)	0.00 (0.72)
High	**0.06 (<0.01*)**	**0.05 (0.03*)**	0.02 (0.56)	0.02 (0.50)	0.01 (0.59)	**0.06 (<0.01*)**	**0.04 (0.04*)**	0.02 (0.08)	0.02 (0.03)
Very high	**0.08 (<0.001*)**	**0.08 (<0.001*)**	0.02 (0.47)	**0.06 (0.05)**	0.04 (0.15)	**0.08 (<0.001*)**	**0.07 (<0.001*)**	0.00 (0.77)	0.02 (0.10)

	Minimally adjusted analysis[a]								
	interest	**depressed**	**sleeping**	**tired**	**eating**	**confidence**	**concentrate**	**move**	**suicidal**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index									
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.02 (0.28)	0.01 (0.63)	-0.02 (0.45)	-0.01 (0.87)	-0.01 (0.76)	0.00 (0.87)	**0.05 (0.02)**	0.01 (0.68)	0.00 (0.98)
Medium	0.01 (0.67)	-0.01 (0.81)	-0.01 (0.82)	0.00 (0.88)	-0.01 (0.81)	0.01 (0.56)	0.03 (0.11)	0.01 (0.32)	0.00 (0.69)
High	0.03 (0.17)	0.02 (0.37)	0.01 (0.70)	0.00 (0.93)	-0.01 (0.72)	0.04 (0.07)	0.03 (0.19)	0.01 (0.30)	0.02 (0.10)
Very high	**0.05 (0.02)**	**0.05 (0.02)**	0.01 (0.84)	0.03 (0.30)	0.01 (0.53)	**0.05 (0.04)**	**0.05 (0.01)**	-0.01 (0.51)	0.00 (0.65)

	Fully adjusted analysis[b]								
	interest	**depressed**	**sleeping**	**tired**	**eating**	**confidence**	**concentrate**	**move**	**suicidal**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index									
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.03 (0.18)	0.01 (0.67)	-0.01 (0.83)	0.01 (0.70)	-0.01 (0.54)	-0.01 (0.55)	0.03 (0.17)	0.00 (0.96)	0.01 (0.15)
Medium	0.00 (0.98)	0.00 (0.96)	0.00 (0.95)	0.00 (0.95)	-0.03 (0.24)	0.00 (0.9)	0.01 (0.64)	0.00 (0.89)	0.01 (0.54)
High	0.03 (0.22)	0.02 (0.32)	0.03 (0.42)	0.00 (0.91)	-0.02 (0.45)	0.02 (0.28)	0.00 (0.84)	0.00 (0.58)	0.01 (0.16)
Very high	0.04 (0.12)	0.03 (0.13)	0.04 (0.24)	0.03 (0.40)	-0.02 (0.56)	0.02 (0.43)	0.01 (0.57)	-0.01 (0.63)	0.00 (0.64)

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, history of depression, alcohol, smoking, and sleep duration

Table 3.a - Univariable and multivariable logistic regression using complete cases (n=5085) for the relationship between walkability index and anxiety condition

Outcome: Anxiety (Yes – No)			
	Unadjusted model	**Minimally adjusted model[a]**	**Fully adjusted model[b]**
Independent variable	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
Walkability index			
Very low	Ref	Ref	Ref
Low	1.28 (0.83 – 1.98)	1.18 (0.86 – 1.62)	1.22 (0.88 – 1.70)
Medium	1.32 (0.86 – 2.04)	1.02 (0.74 – 1.42)	1.03 (0.73 – 1.45)
High	1.12 (0.72 – 1.75)	0.96 (0.70 – 1.34)	1.02 (0.72 – 1.43)
Very high	**1.74 (1.16 – 2.64)**	**1.35 (1.00 – 1.84)**	**1.43 (1.03 – 1.98)**

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

Table 3.b - Univariable and multivariable linear regression using complete cases (n=5085) for the relationship between walkability index and the total score of anxiety

Outcome: Anxiety total score						
	Unadjusted model		**Minimally adjusted model[a]**		**Fully adjusted model[b]**	
Independent variable	**β**	**p-value**	**β**	**p-value**	**β**	**p-value**
Walkability index						
Very low	Ref		Ref		Ref	
Low	0.16	0.23	0.10	0.47	0.10	0.43
Medium	0.04	0.76	0.14	0.53	-0.12	0.37
High	0.12	0.36	-0.01	0.95	-0.01	0.92
Very high	**0.46**	**<0.001**	**0.39**	**<0.01**	**0.36**	**<0.01**

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

Table 3.c – Unadjusted, minimally adjusted and fully adjusted linear regression using complete cases (n=5085) for the relationship between walkability index and the scores of anxiety components separately.

Outcome: Anxiety component scores

	Unadjusted analysis						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.02 (0.51)	0.03 (0.21)	0.02 (0.52)	0.03 (0.21)	0.01 (0.71)	0.03 (0.19)	0.02 (0.25)
Medium	0.00 (0.89)	0.00 (0.86)	-0.02 (0.45)	0.02 (0.41)	0.01 (0.52)	0.02 (0.49)	0.02 (0.33)
High	0.03 (0.34)	0.02 (0.36)	0.00 (0.90)	0.03 (0.19)	0.00 (0.89)	0.02 (0.32)	0.03 (0.21)
Very high	**0.11 (<0.0001)**	**0.08 (<0.001)**	**0.06 (0.02)**	**0.09 (<0.001)**	0.03 (0.18)	**0.06 (0.01)**	0.05 (0.01)
	Minimally adjusted analysis[a]						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
Walkability index							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.00 (0.95)	0.02 (0.38)	0.00 (0.98)	0.02 (0.36)	0.00 (0.81)	0.03 (0.27)	0.02 (0.37)
Medium	-0.02 (0.38)	-0.01 (0.57)	-0.05 (0.09)	0.01 (0.82)	0.00 (0.88)	0.00 (0.89)	0.00 (0.87)
High	0.01 (0.77)	0.00 (0.96)	-0.02 (0.42)	0.02 (0.45)	-0.02 (0.36)	0.00 (0.86)	0.00 (0.84)
Very high	**0.1 (<0.001)**	**0.07 (0.01)**	0.05 (0.09)	**0.08 (<0.01)**	0.02 (0.36)	**0.05 (0.05)**	0.04 (0.09)
	Fully adjusted analysis[b]						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**

Walkability index							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.01 (0.71)	0.02 (0.33)	0.00 (0.89)	0.03 (0.31)	0.01 (0.75)	0.02 (0.31)	0.02 (0.43)
Medium	-0.02 (0.39)	-0.02 (0.38)	**-0.54 (0.04)**	0.00 (0.86)	-0.01 (0.79)	-0.01 (0.82)	0.00 (0.97)
High	0.01 (0.79)	0.00 (0.95)	-0.03 (0.33)	0.02 (0.53)	-0.02 (0.36)	0.00 (0.89)	0.01 (0.76)
Very high	**0.09 (<0.001)**	**0.07 (0.01)**	0.04 (0.12)	**0.07 (<0.01)**	0.02 (0.36)	**0.05 (0.04)**	0.03 (0.18)

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

Table 4.a - Univariable and multivariable logistic regression using complete cases (n=5085) for the relationship between green space (NDVI) and depression condition

Outcome: Depression (Yes – No)			
	Unadjusted model	**Minimally adjusted model[a]**	**Fully adjusted model[b]**
Independent variable	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
NDVI			
Very low	Ref	Ref	Ref
Low	0.89 (0.60 – 1.33)	0.93 (0.69 – 1.24)	1.05 (0.68 – 1.60)
Medium	0.86 (0.58 – 1.28)	1.06 (0.80 – 1.40)	1.11 (0.74 – 1.68)
High	0.97 (0.66 – 1.44)	1.03 (0.78 – 1.37)	1.10 (0.73 – 1.67)
Very high	0.72 (0.47 – 1.10)	0.82 (0.60 – 1.12)	0.97 (0.62 – 1.51)

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, history of depression, alcohol, smoking, and sleep duration

Table 4.b - Univariable and multivariable linear regression using complete cases (n=5085) for the relationship between green space (NDVI) and the total score of depression

Outcome: Depression total score						
	Unadjusted model		**Minimally adjusted model[a]**		**Fully adjusted model[b]**	
Independent variable	**β**	**p-value**	**β**	**p-value**	**β**	**p-value**
NDVI						
Very low	Ref		Ref		Ref	
Low	-0.12	0.34	-0.06	0.65	0.09	0.42
Medium	-0.11	0.35	0.02	0.89	0.11	0.33
High	-0.19	0.122	0.01	0.94	0.10	0.40
Very high	**-0.39**	**<0.01**	-0.22	0.09	-0.05	0.64

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, history of depression, alcohol, smoking, and sleep duration

Table 4.c – Unadjusted, minimally adjusted and fully adjusted linear regression using complete cases (n=5085) for the relationship between green space (NDVI) and the scores of depression components separately.

Outcome: Depression component scores

	Unadjusted analysis								
	interest	**depressed**	**sleeping**	**tired**	**eating**	**confidence**	**concentrate**	**move**	**suicidal**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
NDVI									
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	-0.02 (0.33)	-0.04 (0.05)	0.02 (0.40)	0.02 (0.42)	-0.02 (0.49)	-0.03 (0.10)	-0.03 (0.16)	-0.01 (0.47)	-0.02 (0.07)
Medium	-0.02 (0.23)	-0.04 (0.05)	0.04 (0.13)	-0.02 (0.46)	-0.01 (0.54)	-0.05 (0.02)	0.00 (0.97)	0.00 (0.67)	-0.01 (0.20)
High	-0.03 (0.21)	**-0.02 (<0.01)**	0.04 (0.21)	-0.03 (0.26)	-0.01 (0.61)	**-0.05 (<0.01)**	-0.03 (0.09)	0.00 (0.77)	-0.01 (0.13)
Very high	**-0.06 (<0.01)**	**-0.05 (<0.01)**	0.00 (0.94)	-0.05 (0.08)	**-0.05 (0.04)**	**-0.02 (<0.01)**	**-0.07 (<0.001)**	**-0.03 (0.01)**	**-0.02 (0.01)**

	Minimally adjusted analysis[a]								
	interest	**depressed**	**sleeping**	**tired**	**eating**	**confidence**	**concentrate**	**move**	**suicidal**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
NDVI									
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	-0.01 (0.75)	-0.03 (0.09)	0.03 (0.29)	0.01 (0.65)	0.00 (0.92)	-0.02 (0.41)	-0.02 (0.21)	-0.01 (0.63)	-0.01 (0.29)
Medium	0.01 (0.68)	-0.02 (0.21)	0.04 (0.17)	-0.02 (0.55)	0.04 (0.13)	-0.02 (0.30)	0.00 (0.83)	0.01 (0.59)	-0.01 (0.20)
High	0.01 (0.75)	-0.01 (0.61)	0.06 (0.06)	0.00 (0.97)	0.01 (0.54)	-0.01 (0.48)	**-0.04 (0.04)**	0.00 (0.70)	-0.01 (0.15)

Very high	-0.02 (0.28)	-0.03 (0.16)	-0.01 (0.74)	-0.04 (0.15)	0.00 (0.96)	-0.04 (0.09)	**-0.05 (0.01)**	-0.01 (0.47)	-0.02 (0.05)

	Fully adjusted analysis[b]								
	interest	**depressed**	**sleeping**	**tired**	**eating**	**confidence**	**concentrate**	**move**	**suicidal**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
NDVI									
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.01 (0.74)	-0.01 (0.61)	0.05 (0.15)	**0.08 (<0.01)**	0.00 (0.87)	0.00 (0.91)	-0.02 (0.29)	-0.01 (0.47)	**-0.02 (0.03)**
Medium	0.01 (0.76)	-0.01 (0.59)	**0.08 (0.02)**	0.02 (0.43)	0.02 (0.48)	-0.03 (0.22)	0.01 (0.80)	-0.01 (0.56)	-0.01 (0.18)
High	0.03 (0.13)	-0.01 (0.61)	**0.07 (0.04)**	0.00 (0.99)	0.03 (0.17)	-0.01 (0.56)	-0.01 (0.77)	0.01 (0.39)	-0.01 (0.18)
Very high	0.01 (0.78)	0.02 (0.46)	**0.07 (0.03)**	0.04 (0.20)	0.02 (0.48)	-0.01 (0.72)	-0.03 (0.18)	-0.01 (0.31)	-0.02 (0.07)

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, history of depression, alcohol, smoking, and sleep duration

Table 5.a - Univariable and multivariable logistic regression using complete cases (n=5085) for the relationship between green space (NDVI) and anxiety condition

Outcome: Anxiety (Yes – No)			
	Unadjusted model	**Minimally adjusted model[a]**	**Fully adjusted model[b]**
Independent variable	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**

NDVI			
Very low	Ref	Ref	Ref
Low	0.88 (0.60 – 1.27)	0.93 (0.69 – 1.24)	0.96 (0.71 – 1.30)
Medium	**0.62 (0.41 – 0.92)**	0.92 (0.69 – 1.22)	0.92 (0.68 – 1.23)
High	0.71 (0.48 – 1.05)	0.85 (0.63 – 1.13)	0.81 (0.59 – 1.09)
Very high	**0.60 (0.39 – 0.90)**	0.97 (0.73 – 1.30)	0.99 (0.73 – 1.34)

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

Table 5.b - Univariable and multivariable linear regression using complete cases (n=5085) for the relationship between green space (NDVI) and the total score of anxiety

Outcome: Anxiety total score						
	Unadjusted model		**Minimally adjusted model[a]**		**Fully adjusted model[b]**	
Independent variable	**β**	**p-value**	**β**	**p-value**	**β**	**p-value**
NDVI						
Very low	Ref		Ref		Ref	
Low	-0.11	0.35	0.02	0.86	0.03	0.79
Medium	-0.02	0.90	-0.03	0.84	0.00	1.00
High	-0.16	0.20	-0.02	0.88	-0.03	0.81
Very high	-0.19	0.13	-0.08	0.54	-0.02	0.85

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

Table 5.c – Unadjusted, minimally adjusted and fully adjusted linear regression using complete cases (n=5085) for the relationship between green space (NDVI) and the scores of anxiety components separately.

Outcome: Anxiety component scores

	Unadjusted analysis						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
NDVI							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	-0.11 (0.35)	-0.01 (0.54)	-0.02 (0.44)	-0.04 (0.13)	0.00 (0.83)	0.02 (0.28)	**-0.05 (0.02)**
Medium	-0.02 (0.90)	-0.01 (0.66)	0.00 (0.96)	-0.01 (0.59)	0.01 (0.57)	0.02 (0.27)	-0.03 (0.14)
High	-0.16 (0.20)	-0.02 (0.37)	-0.04 (0.13)	-0.03 (0.25)	-0.02 (0.20)	-0.02 (0.49)	-0.02 (0.20)
Very high	-0.19 (0.13)	-0.02 (0.27)	-0.02 (0.38)	**-0.06 (0.01)**	-0.02 (0.17)	0.00 (0.99)	-0.03 (0.10)

	Minimally adjusted analysis[a]						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
NDVI							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.00 (0.94)	0.01 (0.74)	0.00 (0.94)	-0.02 (0.53)	0.01 (0.44)	0.03 (0.15)	-0.03 (0.16)
Medium	-0.01 (0.68)	0.02 (0.41)	-0.01 (0.62)	-0.01 (0.54)	0.03 (0.11)	0.01 (0.57)	-0.02 (0.28)

High	0.00 (0.88)	0.01 (0.77)	-0.01 (0.68)	-0.02 (0.53)	0.01 (0.74)	-0.02 (0.51)	0.00 (0.89)
Very high	0.00 (0.95)	-0.01 (0.77)	0.00 (0.85)	**-0.05 (0.03)**	-0.01 (0.51)	0.02 (0.48)	-0.02 (0.24)

	Fully adjusted analysis[b]						
	Nervous	**Worrying1**	**Worrying2**	**Relax**	**Restless**	**Annoyed**	**Afraid**
	β (p-value)	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**	**β (p-value)**
NDVI							
Very low	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Low	0.01 (0.77)	0.01 (0.63)	0.01 (0.83)	-0.02 (0.53)	0.01 (0.45)	0.03 (0.23)	-0.02 (0.22)
Medium	0.00 (0.96)	-0.01 (0.60)	-0.01 (0.78)	-0.01 (0.65)	0.03 (0.14)	0.02 (0.49)	-0.02 (0.27)
High	0.01 (0.75)	0.01 (0.80)	-0.01 (0.61)	-0.01 (0.58)	0.00 (0.89)	-0.02 (0.36)	-0.01 (0.78)
Very high	0.01 (0.67)	0.00 (0.87)	0.02 (0.48)	-0.05 (0.07)	-0.02 (0.40)	0.02 (0.37)	-0.02 (0.39)

[a] Minimally adjusted model is adjusted for age, sex, and income

[b] Fully adjusted model is adjusted for age, sex, income, education, health perception, alcohol, smoking, and sleep duration

15.4. Discussion

Our study investigated the relationship between walkability index and depression, employing three regression models—unadjusted, minimally adjusted, and fully adjusted—for both categorical and continuous outcomes of depression. In the logistic regression model we did not observe any significant association between walkability index and categorical depression measure in any of the regression models. The continuous outcome analysis, measured as the total score of depression, revealed higher walkability index was associated with a higher depression score in the unadjusted model, reaching statistical significance for high and very high levels. However, these associations were considerably attenuated in both minimally adjusted and fully adjusted models. The lack of a significant association in the minimally adjusted model, which considered age, sex, and income, suggests that these factors may be confounding the relationship between walkability and depression. This is in line with previous literature that has identified age, sex, and income as significant determinants of mental health. The fully adjusted model further attenuated the relationship between walkability and depression, underscoring the possible role of other variables such as education, health perception, history of depression, alcohol, smoking, and sleep duration in influencing this association. On the other hand, the unadjusted regression model on the association between walkability index and various components of depression showed significant associations between high and very high walkability indices and multiple depression components, namely interest, depressed mood, confidence, concentration, and suicidal thoughts. However, these associations were attenuated in the minimally adjusted and fully adjusted models, suggesting that confounding variables may be playing a considerable role.

Similar to our findings, Guo et al in 2020 showed that walkability was associated with fewer depressive symptoms or continuous total depression score, but this association was not observed in categorical depression in the elderly in Hong Kong. There are some other cross-sectional studies observing an inverse relationship between walkability index and depression among older adults (Keats et al., 2020; Koohsari et al., 2019; R. Wang et al., 2019). In contrary, a cross-sectional study by Koohsari et al in 2023 showed that higher total perceived walkability was also associated with lower odds of having mild depressive symptoms in both men and women, while none of the objective built environment attributes were associated with depressive symptoms in women or men (Koohsari et al., 2023). Another recent cross-sectional study on older adults by Siqueira Junior et al, could not find any association between walkability index and depressive symptoms in either crude or adjusted models (Siqueira Junior et al., 2022).

The observed attenuation in the adjusted models and the mixed findings in the literature raises questions about the possible mechanisms by which walkability might influence depression. It's conceivable that walkability itself is not a direct predictor of depression but rather interacts with other lifestyle and demographic factors. Another explanation could be the "urban paradox," where areas with higher walkability also have higher stressors like noise and pollution, potentially affecting mental health adversely.

The present study aimed to explore the relationship between walkability index and anxiety measures. Both logistic and linear regression models were employed to understand these associations more comprehensively. In the unadjusted model, participants residing in areas with a "very high" walkability index were 1.74 times more likely to report experiencing anxiety compared to those living in areas with a "very low" walkability index. After controlling for age, sex, and income in the minimally adjusted model, the odds ratio decreased to 1.35, and further reduced to 1.43 in the fully adjusted model. Although the magnitude of the relationship attenuated with adjustment, the association remained statistically significant in the fully adjusted model. This suggests that while confounding variables play a role, there is a unique and positive association between high walkability and the likelihood of experiencing anxiety. Similarly, in the linear regression model examining continuous anxiety scores, a significant association was observed in the "very high" walkability index category. In the unadjusted model, living in a "very high" walkability area was associated with a higher total anxiety score. This association remained robust in both minimally adjusted and fully adjusted models, indicating that high walkability is associated with increased total anxiety scores, irrespective of the covariates adjusted for. The current study also aimed to assess the relationship between walkability indices and various components of anxiety. In the unadjusted analysis, a significant association was observed only in the "very high" walkability index category across multiple anxiety components, such as nervousness, worrying1, worrying2, relaxation, annoyance, and fearfulness. After adjusting for age, sex, and income in the minimally adjusted model, we noticed a slight attenuation but the significance was maintained for many of the anxiety components like nervousness, worrying1, and relaxation, particularly in very high walkability areas. Further adjusting for education, health perception, history of depression, alcohol, smoking, and sleep duration in the fully adjusted model did not dramatically alter the outcome, especially in the "very high" walkability index category. This suggests that walkability may indeed have a unique relationship with individual components of anxiety, independent of several other factors.

There is a research gap on the number of studies investigating the association between walkability index and anxiety measure. According to a study performed by Wang et al in 2019, street walkability was negatively associated with Geriatric Depression Scale scores (GDS 15-item) and Geriatric Anxiety Inventory scores (GAI 20-item), and the associations were stronger for disadvantaged older adults than others (R. Wang et al., 2019). In contrary, a study conducted by Mehta et al, revealed that higher walkability was associated with elevated odds of anxiety symptoms (Mehta et al., 2022). While high walkability is generally considered beneficial for physical health, our findings indicate a complex relationship with emotional and mental well-being. One possible interpretation could be that very high walkability areas are often urban centers with various stressors like noise, crowding, and overstimulation, potentially contributing to multiple facets of anxiety. Understanding these relationships is crucial for healthcare professionals to make more informed recommendations and interventions for mental health in different urban settings.

This study was designed to investigate the relationship between the availability of green space, measured through the Normalized Difference Vegetation Index (NDVI), and both categorical and continuous measures of depression. In the unadjusted logistic regression model, the odds ratios (ORs) were generally below 1, suggesting a potential protective effect of green space on depression, although this was not statistically significant. For the continuous depression score, the unadjusted model found a significant association only in the "very high" NDVI category. When the model was minimally adjusted for age, sex, and income, the ORs and β-values moved closer to 1 and lost their statistical significance, indicating that these factors may partially explain the initial associations seen in the unadjusted model. The fully adjusted model, accounting for additional confounders, also did not find a statistically significant relationship between green space and depression, suggesting that the initial protective effect might be influenced by these other variables.

A cross-sectional study conducted by Klompmakera showed that NDVI 300 m was inversely associated psychological distress which is a combined measure of depressive symptoms and anxiety. However, NDVI 1000m (OR: 0.98) showed no significant association with psychological distress (Klompmaker et al., 2019). According to another study by Saarloos et al in 2011 on elderly men in Australia, higher degrees of land-use mix, specifically through retail availability, independent of other walkability factors including street connectivity and residential density was associated with higher odds of depression in elderly men in Australia (Saarloos et al., 2011). On the other hand, a study by Moreira et al in 2022 found no significant results for depression and percentage of different green spaces within districts (Moreira et al., 2022).

Our findings present a complex narrative. While the unadjusted model suggested a protective role for very high green spaces in reducing depression scores, this effect was attenuated after controlling for confounders. This could imply that the benefits of green spaces may be more complex and potentially confounded by social, economic, or lifestyle factors.

The current study also investigated the impact of green spaces on various components of depression employed three different regression models. In the unadjusted model, NDVI levels mostly showed negative β-values for interest, depressed mood, eating habits, confidence, and concentration; however, the results reached statistical significance only in the "very high" NDVI category for most components except for sleeping and tiredness. Notably, the variables confidence and depressed were significantly impacted even at high levels of NDVI. The minimally adjusted model, accounting for age, sex, and income, showed a dilution of the associations between NDVI levels and most depression components, with only the "concentrate" component in the "very high" NDVI showing a significant relationship ($\beta = -0.05$, $p = 0.01$). In the fully adjusted model, statistical significance was further reduced for most components. Interestingly, the sleeping component showed a significant positive relationship with medium, high and very high NDVI levels, suggesting that higher green space may not necessarily be beneficial for this specific aspect of depression.

A cross-sectional study by Cottagiri et al in 2021 showed an inverse association between self-reported clinical diagnosis of depression in relation to an increase of NDVI within a 500 m buffer of the participant's residence (Cottagiri et al., 2022). There are plenty of research showing the inverse relationship between green space and depression (Cottagiri et al., 2022; Gariepy et al., 2014; Krols et al., 2022; Liu et al., 2019; R. Wang et al., 2019). Interesting, a longitudinal study by Astell-Burt et al in Australia in 2022 revealed that a 10% increase in green space was associated with higher levels of antidepressant prescription (Astell-Burt et al., 2022). In addition, a study by Helbich et al in 2021 showed there was no statistically significant evidence that people with less urban residential greenness had higher depression or anxiety scores than those exposed to higher levels (Helbich et al., 2021).

Inconsistencies in the literature, and attenuation of initial associations in the unadjusted models in the current study when adjusted minimally and fully, underscore the complexity of the impact of green spaces on mental health. For instance, the availability of green space might help improve concentration and confidence but not necessarily sleep quality. This multifaceted impact has implications for public health interventions and urban planning.

Current study also examined the relationship between varying levels of green space and anxiety. In the unadjusted logistic regression model on green space and categorical anxiety, individuals residing in areas with medium and very high NDVI levels were less likely to report anxiety. However, upon controlling for confounding factors, the strength and significance of these associations were attenuated. In both the minimally adjusted and fully adjusted models, no statistically significant relationships were observed between NDVI levels and the likelihood of experiencing anxiety. For the continuous anxiety scores, no statistically significant relationship was observed in any of the models. The β coefficients in both minimally and fully adjusted models were negligible and not statistically significant, suggesting that green space might not have a measurable impact on the overall anxiety score under the conditions studied. The current study also assessed the relationship between green space, as indicated by the and various components of anxiety. In the unadjusted analysis, living in areas with "Very High" NDVI levels seemed to be somewhat associated with lower scores in the "Relax" component and living in areas with "low" NDVI levels seemed to be somewhat associated with lower scores in the "Afraid" component. In the minimally adjusted model, the significant association for the "Relax" component remained. Interestingly, in the fully adjusted model, the "Relax" component's significant association was slightly attenuated and became marginally non-significant. All other components showed no statistically significant associations with NDVI levels.

In a 2019 study in Quebec Canada, Hystad and colleagues found that in fully controlled models, a small increase (0.1) in local green space, as measured by NDVI within a 500-metre radius, was linked to a reduced likelihood of both depression and moderate anxiety (Hystad et al., 2019). Similarly, in a study by Moreira et al in 2022, The percentage of different green spaces within districts was negatively associated with the presence of anxiety (Moreira et al., 2022). In contrast there are several studies revealing there were no significant association between green space and anxiety (Generaal et al., 2019; Helbich et al., 2021; Pun et al., 2018).

The attenuated effects observed after adjusting for potential confounders suggest that while green spaces may have a mild relaxing effect, this is not sufficiently robust to stand up against a range of socio-economic and lifestyle factors.

15.5. Conclusion

15.5.1. Limitations and Future Directions

It is crucial to acknowledge the limitations of this study. The current study has a limitation in the cross-sectional design, limiting the ability to draw causal inferences. Additionally, while we adjusted for several potential confounders, unmeasured influential variables, such as social cohesion, neighbourhood crime rates, and environmental pollution might still influence the observed associations.

Given these limitations, future research should prioritize longitudinal designs and incorporate a broader set of variables. Qualitative studies could also be invaluable, providing context to the statistical relationships and helping design more effective public health interventions.

15.5.2. Policy Implications

The complexities unveiled in our studies have significant implications for urban planning and healthcare policies. A one-size-fits-all approach to public health interventions based on walkability or green spaces would be insufficient. Policymakers and healthcare providers should adopt a multidimensional approach that accounts for these intricate relationships.

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16. Appendix F: Health Impacts - Full Article - The Effect of Residential Greenness and Walkability on Cancer Risk in the Greater Vancouver Region

16.1. Background

Cancer is the leading cause of death in Canada with lung, breast, colorectal, and prostate cancer accounting for approximately half of the cancer cases diagnosed[1,2]. Two out of five Canadians are expected to receive a diagnosis of cancer in their lifetime resulting in one in four cancer related deaths after diagnosis. Furthermore, due to aging population demographics, Canada is expected to face an increased burden of cancer[1]. Despite advances in detection and treatment, lung cancer is the leading cause of death in Canada with a 5-year survival of 19%[1]. While estimated mortality rates for breast cancer declined by 49% from 1986 to 2020[2], improvements are mainly limited to women with early-stage cancers[3,4]. The incidence of colorectal cancers is lowest among persons under 50 years but is increasing in younger age groups[1,5,6]. Similarly, the incidence of prostate cancer has been decreasing since 2007, yet it is the most commonly diagnosed cancer in men accounting for 20% of new cases in 2021[1,3]. Cancer morbidity and mortality can be mitigated by interventions reducing exposure to risk factors. Smoking, alcohol consumption, physical activity, and diet have been shown to affect cancer risk15, but interventions to influence these factors are focused on individual-level behavior change which can be ineffective if they fail to account for multi-faceted socio-cultural barriers to change[7,8]. The built environment, which influences behaviors, can be altered to reduce cancer incidence[7].

The built environment is the infrastructure and its layout made by humans[9] including, but not limited to, urban green spaces, road and pedestrian networks, and residential and commercial establishments. Environmental models consider the built environment as a factor affecting health status moderated through factors such as dietary choices, physical activity, obesity, social engagement, greenness, hormonal changes, air pollution, and ambient exposures[10-12]. Walkable city designs with access to transit, healthy food environments, and amenities like parks can lead to increased physical activity and promote healthier diets[9-11], which are associated with reduced risks of lung, breast, prostate, and colorectal cancers[13-18]. Walkability indices are a measure of characteristics like sidewalk completeness, and residential and commercial densities, and are correlated with physical activity[19,20]. However, studies investigating associations of walkability with cancer risk are few, have produced mixed findings, and have mostly focused on all-cancer risk[21-23]. A higher measure of greenness or normalized difference vegetation index (NDVI), which is rarer in urban environments, has been associated with decreased risk of breast[24,25], prostate[26,27], and lung cancers[28,29], but a recent meta-analysis reported no association with these cancers[30]. There is growing evidence of the association between morbidity and the built environment in recent times, but the majority of research has focused on the association with mortality, acute outcomes, or post-treatment rehabilitation.

With studies mainly focusing on the built environment and mortality rates, the mixed associations reported for NDVI, and the lack of research for walkability with cancer risk, it is essential to further investigate the causal associations using longitudinal study designs. Through this study, we examined the effect of residential greenspace and walkability on the risk of lung, colorectal, breast, and prostate cancers. We hypothesize that after accounting for socio-demographic and other individual factors the built environment with infrastructure promoting healthier lifestyles such as increased physical activity, or access to urban green space would lead to a lower risk of cancer outcomes compared to areas with poorly built infrastructures. However, the decreased risk could potentially be offset by collinear factors such as increased air, noise, and light pollution.

16.2. Methods

Data Sources: We conducted a longitudinal analysis using secondary data merged from multiple sources.

i) The British Columbia Generations Project is a longitudinal cohort established in October 2009 and designed to follow participants for 50 years. A total of 29,500 participants were recruited from 2009-2016 using volunteer sampling methods, and follow-up data were collected between 2016-2019. Participants were 35 years or above at recruitment and residents of British Columbia. Information about socio-demographic characteristics, health, diet, and other lifestyle factors such as physical activity, smoking habits, alcohol intake, and medical and family history was collected through questionnaires. A subset of participants also provided physical measurements which were either self-reported or measured at assessment centers. The environmental exposures were linked to participants based on self-reported residential postal codes and income tax records over time.

ii) The Where Matters project developed an annual walkability index for the Greater Vancouver region in the province of British Columbia, Canada from 2000-2016. The index was developed at the postal code level using four components, *viz.* residential density, intersection density, commercial floor density, and land use mix. We averaged the measurements from 2000-2006 to create the components for the 2006 index. Similarly, measurements from 2007-2011 and 2012-2016 were averaged for the 2011 and 2016 indices respectively. We calculated z-scores for each component standardized to the mean and standard deviation of the 2006 measurements. The z-scores were summed to compute a composite walk score for each time point.

iii) The Canadian Urban Environmental and Health Research Consortium (CANUE) provided data on the 2006 Canadian Active Living Environment (Can-ALE) walkability index and the Normalized Difference Vegetation Index (NDVI). The Can-ALE index was developed for dissemination areas and was computed using z-scores for individual components of intersection and residential densities. The NDVI is the measured vegetation in an area derived from satellite (LANDSAT 5 and 8) readings. Annual measurements are available from enrolment to 2016 and were calculated as the ratio of the difference between and the sum of the red and near infrared band values: (NIR – R)/(NIR + R), ranging from -1 to 1. The NDVI measurements were considered only from cloud free annual composites and after the masking of water features. Annual nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$) concentrations were available as air pollution metrics.

iv) Based on passive annual follow-up, the British Columbia Cancer Registry provided information on mortality and cancer diagnoses which were categorized according to the International Classification of Diseases for Oncology, third edition (ICD-O-3) site codes. Only primary cancer diagnoses for each cancer type were considered for their individual analysis.

Analytical Sample and Variables: A total of 10,929 BCGP participants were included in the study sample (Figure 16-1). To be eligible, participants had to be residing in the Greater Vancouver region. Participants who developed cancer prior to enrolment, and with missing information about the year of enrolment were excluded from the analysis.

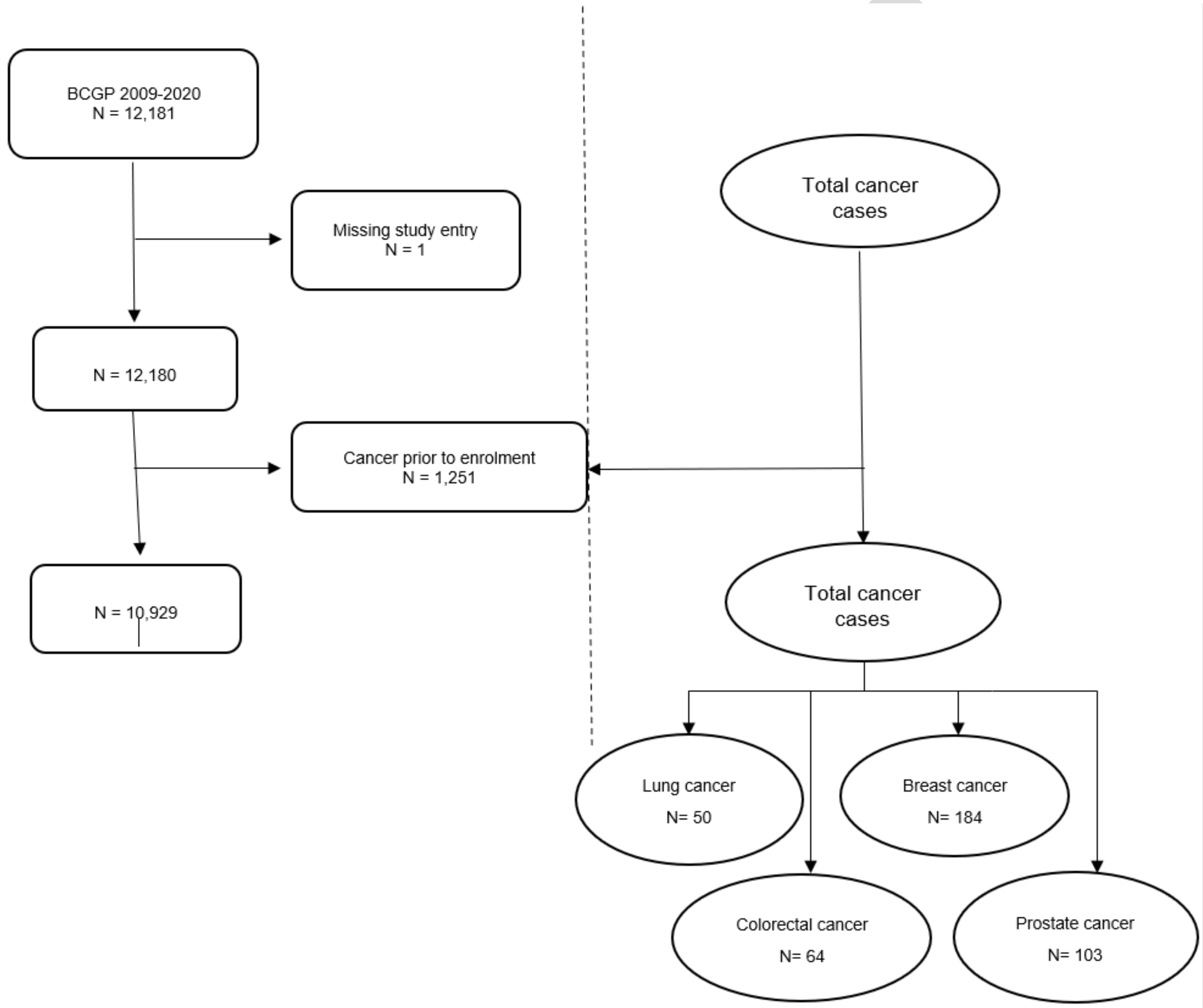

Figure 16-1: BCGP Sample and Cancer Case Distribution

The Where Matters walkability scores were lagged by using the 2006 walkability index for the years 2006-2010, the 2011 index for the years 2011-2015, and the 2016 index for 2016 and onwards. The final z-scores were standardized using the mean and standard deviation of the 2006 measurements of the sample to facilitate the assessment of longitudinal changes. Since CanALE was measured only in 2006, the same index was attributed to the entire length of follow-up. Due to the limited number of incident cancer cases the environmental exposures were classified into three equal groups of low, medium, and high exposure based on the sample size. We calculated a rolling average of NDVI values (1983-2015) and the distribution at the time of enrolment was utilized to determine the cut points of the three groups. We considered responses such as “Don’t know” or “Refused” as missing data. Family history denoted the occurrence of the primary cancer in biological parents or siblings. Similar to NDVI, rolling averages were calculated for $PM_{2.5}$, and NO_2, which were simultaneously used to impute missing values. Other variables were imputed using the last observed value over the follow-up period. Categorizations of the covariates considered for the model are provided in Table 1.

Statistical Analysis: We conducted separate time-varying Cox proportional hazards models to assess the hazard ratio for the primary diagnosis of each cancer type based on the annual environmental exposures. Participants were censored at the year of cancer diagnosis, death, or end of follow-up. The analyses for lung and colorectal cancers were conducted in the entire sample, while the analyses for breast and prostate cancers were restricted to females and males respectively. Age, sex, race, marital status, education level, and income were considered as socio-economic and demographic factors, while alcohol intake, smoking habits, hormonal replacement therapy (HRT), contraceptive use, family history of the primary cancer diagnosis, and air pollution factors ($PM_{2.5}$ and NO_2) were considered as risk factors. Variables were selected for each cancer type based on established risk factors, researcher assumptions, and change in effect estimates. due to the limited number of incident cases the number of variables in the models estimating the hazard ratio for lung and colorectal cancers were limited to a maximum of 7 and 9 respectively. Greenness was adjusted in all models while assessing walkability to account for any confounding effect. After variable selection, a second model was created which included NO_2 to adjust for the effects of air pollution. The assumption of proportional hazards was verified by using Schoenfeld residuals. In case of deviations from the proportional hazards assumption, we introduced interaction terms with time for continuous variables and stratified by categorical variables.

16.3. Results

Baseline characteristics of BCGP participants are provided in Table 1. The eligible study sample consisted of 10,298 participants. The average age of the participants was 55 years and were mostly female (70%). The majority of the participants (83%) had a level of education greater than high school. Approximately 83% of the population was Caucasian and 61% had moderate to high total family income of ≥\$75,000. Only 5% of the participants were current smokers while 90% were current drinkers. The average length of follow-up was 5.5 years with participants accounting for a total of 59,935.60 person-years. A total of 50 lung cancer, 64 colorectal cancer, 184 breast cancer, and 103 prostate cancer cases were eligible over follow-up. The results from the Cox analyses studying the association between the primary environmental exposures and individual cancer risks are presented in Tables 2-5.

Table 1. Baseline characteristics of eligible British Columbia Generations Project participants stratified by sex

Characteristics	**Sex**		
	Overall N = 10,929	**Females N = 7,611**	**Males N = 3,318**
Normalized Difference Vegetation Index	0.33 (0.12)	0.34 (0.12)	0.33 (0.12)
Canadian Active Living Environment, z-score	1.19(2.21)	1.14 (2.16)	1.30 (2.30)
Walk Index- WM Mean(SD), z-score	-0.22 (3.10)	-0.26 (3.06)	-0.13 (3.18)
Nitrogen Dioxide, Mean(SD), μg/m³	13.20	13.11 (4.56)	13.43 (4.66)
Fine Particulate Matter, Mean(SD), μg/m³	5.38 (0.91)	5.38 (0.91)	5.38 (0.90)
Age Mean(SD), years	54.56 (8.96)	61.48 (6.78)	55.69 (8.91)
Race n(%)			
Caucasian	8,667 (82.50)	6,061 (82.90)	2,606 (81.40)
Others	1,844 (17.50)	1,247 (17.10)	597 (18.60)
Education n(%)			
≤ High School	1,824 (16.80)	1,348 (17.80)	476 (14.40)
> High School & ≤ Bachelor's Degree	6,889 (63.30)	4,858 (64.10)	2,031 (61.50)
≥ Graduate Degree	2,162 (19.90)	1,368 (18.10)	794 (24.10)
Income n(%)			
<\$55,000	2,090 (20.50)	1,549 (22.00)	541 (17.20)
\$55,000-\$74,999	1,926 (18.90)	1,366 (19.40)	560 (17.80)
\$75,000-\$99,999	1,764 (17.30)	1,239 (17.60)	525 (16.70)
≥\$100,000	4,406 (43.30)	2,884 (41.00)	1,522 (48.30)
Marital Status n(%)			
Not Married	2,939 (27.00)	2,327 (30.70)	612 (18.50)
Married/Live-in Relationship	7,944 (73.00)	5,255(69.30)	2,689 (81.50)

Family History of Cancer n(%)			
No	4,033 (38.10)	2,739 (37.10)	1,294 (40.40)
Yes	6,546 (61.90)	5,255 (62.90)	1,910 (59.60)
Smoking History n(%)			
Never Smoker	6,141 (57.00)	4,318 (57.60)	1,823 (55.60)
Former Smoker	4,058 (37.60)	2,789 (37.20)	1,269 (38.70)
Current Smoker	580 (5.40)	395 (5.30)	185 (5.60)
Alcohol n(%)			
Never Drinker	452 (4.20)	342 (4.50)	110 (3.30)
Former Drinker	647 (6.00)	441 (5.80)	206 (6.20)
Current Drinker	9,740 (89.90)	6,759 (89.60)	2,981 (90.40)

Associations with lung cancer risk

There was no significant association between NDVI and lung cancer risk in the primary model (Table 2). Similarly, the CanALE walkability index showed no significant associations while comparing the lung cancer risk in moderate (HR = 0.95, 95% CI = 0.47 - 1.93) and high (HR = 0.48, 95% CI = 0.22 - 1.06) walkability regions to low walkability regions. Results for the Where Matters walkability index were very similar to those of the CanALE estimates in magnitude and trend. Although the findings were not statistically significant, an increase in both CANUE and Where Matters walkability metrics showed noticeable decreasing trends for lung cancer hazards. The Cox proportional hazards analysis for NDVI from Model 2, which was additionally adjusted for rolling averages of NO_2, elicited a reversal in the direction of effect for lung cancer risk while comparing the high NDVI group to the low NDVI group (HR = 0.96, 95% CI = 0.46 - 1.99). While assessing the walkability indices, model 2 estimates showed similar estimates and trends to those from Model 1.

Table 2. Results for lung cancer: Hazard ratio using Cox proportional models

N = 10,929	Lung Cancer (N= 50)		
Environmental Exposures	**Model 1**	**Model 2[c]**	**Cases (N)**
Normalized Difference Vegetation Index[a]			46 (10,274)
Medium	0.71 (0.33, 1.50)	0.63 (0.29, 1.37)	
High	1.14 (0.58, 2.23)	0.96 (0.46, 1.99)	
Canadian Active Living Environment[b]			45 (10,137)
Medium	0.95 (0.47, 1.93)	0.99 (0.48, 2.03)	
High	0.48 (0.22, 1.06)	0.53 (0.23, 1.23)	
Where Matters Walkability Index[b]			44 (10,028)
Medium	0.86 (0.39, 1.85)	0.89 (0.41, 1.96)	
High	0.54 (0.24, 1.23)	0.60 (0.26, 1.40)	

a: adjusted for age, race, family history of lung cancer, and smoking history

b: adjusted for tertiles of NDVI, age, race, family history of lung cancer, and smoking history

c: adjusted for tertiles of NDVI, age, race, family history of lung cancer, smoking history, and rolling average of nitrogen dioxide concentrations

Associations with colorectal cancer risk

Colorectal cancer risk was not significantly associated with NDVI, the CanALE walkability index, and the Where Matters walkability index in the primary model. However, there was a decreasing trend in the estimates with increasing NDVI exposure when compared to low NDVI exposure (HR = 0.96, 95% CI =0.53, 1.77 vs. HR = 0.75, 95% CI =0.40, 1.42). Adjusting for rolling averages of NO_2 in Model 2 did not result in changes in estimates or trends.

Table 3. Results for colorectal cancer: Hazard ratio using Cox proportional models

N = 10,929	Colorectal Cancer (N= 64)		
Environmental Exposure	**Model 1**	**Model 2[c]**	**Cases (N)**
Normalized Difference Vegetation Index[a]			61 (10,431)
Medium	0.96 (0.53, 1.77)	0.99 (0.54, 1.84)	
High	0.75 (0.40, 1.42)	0.79 (0.40, 1.56)	
Canadian Active Living Environment[b]			59 (9,912)
Medium	1.00 (0.53, 1.91)	0.98 (0.51, 1.87)	
High	0.88 (0.44, 1.74)	0.82 (0.40, 1.69)	
Where Matters Walkability Index[b]			56 (9,824)
Medium	0.88 (0.43, 1.83)	0.90 (0.43, 1.87)	
High	1.11 (0.54, 2.25)	1.15 (0.55, 2.40)	

a: adjusted for age, marital status, race, alcohol intake, and smoking history

b: adjusted for tertiles of NDVI, age, marital status, income, alcohol intake, and smoking history

c: adjusted for tertiles of NDVI, age, race, family history of colorectal cancer, smoking history, and rolling average of nitrogen dioxide concentrations

Associations with breast cancer risk

There was no association between NDVI and breast cancer risk in both models analyzed (Table 4). While analyzing breast cancer risk with the CanALE walkability index, we found a decreased risk of breast cancer nearing statistical significance when comparing the highest walkable areas to the lowest walkable area (HR = 0.65, 95% CI = 0.42-1.00). Similar point estimates and trends were obtained from model 2, although with wider confidence intervals (HR = 0.68 95% CI =0.43, 1.08). We found no significant association while analyzing the association of breast cancer risk with the Where Matters walkability index. However, a reducing trend in breast cancer risk approaching statistical significance was observed (medium vs. low walkability: HR = 0.83, 95% CI =0.56, 1.24, high vs. low walkability: HR = 0.70 95% CI =0.46, 1.07).

Table 4. Results for breast cancer: Hazard ratio using Cox proportional models

N = 7,611	Breast Cancer (N= 184)		
Environmental Exposure	**Model 1**	**Model 2[c]**	**Cases (N)**
Normalized Difference Vegetation Index[a]			162 (6,822)
Medium	0.95 (0.65, 1.40)	0.91 (0.62, 1.34)	
High	0.91 (0.62, 1.34)	0.84 (0.56, 1.27)	
Canadian Active Living Environment[b]			161 (6,736)
Medium	1.24 (0.85, 1.82)	1.27 (0.86, 1.87)	
High	0.65 (0.42, 1.00)	0.68 (0.43, 1.08)	
Where Matters Walkability Index[b]			157 (6,655)
Medium	0.83 (0.56, 1.24)	0.86 (0.57, 1.29)	
High	0.70 (0.46, 1.07)	0.73 (0.47, 1.14)	

a: adjusted for age, marital status, income, education status, race, family history of breast cancer, alcohol intake, smoking history, history of oophorectomy/hysterectomy, history of hormone replacement therapy, and interaction term of age with time

b: adjusted for tertiles of NDVI, age, marital status, income, education status, race, family history of breast cancer, alcohol intake, smoking history, history of oophorectomy/hysterectomy, history of hormone replacement therapy, and interaction term of age with time

c: adjusted for age, marital status, income, education status, race, family history of breast cancer, alcohol intake, smoking history, history of oophorectomy/hysterectomy, history of hormone replacement therapy, interaction term of age with time, and rolling average of nitrogen dioxide concentrations

Associations with prostate cancer risk

There was no significant association between NDVI and prostate cancer risk in the results from Model 1 (medium vs. low NDVI: HR = 0.92, 95% CI =0.52, 1.63, high vs. low NDVI: HR = 1.48 95% CI =0.88, 2.47). Similarly, while analyzing the CanALE (medium vs. low walkability: HR = 1.18, 95% CI =0.70, 2.00, high vs. low walkability: HR = 0.97 95% CI =0.53, 1.77) and Where Matters (medium vs. low walkability: HR = 0.92, 95% CI =0.54, 1.57, high vs. low walkability: HR = 0.87 95% CI =0.50, 1.54) walkability indices, there were no significant associations or noticeable trends in prostate cancer risk. Identical results were observed in Model 2 after adjusting for NO_2 concentrations for all three exposures.

Table 5. Results for prostate cancer: Hazard ratio using Cox proportional models

N = 3,318	Prostate Cancer (N= 103)		
Environmental Exposure	**Model 1**	**Model 2[c]**	**Cases (N)**
Normalized Difference Vegetation Index[a]			91 (3,016)
Medium	0.92 (0.52, 1.63)	0.91 (0.51, 1.62)	
High	1.48 (0.88, 2.47)	1.43 (0.83, 2.45)	
Canadian Active Living Environment[b]			89 (2,971)
Medium	1.18 (0.70, 2.00)	1.23 (0.72, 2.12)	
High	0.97 (0.53, 1.77)	1.04 (0.55, 1.97)	
Where Matters Walkability Index[b]			88 (2,955)
Medium	0.92 (0.54, 1.57)	0.98 (0.57, 1.67)	
High	0.87 (0.50, 1.54)	0.99 (0.56, 1.79)	

a: adjusted for age, marital status, income, education status, race, family history of prostate cancer, alcohol intake, and smoking history

b: adjusted for tertiles of NDVI, age, marital status, income, education status, race, family history of prostate cancer, alcohol intake, and smoking history

c: adjusted for tertiles of NDVI, age, race, family history of prostate cancer, smoking history, and rolling average of nitrogen dioxide concentrations

16.4. Discussion

Our study investigates the association between residential environmental exposures of greenness (NDVI) and walkability with cancer risk using a longitudinal cohort design. Although none of the effects were statistically significant, we observed potentially important trends through our analyses.

Greenness and cancer risk

We did not find statistically significant associations between NDVI exposure levels and lung and colorectal cancer risk in our analysis. However, on adjusting for air pollution factors we found a change in the direction of association from harmful to protective for lung cancer risk while comparing the highest NDVI exposures to the lowest (Table 2), highlighting the importance of accounting for the confounding effect of multiple collinear environmental exposures. Our analyses for lung and colorectal cancers were hampered by the low number of eligible incident cases, 50 and 64 respectively. However, previous research has shown a protective trend with lung cancer and no association with colorectal cancers[24,30,31]. A study by Huang et al. (2022) found a 5%

decrease in lung cancer risk using a Cox proportional hazards model with baseline covariates and lung cancer (HR: 0.95, 95% CI: 0.91–0.99)[28] while Kayyal-Tarabeia et al. (2022) found a 25% reduction in risk with a unit IQR increase in NDVI (HR = 0.75, 95% CI: 0.66–0.85)[29]. A third study by Sakhvidi et al. (2021) found no association between NDVI at a 100 m buffer and lung cancer risk (HR = 0.870, 95% CI= 0.691 - 1.095) but still exhibited a decreasing trend with increasing NDVI[32]. Both Huang et al. (2022) and Kayyal-Tarabeia et al. (2022) had a considerably larger number of cases and longer follow-up periods. Consequently, we believe the finding of no associations from the primary analysis could be a chance finding or an attribute of the limited number of cases developed in the cohort due to the short follow-up time. The proportional hazards Cox model performs better with more events and longer follow-up which helps in informed censoring.

While assessing breast cancer risk with measures of greenness findings have been mixed. Sakhvidi et al. (2021) and Kayyal-Tarabeia et al. (2022) found a decreased risk of breast cancer incidence[29,32]. However, similar to our findings Huang et al. (2022) found no association with NDVI[28]. We also found no association between NDVI and incidence of prostate cancer. While using low NDVI as the reference group, high NDVI exposure had higher point estimates of prostate cancer compared to medium NDVI exposure (medium vs. low NDVI: HR = 0.92, 95% CI =0.52, 1.63, high vs. low NDVI: HR = 1.48 95% CI =0.88, 2.47), but the estimates are likely the attribute of the wider confidence intervals, due to limited male sample size living in areas with the highest NDVI exposure, and not an actual increase in cancer risk.

From our findings and previous research, we surmise that exposure to increased green space can potentially decrease the risk of lung and breast cancer. While we could account for NO_2 as an air pollution factor, there could be other significant collinear exposures such as ambient night at light and noise pollution we have not considered in our analysis. Although NDVI is a popular method for measuring surrounding greenness[33], several other vegetation indices are available[34] in addition to discrete measures such as park count, and the choice of metric can affect research findings. Although dependent on the type of greenness (urban greenspace amenities vs. dense vegetation), increased exposure could also promote health by means of increased physical activity, and other physiological and psychological impacts[35].

Walkability and cancer risk

To our knowledge, there are no longitudinal studies investigating the direct effect of residential walkability on individual cancers making our study the first of its kind. A study by Keats et al. (2020) based on the Atlantic PATH cohort found no association between quintiles of the CanALE index and all-cancer risk[21]. Given that different cancer types have different etiologies, it is important to conduct epidemiologic studies for each cancer type. Although statistically non-significant, we found a decrease in lung cancer risk estimates with increased walkability while analyzing the 2006 CanALE index. Similar trends and estimates were obtained from the Where Matters (WM) walkability index. We did not find any significant associations or remarkable trends while examining the effect of walkability on colorectal and prostate cancer risk. However, all hazard ratio estimates for breast cancer risk, with the exception of the medium walkability exposure while assessing the CanALE index, were below the null effect of 1. This potentially signals a protective effect with longer follow-up durations as the cancer diagnoses in the initial follow-up could likely belong to susceptible individuals.

The difference in estimates from the two walkability indices could be the result of multiple factors. One is the difference in geographical units utilized to estimate the exposure. The Where Matters walkability was created at the residential postal code level while the CanALE index was created by using dissemination areas (DA) as the smallest unit. Dissemination areas are larger geographical units comprising of multiple postal codes. Secondly, the WM index also considers commercial floor area and land use mix to measure walkability, in addition to the residential and intersection density assessed by CanALE. As a result, we believe the WM index captures greater variability in the exposure, which also led to larger confidence intervals in the estimates. Moreover, the WM index is longitudinal in nature and able to account for changes in the participant's exposure over time.

Strengths and Limitations

The study has multiple strengths due to the longitudinal design, especially the ability to investigate temporal associations. Based on residential postal codes linked by self-report and tax records our analysis incorporates changes in residential exposures for greenness and the Where Matters walkability index and is not restricted to baseline estimates. With respect to cancer risk, the longitudinal design of the study enables us to evaluate causal relationships using highly quantitative spatially resolved exposure data.

The recruitment process for BCGP was based on non-probability sampling leading to non-representative samples for the province. The study population could differ in characteristics such as health-seeking behaviors from the general population, with differences potentially extending into the unobserved characteristics of individuals residing in well-developed areas with better infrastructure compared to those in lesser developed areas. Although we could account for behavioral risk factors like smoking and alcohol intake, observational studies always suffer from residual and/or unmeasured confounding. Self-reported data such as alcohol consumption, smoking habits, diet, and physical activity may suffer from social desirability bias. These factors might affect external validity to a certain extent; however, we expect strong internal validity due to the in-depth questionnaires curated to assess cancer risk and confounders. The sample sizes and cancer cases were limited to support detailed analyses of clinically relevant cancer subgroups. Nevertheless, the study sample, consisting of approximately 11,000 individuals, allowed us to study a range of environmental exposures over the Greater Vancouver Region increasing the variability in exposures.

16.5. Conclusion

Through our study, we were able to identify potential protective trends for greenness and walkability on certain cancer types. Individual-level behaviour interventions can influence public health considerably. As an example, due to effective public health campaigns about the ill effects of smoking, we have seen decreasing trends in tobacco-use and lung cancer incidence. However, lung cancer is still the leading cause of cancer death in Canada and other avenues, such as modifying the built environment, must be explored to reduce its burden on a wide-reaching scale. Given the complex nature of the built environment and the potential for interaction between multiple environmental factors, further research is required to confirm our findings.

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17. Appendix G: Travel & Climate Impacts - Full Article - The Association of Built Environment Factors on Active and Sedentary Travel Behaviour: A Cross-Sectional Travel Diary Study

17.1. Background

In North American we are currently facing both an epidemic of sedentary behaviour as well as a need to reduce greenhouse gas (GHG) emissions to mitigate further climate change. Initiatives to reduce the reliance on private vehicle travel, and instead promote the use of active travel modes (walking and cycling) and public transportation, may serve as a strategy to promote public health, and mitigate GHG emissions. Previous work has found a number of built environment factors to be associated with the amount of active travel (E. J. Kim et al., 2020; Koohsari et al., 2017; Liao et al., 2020; Thielman et al., 2015). This current study builds upon these previous works by utilizing detailed trips diary data from a regionally representative sample of households as well as more robustly attributing neighbourhood walkability through the use of the previous described walkability index.

The aim of this study is to examine the association between neighbourhood walkability and travel behaviour across mode (walking, biking, transit, and vehicle). We hypothesize that living in a more walkable neighbourhood would be associated with more trips made by an active mode (walking, biking, and/or transit) whereas living in a less walkable neighbourhood would be associated with more trips made by a sedentary mode (vehicle).

17.2. Methods

17.2.1. Data source, survey design, and ethics

This cross-sectional analysis utilized regionally representative data collected through TransLink's 2017 Trip Diary Data (TDD)[33]. Households through the Metro Vancouver

[33] https://public.tableau.com/app/profile/translink/viz/Trip_Diary_2017/TripDiary2017

Regional District (MVRD) and Fraser Valley Regional District (FVRD) were recruited through a stratified random sample with approximately 2.5% of households in the region completing the survey (83% via web survey and 17% using smartphone app). The TDD collected data on weekday travel patterns for all individuals living in the recruited households between September 15 and December 12, 2017. In addition to information about the origins and destination, travel mode, and trip purposes, household and individual demographic data was collected.

Neighbourhood walkability was calculated using a composite *Walkability Index* comprised of four component measures (net residential density, commercial floor area, intersection density, and land use mix). This study was reviewed and approved by the University of British Columbia's Research Ethics board (#H20-03032).

17.2.2. Study sample and study variables

The Walkability Index is a composite measure of neighbourhood walkability, comprised of 4 component variables (net residential density, commercial floor area, intersection density, and land use mix). Within this current analysis, the walkability value for each household was defined as the composite index value within a 1-kilometre network buffer, which follow a walkable road network, surrounding the location of the home (as defined by home 6-digit postal code). The values for each component measure were calculated beginning at the home postal code location and were then converted to z-scores to calculate the overall walkability index. The 1-km network buffer size was selected to represent the distance individuals could reasonably travel in a 10–15-minute walking trip and has been previous used to define the home "neighbourhood" area. (Colabianchi et al., 2007).

Individual and household demographic data were obtained from the TDD. For this current analysis the following variables were utilized and categorized as follows: gender (dichotomized as female or male), age (categorized as child/youth [age 5-18], adult [age 19-64], and older adult [65+]), driver's license status (dichotomous yes/no), car share status (continuous 0-4, the number of car share membership participants reporting having), employment status (categorized as 'full time employed', 'full time student', 'part time worker or student, or self-employed' or 'non-worker/non-student'), household income (categorized as <$50,000, $50,000-100,000, and >$100,000), household size (continuous 1-10), number of household bicycles (continuous 0-10), number of vehicles per adult in the home (dichotomized as less vehicles than adults [vehicles < adults] and 1 or more vehicle per adult in the home [vehicles > = adults]).

In addition to neighbourhood walkability, regional accessibility and sidewalk connectivity were calculated at the 6-digit postal code level and linked to the residential location. Regional accessibility was calculated by the mean number of minutes to travel to regional growth centers from the home location in morning peak traffic. These values were calculated for both vehicle travel, which provides an estimation of peak travel time from the home location if traveling by vehicle, as well as for transit travel, which conversely provides as estimation of peak travel time from the home if traveling by transit. Additionally, sidewalk connectivity, a measure of the completely of the pedestrian infrastructure, was calculated using methods similar to the walkability index in the 1-km network buffer surrounding the home.

17.2.3. Statistical analysis

We calculated descriptive statistics to characterize the study sample stratified by neighhourhood walkability. All analyses were completed in R version 3.6.1; we used the glmer function within the 'lme4' package to run generalized linear mixed-effect models.

Adjusted odds ratios (OR) and 95% confidence intervals (CI) were calculated using logistic regression and three iterations of adjustment variables. Three adjustment models were developed based on existing literature and conceptual understanding of individual and environmental factors associated with travel behaviour. Multi-level (or mixed effects) models were developed to account for the hierarchical nature of the TDD (e.g., multiple participants living in the same household). A two-level model was used to account for clustering of participants within households. Additionally, survey weights obtained from the TDD were utilized in these analyses.

17.3. Results

Walking

Certain individual and household characteristics increased the odds of reporting walking trips (

Table 17-1). Numerous individual variables were significantly associated across each iteration of these analyses including gender, age, employment status, car share status, and driver's licence status. Female participants had 1.22 times the odds of males to make a walking trip in the minimally adjusted model, when accounting for additional variables these results were attenuated, but remained statistically significant. Younger participants reported the most walking trips, with a 15% increase in odds of walking compared to adults (in the fully adjusted model). Participants who reported non-worker/non-student status reported the most walking trips, with 11% increase in odds of walking compared to full time workers. Conversely, participants who reported having a driver's licence had 14% reduced odds of reporting a walking trip compared to those without a driver's licences.

Regional accessibility did not have a significant effect on walking trips, however increased sidewalk connectivity did have a small but significant association with walk trips. There was a graded relationship between walkability and walking, for each increase in walkability there was a corresponding increase in walking trips, with this association being significant across each level of walkability. Participants in the most walkable neighbourhoods reported 13% increased odds in making a walk trip compared to those living in the least walkable neighbourhoods.

Table 17-1: Odds of walking trips across walkability quintiles

	Mod 1		Mod 2		Mod 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Gender						
Male	REF		REF		REF	
Female	**1.22**	**1.15, 1.30**	**1.02**	**1.01, 1.03**	**1.03**	**1.02, 1.03**
Age						
5-18	**2.32**	**1.98, 2.72**	**1.14**	**1.12, 1.17**	**1.15**	**1.12, 1.18**
19-64	REF		REF		REF	
65+	**0.54**	**0.48, 0.62**	**0.97**	**0.95, 0.98**	**0.97**	**0.95, 0.98**
Drivers License						
No	REF		REF		REF	
Yes	**0.30**	**0.27, 0.33**	**0.85**	**0.84, 0.87**	**0.86**	**0.84, 0.87**
Car share						
+1	**2.73**	**2.55, 2.94**	**1.10**	**1.08, 1.12**	**1.09**	**1.08, 1.11**
Status						
Full time employed	REF		REF		REF	
Full time student	**1.23**	**1.07, 1.41**	**1.03**	**1.01, 1.05**	**1.03**	**1.01, 1.05**
Part time employed/student or self-employed	**1.43**	**1.29, 1.58**	**1.05**	**1.03, 1.06**	**1.05**	**1.03, 1.06**
Non-worker/non-student	**2.09**	**1.87, 2.35**	**1.11**	**1.09, 1.12**	**1.11**	**1.09, 1.11**
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	**0.78**	**0.70, 0.87**	**0.98**	**0.97, 0.99**	0.98	0.97, 1.00
>$100,000	**0.89**	**0.80, 0.99**	**0.98**	**0.96, 0.99**	0.98	0.99, 1.00
Household size						
+1	**0.75**	**0.73, 0.77**	**0.99**	**0.98, 0.99**	0.99	0.99, 1.00
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		0.95	0.90, 1.00	0.96	0.91, 1.01
Bicycles						
+1	-		**1.02**	**1.01, 1.04**	**1.03**	**1.01, 1.04**
Regional Accessibility						
Vehicle	-		1.00	1.00, 1.00	1.00	1.00, 1.00
Transit	-		0.99	0.99, 0.99	0.99	0.99, 0.99
Sidewalk connectivity					**1.05**	**1.01, 1.09**
Walkability						
1	-		-		REF	

2	-		-		**1.04**	**1.01, 1.06**
3	-		-		**1.07**	**1.04, 1.10**
4	-		-		**1.11**	**1.08, 1.14**
5	-		-		**1.13**	**1.08, 1.19**

Notes: bolded results indicate statistical significance at p<0.05
Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.
Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

Cycling

The patterns for cycling trips differed considerable compared to the trends for walking trips (Table 17-2). Females had 58% decreased odds of making a bike trip, and full-time students reported lower odds of cycling trips (81% decrease in odds) compared to full time workers. Participants in households with more bicycles reported increased odds in making a cycling trip. There was no significant association between neighbourhood walkability and odds of participants making a cycling trip.

Table 17-2: Odds of cycling trips across walkability quintiles

	Mod 1		Mod 2		Mod 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Gender						
Male	REF		REF		REF	
Female	**0.37**	**0.31, 0.45**	**0.41**	**0.41, 0.42**	**0.42**	**0.30, 0.58**
Age						
5-18	**1.46**	**0.88, 2.43**	**4.86**	**4.85, 4.86**	**4.72**	**1.83, 12.2**
19-64	REF		REF		REF	
65+	**0.38**	**0.24, 0.59**	**0.73**	**0.73, 0.73**	0.68	0.32, 1.42
Drivers License						
No	REF		REF		REF	
Yes	**0.67**	**0.47, 0.95**	**0.56**	**0.56, 0.56**	**0.55**	**0.30, 0.99**
Car share						
+1	**3.29**	**2.86, 3.80**	**2.74**	**2.74, 2.74**	**2.71**	**1.94, 3.77**
Status						

Full time employed	REF		REF		REF	
Full time student	**0.42**	**0.28, 0.67**	**0.18**	**0.18, 0.18**	**0.19**	**0.07, 0.48**
Part time employed/student or self-employed	0.79	0.58, 1.05	**0.69**	**0.68, 0.69**	0.68	0.39, 1.19
Non-worker/non-student	0.98	0.67, 1.41	**1.37**	**1.37, 1.37**	1.40	0.73, 2.67
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	0.84	0.59, 1.20	**1.39**	**1.39, 1.39**	1.39	0.68, 2.85
>$100,000	1.15	0.82, 1.63	**1.34**	**1.34, 1.34**	1.31	0.64, 2.68
Household size						
+1	0.81	**0.73, 0.88**	**0.97**	**0.96, 0.97**	0.95	0.81, 1.11
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		0.47	0.09, 2.31	0.52	0.08, 3.47
Bicycles						
+1	-		**4.75**	**4.75, 4.76**	**4.75**	**3.56, 6.34**
Regional Accessibility						
Vehicle	-		**1.04**	**1.04, 1.04**	1.02	0.95, 1.01
Transit	-		**0.97**	**0.97, 0.97**	0.98	0.95, 1.01
Sidewalk connectivity	-		-		2.66	0.73, 9.68
Walkability						
1	-		-		REF	
2	-		-		0.83	0.39, 1.73
3	-		-		0.84	0.36, 1.98
4	-		-		0.42	0.12, 1.42
5	-		-		1.76	0.53, 5.85

Notes: bolded results indicate statistical significance at $p<0.05$
Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.
Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations
Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

Transit

Female participants reported increased odds (17%) of making a transit trip compared to male participants (

Table 17-3). Both child/youth respondents and older adult participants had lower odds of transit trips compared to adult participants. Similar to the effects for both walking and cycling travel mode, participants with a driver's license has lower odds of transit trips (89%), whereas participants with car share memberships were more likely to make a transit trip (119%). There was a large effect for employment status, with full-time student participants reporting 12.8 times (95% CI 10.6, 15.4) the odds of making a transit trip compared to participants who were employed full time. Unlike walking and cycling, income was associated with odds of participants reporting a transit trip, with higher income associated with lower odds of transit trips (45% decrease in the middle-income category, and 37% decrease in the higher income category compared to the lower income category), with these results remaining significant in the fully adjusted model. Increased neighbourhood walkability was also associated with greater odds of transit use, however, these results were less consistent across the levels of walkability when compared to the trends for walking trips. Participants with neighbourhood walkability in the 4th and 5th levels (e.g., the most walkability and second most walkable), reported greater odds of making a transit trip when compared to participants living in the least walkable neighbourhoods. However, these results do not follow the same graded response as for walking trips.

Table 17-3: Odds of transit trips across walkability quintiles

	Mod 1		Mod 2		Mod 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Gender						
Male	REF		REF		REF	
Female	**1.18**	**1.11, 1.26**	**1.15**	**1.05, 1.26**	**1.17**	**1.07, 1.28**
Age						
5-18	**0.01**	**0.01, 0.02**	**0.01**	**0.01, 0.02**	**0.02**	**0.01, 0.02**
19-64	REF		REF		REF	REF
65+	**0.73**	**0.64, 0.83**	**0.82**	**0.68, 0.99**	**0.81**	**0.67, 0.98**
Drivers License						
No	REF		REF		REF	
Yes	**0.09**	**0.08, 0.11**	**0.10**	**0.09, 0.12**	**0.11**	**0.10, 0.13**
Car share						
+1	**2.15**	**2.00, 2.30**	**2.30**	**1.98, 2.67**	**2.19**	**1.88, 2.55**
Status						
Full time employed	REF		REF		REF	
Full time student	**12.0**	**10.5, 13.7**	**13.8**	**11.4, 16.6**	**12.8**	**10.6, 15.4**
Part time employed/student or self-employed	0.93	0.84, 1.03	1.07	0.93, 1.25	1.08	0.93, 1.25
Non-worker/non-student	**0.60**	**0.53, 0.68**	**0.52**	**0.44, 0.63**	**0.53**	**0.44, 0.63**
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	**0.51**	**0.46, 0.57**	**0.56**	**0.47, 0.66**	**0.57**	**0.48, 0.67**
>$100,000	**0.54**	**0.48, 0.60**	**0.61**	**0.51, 0.73**	**0.63**	**0.53, 0.75**
Household size						
+1	**0.89**	**0.86, 0.92**	**0.93**	**0.89, 0.98**	**0.95**	**0.91, 0.99**
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		**0.18**	**0.08, 0.41**	**0.28**	**0.13, 0.60**
Bicycles						
+1	-		**0.75**	**0.66, 0.85**	**0.74**	**0.65, 0.84**
Regional Accessibility						
Vehicle	-		**1.08**	**1.06, 1.10**	**1.07**	**1.05, 1.09**
Transit	-		**0.94**	**0.93, 0.95**	**0.94**	**0.94, 0.95**
Sidewalk connectivity			-		**2.13**	**1.44, 3.16**
Walkability						
1	-		-		REF	

	2	-	-	1.10	0.88, 1.38
	3	-	-	1.22	0.95, 1.58
	4	-	-	**1.78**	**1.32, 2.42**
	5	-	-	**1.58**	**1.02, 2.44**

Notes: bolded results indicate statistical significance at $p<0.05$
Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.
Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

Vehicle

Individual and household characteristics that were associated with participants reporting a vehicle trip (either as the driver or passenger) differed considerable from the other modes of travel (

Table 17-4). Both child/youth participants and older adult participants reported significantly increased odds of making a vehicle trip compared to participants aged 19-64 years, with children/youth reporting the greatest odds of making a vehicle trip. Reporting being full time employed was associated with the greatest odds of vehicle travel, with full time students (86% reduced), part time employed/student or self-employed (33% reduced), and non-worker/non-student (51% reduced) categories reporting reduced odds of any vehicle trip. Unlike the other modes of travel, higher income was associated with greater odds of making a vehicle trip (this is opposite to transit travel, whereas there was no significant association for income and either walking or cycling trips). Additionally, participants with a driver's license had over 15 times the odds of taking a vehicle trip (either as the driver or passenger), compared to participants without a driver's licence. In the fully adjusted model, the ratio of household vehicles to adults in the home was not significantly associated with vehicle trips. Participants in the least walkable neighbourhoods reported the greatest odds of vehicle travel, however, only 4th walkability bin was associated with a significant decreased in odds of vehicle travel.

Table 17-4: Odds of vehicle trips across walkability quintiles

	Mod 1		Mod 2		Mod 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Gender						
Male	REF		REF		REF	
Female	**1.10**	**1.03, 1.18**	1.08	0.98, 1.18	1.07	0.97, 1.17
Age						
5-18	**9.06**	**7.69, 10.7**	**8.37**	**6.68, 10.5**	**7.72**	**6.16, 9.66**
19-64	REF		REF		REF	
65+	**1.34**	**1.17, 1.53**	**1.29**	**1.06, 1.57**	**1.29**	**1.06, 1.58**
Drivers License						
No	REF		REF		REF	
Yes	**14.5**	**13.0, 16.3**	**16.5**	**14.0, 19.4**	**15.7**	**13.3, 18.4**
Car share						
+1	**0.46**	**0.43, 0.50**	**0.60**	**0.51, 0.71**	**0.63**	**0.53, 0.74**
Status						
Full time employed	REF		REF		REF	
Full time student	**0.18**	**0.16, 0.20**	**0.13**	**0.11, 0.16**	**0.14**	**0.11, 0.17**
Part time employed/student or self-employed	**0.91**	**0.82, 1.01**	**0.67**	**0.57, 0.79**	**0.67**	**0.57, 0.79**
Non-worker/non-student	**0.71**	**0.62, 0.79**	**0.49**	**0.41, 0.58**	**0.49**	**0.41, 0.59**
Household income						
< $50,000	REF		REF		REF	
$50,000 - $100,000	**2.10**	**1.87, 2.35**	**1.85**	**1.55, 2.21**	**1.82**	**1.52, 2.18**
>$100,000	**2.31**	**2.06, 2.60**	**2.31**	**1.91, 2.80**	**2.24**	**1.85, 2.72**
Household size						
+1	**1.14**	**1.10, 1.17**	0.96	0.91, 1.01	**0.95**	**0.90, 0.99**
Household vehicles						
Vehicles < Adults	-		REF		REF	
Vehicles > = Adults	-		**2.23**	**1.08, 4.62**	1.93	0.93, 3.98
Bicycles						
+1	-		**1.31**	**1.14, 1.51**	**1.33**	**1.16, 1.53**
Regional Accessibility						
Vehicle	-		**0.93**	**0.91, 0.95**	**0.93**	**0.91, 0.95**
Transit	-		**1.07**	**1.06, 1.08**	**1.06**	**1.05, 1.07**

Sidewalk connectivity		-	**0.41**	**0.26, 0.63**
Walkability				
1	-	-	REF	
2	-	-	0.91	0.71, 1.17
3	-	-	0.76	0.57, 1.02
4	-	-	**0.59**	**0.42, 0.82**
5	-	-	0.69	0.42, 1.14

Notes: bolded results indicate statistical significance at $p<0.05$
Model 1 adjusted for gender, age, having a driver's licence, car share membership, employment status, household income, and household size. Model 2 adjusted for Model 1 variables, plus ratio of household vehicles to number of adults in household, number of household bicycles, and vehicle and transit regional accessibility. Model 3 adjusted for Model 2 variables, plus, sidewalk connectivity and 1km-network based walkability surrounding residential location.
Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations
Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

17.4. Discussion

This chapter describes the relationship between individual, household, and neighbourhood factors and trip mode reported in TransLink's 2017 Trip Diary Data. Overall, these analyses found an increase in active travel mode trips completed (in particular walking trips) and a reduction in sedentary modes (vehicle trips) as neighrbouhood walkability increased, when adjusting for other individual, households, and neighbourhood factors. This effect was most apparent for walking trips, with each increase in niehgbourhood walkability associated with a further significant increase in walking trips. These results are consistent with previous work which found an increase in walking trips completed in more walkable neighbourhoods (Kim et al., 2020), additionally, similar individual and household characteristics were found, with women, younger age, and lower household incomes associated with completing more walking trips. This same pattern was also seen when examining utilitarian walking trips across urban areas in Canada, with increased walking trips reported in more walkable neighbourhoods (Wasfi et al., 2016). Additionally, previous work which looked at components of walkability, found that residential density and land use mixed were also independently associated with increased transportation walking (Eriksson et al., 2012).

Similar to previous work (Riggs & Sethi, 2020), there were increased odds of transit trips in more walkable neighbourhoods, however, this effect was only significant and in the two most walkable quintiles. Previous work also tended to find more biking trips complete in more walkable areas, however this was only seen in the most walkable quintile in this current analysis.

There are a number of strengths of this current work, including the generalizability to the population of the MVRD. However, the cross-sectional nature of these data limit the ability to determine cause and effect, and therefore these results represent correlations rather than causal relationships.

17.5. Conclusions

Analysis results showed that individual, household, and neighbourhood characteristics are all associated with trip mode. When controlling for other factors, living in more walkable areas was associated most strongly with reporting walking trips.

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18. Appendix H: Travel & Climate Impacts - Full Report - Transportation Emissions Estimates for Integrated Environment-Health Modelling

18.1. Methods for emission estimates

18.1.1. Data sources

Trip Diary Data

The main source of travel information is TransLink's 2017 Trip Diary Data (TDD) (Ipsos, 2018). Sample households for the TDD were recruited from Grater Vancouver Regional District and Fraser Valley Regional District[34] by a pre-notification letter and followed up by telephone recruitment. Participants completed the survey primarily online and some opted to use a smartphone app. A travel diary instrument was used to record all travel by members of the sampled households over 1 day (or 3 days if they used the smartphone app) between September 15 and December 12, 2017. Person and household sampling weights[35] are included in the TDD to account for representation differences between the sample and the regional population (as indicated by census data). This study was reviewed and approved by the University of British Columbia's Research Ethics board (#H20-03032).

The TDD were initially processed and cleaned by data verifications (e.g., verifying trip mode based on trip characteristics) and logic checks (e.g., changing underage drivers to passengers) as part of the data collection process before we gained access to the data. For our analysis, two additional data processing steps were undertaken.

1. We executed automated and manual corrections of the text string descriptions of vehicles to enable matching to external vehicle datasets, as described below. For example, "F150" was replaced by "F-150".
2. We filtered to remove trips with at least one trip-end (origin or destination) outside the geographic scope of our analysis: metropolitan Vancouver (which is provided

[34] Illustrated in https://public.tableau.com/app/profile/translink/viz/Trip_Diary_2017/TripDiary2017

[35] The TDD provides expansion weights (sometimes referred to as expansion factors), which we normalize to sampling weights by dividing by the mean expansion weight (to avoid inflating standard errors in subsequent weighted regression analysis).

as a variable in the TDD). This eliminated 1,333 trips (0.59% of the TDD), primarily auto driver (65%) or auto passenger (26%) trips.

In total, the TDD consist of 224,525 trips by 57,431 persons in 27,980 households, who collectively own 37,148 motor vehicles and 35,146 bicycles. Based on the geographic study scope (see above), 1333 trips (0.59%) were excluded, leaving 223,192 trips for analysis. The primary mode shares for the analyzed trips were auto driver (55%), auto passenger (14%), walk (15%), transit (13%), and bicycle (2%) – see Table 18-1.

The key information extracted from the TDD for emissions estimates included:

1. Trip-end locations (origin and destination)
2. Departure time
3. Travel modes
4. Vehicle
5. Vehicle occupancy

Table 18-1. Modal distribution of trips in the TDD

Primary mode	Single mode	Multi-mode	Total	
Auto Driver	122,880	142	123,022	55.1%
Auto Passenger	31,336	68	31,404	14.1%
Taxi	518	3	521	0.2%
Transit Bus	11,867	819	12,686	5.7%
Sky Train	6,919	9,061	15,980	7.2%
Westcoast Express	69	161	230	0.1%
Handy Dart	150	3	153	0.1%
Sea Bus	97	90	187	0.1%
Walk	33,516	0	33,516	15.0%
Bike	4,266	5	4,271	1.9%
School bus	609	21	630	0.3%
Other mode	591	1	592	0.3%
Total	212,818	10,374	223,192	100.0%

Some trips reported in the TDD involved the use of multiple modes of travel. The TDD defines the "primary" mode as the mode that was most likely used for the largest proportion of the trip, with a hierarchy of rail transit, bus transit, then automobile and other modes for multi-modal trips (TransLink, 2013b). For emissions estimation, we disaggregate multi-modal trips into modal "segments", as described below (after the description of methods for uni-modal trips).

Regional travel model data

TransLink's regional travel model (RTM) provided essential additional information to enhance the precision of the emissions estimates. TransLink's RTM is a four-step, trip-based travel model, implemented in EMME software (TransLink, 2018). The current version of the RTM was estimated using data from TransLink's 2011 trip diary data (the predecessor to the TDD) (TransLink, 2013b).

The main use for the RTM data was for link-level information on peak and off-peak period network congestion levels. Roadway congestion is an important factor in motor vehicle emission rates, and integration of travel demand and emissions models has been a key environmental analysis tool for decades. In fact, application to travel demand model outputs was a key use case in MOVES model development (U.S. Environmental Protection Agency, 2022b). Mesoscopic emissions models like MOVES enable modellers to account for the emissions impacts of typical microscopic (second-by-second) traffic dynamics in an aggregate analysis through the use of archetypal facility-specific driving patterns (or "drive cycles"), applied at each network link traversed in a trip.

For this application of the RTM, transportation network data were used in the form of shapefiles identifying the locations and attributes of network links. Separate road and transit networks were provided. The RTM road network consists of 20,043 links with an average length of 61.5 m. The road network is a simplification typically used in travel demand models, representing only the facilities used to travel between Transportation Analysis Zones (TAZ), which are themselves aggregations of travel-generating geographic areas (Ortuzar & Willumsen, 2011). The road network data include almost all the primary and secondary roadways, but not most local streets (i.e., most arterials, some collectors, and few local streets). As only inter-zonal (between-TAZ) trips are modelled on the network, "centroid connectors" (synthetic links) are designed and added to the network to represent the intra-zonal portions of inter-zonal trips (i.e., the portion which typically occurs on collector and local streets).

Link attributes in the roadway network include: 1) road type: 19 classes describing modal access (autos, high-occupant vehicles, buses, bicycles, pedestrians, etc.), and 2) mean travel time at 3 modelled time periods: Morning peak (6 to 10 hr), Afternoon peak (15 to 18 hr), and Off peak (all other hours). The transit network includes all of the regularly serviced transit lines in the region, including bus, Sky Train, Sea Bus, and West Coast Express services (i.e., road, rail, and marine transit).

The RTM network data were further processed for application with the TDD and MOVES to emissions estimation. Firstly, to meet the formatting requirements of the routing software used (see below), two-way roads (represented as paired 1-way links in the RTM) were converted into a single 2-way link. Secondly, centroid connectors were manually corrected for 5 TAZ. Thirdly, in accordance with MOVES guidance, link attributes were added to align with the MOVES "Road Type" designation, which is the four combinations of setting (Urban or Rural) and access (Restricted or Unrestricted) (U.S. Environmental Protection Agency, 2016). The setting attribute (Urban/Rural) was based on Metro Vancouver's land use designations (Metro Vancouver, 2020) for the majority of the link length, illustrated in Table 18-2. The access attribute (Restricted/Unrestricted) was based on the RTM link types, using the mapping shown in Figure 18-1.

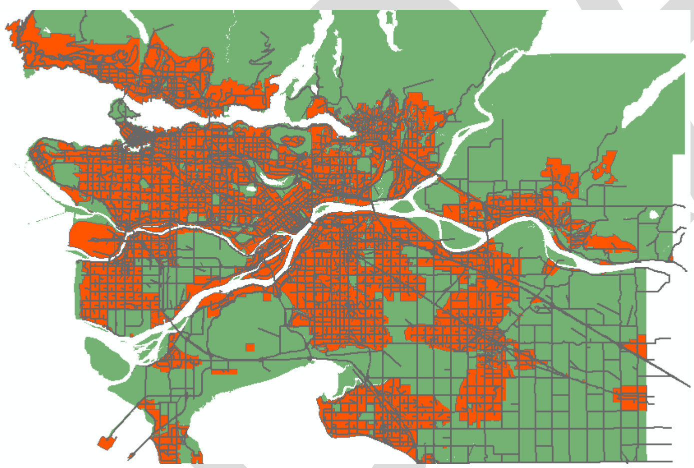

Figure 18-1. Urban (orange) and rural (green) link settings, based on Metro land use designations

Table 18-2. Mapping of RTM to MOVES road types for the network data

RTM network link type	MOVES Road Type
Highway	Restricted
Highway directional ramp	Restricted
Highway loop ramp	Restricted
Freeway	Restricted
Ramp	Restricted
HOV lane	Restricted
Centroid connector	Unrestricted
Arterial	Unrestricted
Collector	Unrestricted
Local	Unrestricted
Commercial vehicle access only	Unrestricted
Other roads	Unrestricted

Transit system operations data

TransLink transit system operation data were used to generate regional, fleet-specific vehicle emission factors and vehicle occupancy (i.e., passenger loads) for metro Vancouver. These data were taken from the 2019 Transit Service Performance Review (TransLink, 2019). Data processing for emissions estimates is described below.

The RTM transit network consists of 16,214 links with an average length of 390 m. These transit network data were enhanced with TransLink's General Transit Feed Specification (GTFS) data for the period September to December 2017, including transit line attributes (TransLink, 2022a).

18.2. Automobile trips

This section describes the estimation of emissions associated with uni-modal trips in automobiles, which includes private automobiles (cars, passenger trucks, vans, sport utility vehicles, etc.) and shared automobiles (both car-share and taxi/ride-hail). Similar methods are also applied to the estimation for Automobile segments of multi-modal trips.

Emissions for automobile trips are calculated as the summation of four components: operating (start and running) and non-operating (fuel and vehicle lifecycles). Non-operating emissions are attributed to vehicle-trips based on the amount of fuel and proportion of vehicle-life consumed by the trip. Vehicle-trip emissions are then attributed to person-trips based on vehicle occupancy (excluding working drivers for ride-hail services). All four automobile emission components are vehicle-dependent, and the operating emissions also vary with facility type, congestion level, and temperature.

Vehicle information

Automobile emissions vary greatly across vehicle types. In the TDD, auto driver and passenger trips were self-reported as made by: 1) a household vehicle, 2) another household's vehicle, 3) a car-share vehicle, or 4) in a taxi/ride-hail vehicle. The vehicle information reported in the TDD for each of these trip types is summarized in Table 18-3, and described next.

Table 18-3. Passenger vehicle information reported in the TDD and assumptions used in analysis

Type of vehicle	Number (share) of automobile trips	TDD vehicle information	Assumptions
Private, traveler's household	148,412 (96%)	Make, model, year, fuel	Imputations for missing data
Private, another household	5,127 (3.3%)	None	Most common registered vehicle in Metro Vancouver in 2017 (2015 Toyota Corolla)
Car-share	677 (0.4%)	None	Representative vehicles based on car-share membership
Taxi	518 (0.3%)	None	2017 Toyota Prius HEV

18.2.1.1. Household private vehicles

For trips made using a private vehicle from the traveler's household, the TDD included self-reported information on the vehicle's make, model, model-year, and fuel type. The entire TDD dataset included trips made by 8,086 unique combinations of vehicle make-model-year. However, vehicle information was missing or incomplete for many trips. Table 18-4 summarizes the extent of missing/incomplete data and the imputation of missing vehicle attributes. Individual missing attributes were assumed as the mode (i.e., most frequent observation) for vehicles with similar non-missing attributes in the 2017 Metro Vancouver automobile fleet (excluding coach and other heavy-duty vehicles), as reported by the Insurance Corporation of British Columbia (ICBC) (2020). The ICBC dataset includes all registered passenger vehicles in British Columbia, filtered to only vehicles registered to households in Metro Vancouver. The ICBC dataset does not include joint distributions of model and year, so the make/model frequency distribution is year-invariant.

Table 18-4. Summary of missing vehicle information for trips by household vehicles

Missing field(s)	Trips as driver of household vehicle	Trips as passenger in household vehicle	Imputation assumptions
None	108,196 (92%)	2 (0%)	Not applicable
Only make	914 (1%)	0 (0%)	Inferred from model
Only year	2004 (2%)	0 (0%)	Most common model-year (2015)
Make and model	112 (0%)	0 (0%)	Most common make/model (Toyota Corolla)
Make and year	551 (0%)	0 (0%)	Most common model-year; make inferred from model
All three (make, model, year)	5,300 (5%)	31,333 (100%)	Concurrent household trip, most-used household vehicle, or random vehicle from Metro Vancouver fleet
Total	117,077 (100%)	31,335 (100%)	Not applicable

If no vehicle information was available for the reported trip (i.e., all three attributes were missing), the following imputation process was used.

1) Look for concurrent (time and location) auto trips within the same household, and use the vehicle information reported for those trips; this was particularly effective for auto passenger trips, for which a concurrent auto driver trip in the same household yielded vehicle information for 14,155 trips (45% of the missing values).
2) For the remaining trips made by household vehicles, the trip was assumed to be made by the most-used vehicle in the traveller's household.
3) For the 883 households with no reported vehicle information but trips reported as having been made by household vehicles, household vehicle information (model-year and then make/model) was drawn from the 2017 Metro Vancouver fleet distribution (ICBC data). Because ICBC provides marginal (not joint) distributions, an existence criterion was imposed (i.e., available models were restricted by the model-year of manufacture).

To obtain additional vehicle attributes, each vehicle make-model-year was matched to US/Canada vehicle fleet datasets from Natural Resources Canada (NRCAN) (Natural Resources Canada, 2022), Canadian Vehicle Specifications (CVS) (Transport Canada, 2021) and the US Department of Energy and Environmental Protection Agency (EPA) (U.S. Department of Energy & U.S. Environmental Protection Agency, 2022), using string matching in R with manual corrections for automated match failures. Missing or erroneous fuel/powertrain types were imputed from the matched vehicle fleet datasets. Fuel type was unknown for only 12 unique make/model/year combinations in the dataset, and powertrain type was unknown for 3. We assumed these vehicles were gasoline ICE, based on the majority of the non-missing vehicle fleet attributes. The final processed fuel/powertrain types for vehicles in the TDD were 92.7% gasoline ICE, 4.6% diesel ICE, 1.9% gasoline-electric hybrid (HEV), 0.3% plug-in gasoline-electric hybrid (PHEV), and 0.5% battery-electric vehicles (BEV).

Vehicle models were not differentiated by engine size or transmission type, consistent with both the emissions model and travel survey scopes. The NRCAN data can contain multiple entries for varying transmission type, engine size, or number of cylinders within a given make, model, and year. Table 18-5 gives the number of unique household vehicles (out of 8086) with multiple matches in the NRCAN data (60% overall) and the number for which the NRCAN data vary by each vehicle attribute (some vary across multiple attributes). The BEV with multiple matches varies by range. The range of NRCAN reported fuel economy within a given make, model, and year averaged 1.2 L per 100 km, or 10% of the mean fuel economy. For these vehicles, we use the average NRCAN fuel economy within the make, model, and year.

Table 18-5. Number of unique household vehicles (out of 8086) matching multiple entries in the NRCAN fuel economy dataset for a given make, model, and year

Powertrain type	Number of matches in NRCAN data[1]			Varying attributes across matches		
	1	2	3+	Transmission type	Engine size	Number of cylinders
ICE	3031	3272	1555	4032	2135	1315
HEV	158	2	0	1	0	0
PHEV	23	0	0	0	0	0
BEV	44	1	0	0	0	0
All	3256	3275	1555	4033	2135	1315

[1] (Natural Resources Canada, 2022)

18.2.1.2. Non-household private vehicles

No vehicle information was recorded for trips made using a private vehicle from another household (#2 above). For these trips, we assigned the most common vehicle registered in Metro Vancouver in the ICBC 2017 fleet data: a 2015 Toyota Corolla (gasoline).

18.2.1.3. Car-share vehicles

For car-share trips (#3 above), the TDD does not include vehicle nor car-share service information. However, the TDD does include person-level car-share memberships for ZipCar, Modo, Car2Go, and Evo (the four major car-share services operating in Metro Vancouver in 2017). We identified a representative vehicle for each car-share service based on their respective fleets (Martin & Shaheen, 2016; Metro Vancouver, 2014) – see Table 18-6.

Table 18-6. Car-share services and vehicles

Service	Service type	Representative vehicle
Evo	A-to-B (1-way)	2017 Toyota Prius
Car2Go	A-to-B (1-way)	2015 Smart for two
Modo	A-to-A (2-way)	2015 Toyota Corolla
ZipCar	A-to-A (2-way)	2015 Toyota Corolla

We then assigned a vehicle to the trip based on the traveller's memberships (for driving trips) or the household's memberships (for passenger trips). Most people (91.6%) in the TDD were not car-share members, while 5.2% had 1 membership, 2.7% had 2 memberships, and 0.6% had 3 or 4 memberships. If multiple memberships were available, we used the following heuristic:

1) The representative vehicle for both 2-way services are the same, so no differentiation is needed.
2) If both 1-way services were available, we assign Evo based on higher overall usage.
3) If both 1-way and 2-way services were available (rare), we assumed a 2-way service was used for complete car-share tours (i.e., no other modes used), and a 1-way service was used otherwise.

18.2.1.4. Taxi vehicles

For taxi or ride-hail trips (#4 above), the specific service was not reported. At the time of the survey, no major ride-hail companies (such as Uber or Lyft) were operating in Metro Vancouver. Hence, it is assumed that the vast majority of the reported trips were by traditional taxi service, which in Metro Vancouver is mostly gasoline-electric hybrid vehicles[36]. We assume all taxi trips are made by 2017 Toyota Prius HEV, based on the most common HEV vehicle in the ICBC 2017 fleet data described above; this make and model is consistent with our observations of the regional taxi fleet.

Occupancy

Vehicle occupancy is a key factor for attributing vehicle emissions passenger-trips. Vehicle occupancy (excluding the driver for taxi/ride-hail trips) was reported for automobile trips in the TDD. If occupancy was missing, occupancy was assumed to be 1.24 for taxi trips (TransLink, 2013a), and 1.60 for all other automobile trips (the average occupancy in the TDD) .

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[36] The largest two operators are Yellow Cab: https://www.yellowcabonline.com/about/about-the-team/ and Black Top & Checker Cabs: https://btccabs.ca/about-us/

Operating emissions

Operating emissions are calculated using the variables shown in Table 18-7. The total person-trip emissions are calculated by summing the start and running vehicle emissions (by link l), adjusted for deadheading, and then dividing by vehicle occupancy:

$$E_o = \frac{e_s + \frac{\sum_l L}{1 - D_r} e_r MF}{\theta}$$

Because MOVES emission rates are uniform within Source Type categories (for a given Model Year and Fuel Type), we apply a make/model-specific adjustment factor (MF) to the MOVES rates (separately for each Road Type), based on model-specific fuel economy test data. This approach enables us to leverage both the link-level congestion-sensitive emission rates from the MOVES model (by Source Type, Fuel Type, Model Year, and Road Type), and the detailed vehicle information (make/model/year) in the TDD to account for efficiency differences by make/model within a given vehicle class. The following sub-sections describe these analysis steps in detail.

Table 18-7. Variables used to calculate automobile operating emissions

Variable	Description	Units	Parameters[1]	Source
θ	Occupancy	People per vehicle (PKT per VKT)	None	TDD
MF	Model factor, to adjust MOVES rates by source type	None	MM, MY, RT	Fleet datasets
L	Link length	km	None	Network and route
D_r	Deadheading rate	Proportion	None	Literature
e_r	Running emission rate	g per km	MY, ST, FT, RT, SP	MOVES modelling
e_s	Start emission rate	g per start	MY, ST, FT, HR	MOVES modelling

[1] Conditioning factors for the variable: FT (fuel type), HR (hour of day), MM (make/model), MY (model year), RT (road type), SP (average speed), ST (source type)

18.2.1.5. MOVES emission rate modelling

Emission rates were estimated in MOVES2014, the latest version of the MOVES (MOtor Vehicle Emissions Simulator) model at the time of analysis (EPA has since released a new version: “MOVES3”). Detailed information about MOVES can be found in EPA reports on its development over several decades (U.S. Environmental Protection Agency, 2022b). Briefly, MOVES is a modal model, which estimates second-by-second emissions for archetypal drive cycles (1-sec speed profiles). The emission rates are conditioned on vehicle fleet parameters such as Source Type (passenger car, passenger truck, motorcycle, transit bus, etc.), Fuel Type (gasoline, diesel, ethanol, compressed natural gas (CNG), electricity, etc.), and Model Year. The drive cycles are conditioned on the Source Type and contextual parameters such as Road Type (combinations of urban/rural and restricted/unrestricted, as well as off-network) and Average Speed Bin (representing link congestion levels, specific to each Road Type). In addition to running exhaust, MOVES includes modules to estimate emissions from vehicle starts, refuelling, evaporation, brake/tire wear, and other processes.

The MOVES model was used to create emission rate lookup tables for application to the TDD, which is one of the recommended modes of operation. For this application, the MOVES Run Specification was set to generate Emissions Rates for a Custom Domain in October 2017 (the time of the TDD). MOVES requires an extensive input database, but not all tables are required for disaggregate emission rates (rather than an emissions inventory). Some MOVES input information was provided by Metro Vancouver's Air Quality and Climate Change team (Metro), which conducts regional air quality modelling and analysis for the Vancouver region. Metro provided the MOVES input files they used to model 2015 regional motor vehicle emissions for air quality analysis (Metro Vancouver, 2018). Metro prepared these input files using local information on the vehicle fleet composition, fuels, vehicle activity distributions across hours, road types, speed bins, weather, inspection/maintenance programs, etc. The values in the provided files were checked by comparison to alternate data sources on the vehicle fleets (Insurance Corporation of British Columbia (ICBC), 2020; Natural Resources Canada, 2022; Statistics Canada, 2010; Transport Canada, 2021), vehicle activity (TransLink, 2013a, 2013b, 2018), and archived weather station data for meteorology (Environment and Climate Change Canada, 2020; Pacific Climate Impacts Consortium, 2020; Weather Underground, 2022). One adjustment was necessary for application to the TDD: MOVES default fuel formulation was used for the E85 ethanol fuel type, which was reported in the TDD (for just 6 automobile trips by one vehicle) but excluded from the Metro modelling.

MOVES execution provided emission rates for GHG (CO_2e) and CAC (VOC, CO, NO_x, $PM_{2.5}$, PM_{10}), as well as fuel consumption rates. *Running* emission rates (per VKT) were generated for each unique combination of: Source Type, Fuel Type, Model Year, Road

Type, and Average Speed Bin. Running emissions included the emission processes: running exhaust, brakewear and tirewear, running evaporative emissions, crankcase running exhaust, and refueling losses. *Start* emission rates (per start) were generated for each unique combination of: Source Type, Fuel Type, Model Year, and Hour (to account for varying ambient and engine temperatures).

18.2.1.6. Assigning vehicles to MOVES categories

A mapping is required to apply the MOVES rates to the TDD automobile trip data. The NRCAN (Natural Resources Canada, 2022) and EPA (U.S. Department of Energy & U.S. Environmental Protection Agency, 2022) fuel economy data were used to determine the Source Type for each unique vehicle (make-model-year) in the TDD, based on MOVES guidance (U.S. Environmental Protection Agency, 2022b). MOVES Passenger cars (Source Type 21) includes sedans, compacts, station wagons, and two-seaters; MOVES Passenger trucks (Source Type 31) includes vans, minivans, pickup trucks, and SUV. The size distribution of vehicles in the TDD is illustrated in Figure 18-2.

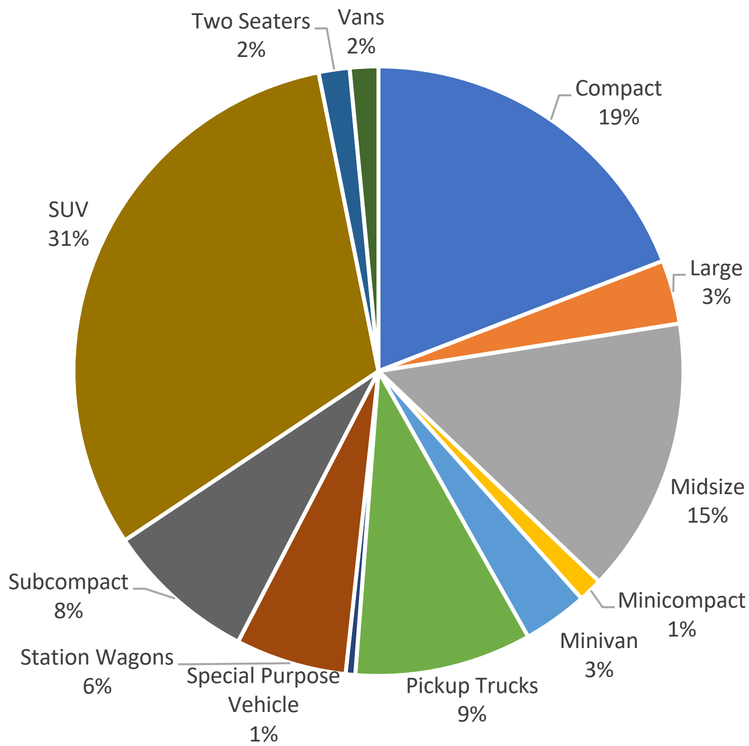

Figure 18-2. Vehicle sizes in the TDD

MOVES does not differentiate powertrains within Fuel Type categories, hence the gasoline Fuel Type includes ICEV, HEV, and PHEV (U.S. Environmental Protection Agency, 2019). This limitation is accounted for with our model-specific MF adjustment. For PHEV, which includes both gasoline and electricity fuel types, we assume a weighted combination of 52.5% gasoline and 47.5% electricity energy sources, based on literature (Kannangara et al. 2021 and Dunn et al., 2015).

18.2.1.7. Model-specific efficiency adjustment

To account for emission rate variation of specific vehicle models within Source Type categories, we develop and apply a Model Factor (MF), calculated as:

$$MF = \frac{FE_{MM,MY,RT}}{FE_{ST,MY,RT}}$$

were $FE_{MM,MY,RT}$ is the fuel economy for the trip-vehicle's specific make/model/year, and $FE_{ST,MY,RT}$ is the fleet-average fuel economy for the relevant MOVES Source Type and Model Year. Fuel economy for the trip's vehicle (in L/100km) is taken from NRCAN data (Natural Resources Canada, 2022), averaged across variations in engine size or transmission type within a given make/model/year as described above. Fleet-average fuel economy for the MOVES Source Type and Model Year (in miles/gallon) is taken from EPA data (U.S. Environmental Protection Agency, 2022a), and then converted into L/100km. For ICE vehicles, fuel economy and MF are separately calculated for "city" and "highway" driving/rates – which are then applied separately to the MOVES unrestricted and restricted link Road Types, respectively.

Figure 18-3 shows the distribution of MF values for the TDD automobile trips. The mean trip-averaged MF was 0.93, indicating that the Metro Vancouver automobile fleet is more fuel-efficient (lower-emitting) than the U.S. average. The mean trip fraction on city (vs. highway) links was 88%, reflecting the urban context and relatively low share of limited-access highways/freeways in the Vancouver region.

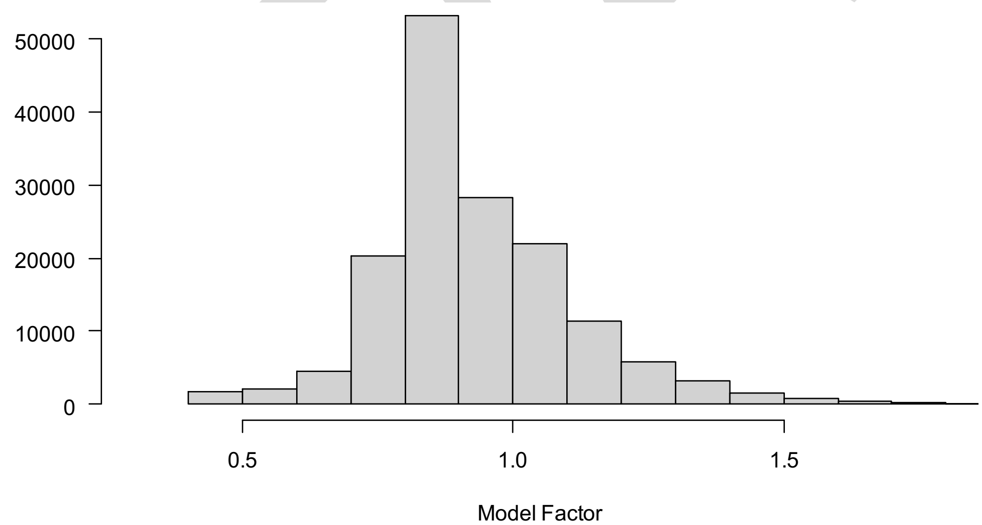

Figure 18-3. Distribution of Model Factor (MF) values

18.2.1.8. Vehicle routing

Automobile trips were routed from origin to destination on the road network data as represented in the RTM. The following RTM network adjustments were made for automobile routing:

1. Remove non-roadway links (pedestrian, water, rail, gondola),
2. Remove non-automobile links (bus only, commercial vehicle access only),
3. Select link travel times based on the start time of the trip (to account for typical congestion level), and
4. Conditionally assign HOV links a travel time of 10,000 minutes if automobile occupancy was 1 (so that they are not used by SOV).

Precise locations (latitude – longitude) for origins and destinations were “snapped” (orthogonal projection) to the nearest centroid connector within their respective TAZ. The network shortest (time) path sequences of links were determined using R software (R Core Team, 2019) with the package igraph (Csárdi et al., 2023). Ties for shortest time routes were broken by similarity to the self-reported distance (km) in the TDD.

The estimated travel times for the routed trips averaged 13.9 min (standard deviation of 12.9), whereas the travel times reported in the TDD averaged 17.1 min (standard deviation of 14.6). The linear correlation between the two travel time estimates was 0.91 ($p<0.01$). Travel times reported in the TDD were estimated using the Google Maps API. This tool was not used for the emissions analysis because it generates route rather than link information, in addition to TDD privacy restrictions.

18.2.1.9. Vehicle starts

Each automobile trip was assumed to generate a single start event. The relevant per-start emission rate from MOVES was determined by the vehicle (Source Type, Model Year, Fuel Type) and the hour of the day that the trip began. No model-specific adjustment was made due to a lack of model-specific start emissions data. The hour parameter serves to account for the effects of varying ambient and engine temperatures on start emissions. We attempted to track vehicle activity through the TDD to calculate soak time (i.e., elapsed time since the last engine-off event) for each vehicle start, but the results were too uncertain. So instead, the hour parameter accounts for the typical distribution of soak times for vehicle starts within given hour of the day.

Non-operating (upstream & downstream) emissions

The non-operating emissions accounted in this analysis include those attributable to 1) upstream activities for fuel provision (i.e., "well-to-tank" emissions), and 2) upstream (production), downstream (disposal/scrappage), and non-operating in-use (maintenance) phases of the vehicle lifecycle. The fuel and vehicle cycle calculations are described in the next two sub-sections.

18.2.1.10. Fuel cycle

Upstream fuel emissions are calculated as proportionate to the amount of fuel consumption (in litres for petrol fuels and kWh for electricity), which assumes that the trip-level fuel consumption is negligibly small with respect to the total vehicle fuel demand (i.e., these specific trips have no direct impact on decisions in the fuel sector). Fixed upstream or "well-to-tank" (WTT) emission rates (in kg CO_2e per unit fuel type) are applied to the operating fuel consumption.

For petrol fuels (gasoline, ethanol, and diesel), WTT emission rates are taken from GHGenius[37] ((S&T) Squared Consultants Inc., 2022), which is supported by Natural Resources Canada and approved for regulatory use in B.C. (B.C. Ministry of Energy, Mines and Petroleum Resources, 2017). GHGenius provides geography-specific lifecycle emissions data for the Canadian context, and is widely used in practice. WTT emission rates are extracted for BC in 2017. The shares of feedstock used in fuel production (fossil versus biomass) are set consistently with the MOVES fuel formulation data provided by Metro Vancouver: fossil feedstocks of 94% for gasoline, 100% for diesel, and 26% for ethanol (and the rest assumed biomass). The resulting WTT emission intensities (in kg CO_2e per L) are 0.8297 for gasoline, 0.8365 for ethanol, and 0.9128 for diesel.

The WTT emission rate for operating electricity (used by PHEV and BEV) is assumed to be 0.0317 kg CO_2e per kWh, based on the GHG intensity of electricity consumed from BC's electricity grid in 2017 as reported by the BC government (B.C. Ministry of Environment and Climate Change Strategy, 2022). Note that this is the GHG intensity of electricity consumption in BC, some of which is produced outside of the province. The GHG intensity of BC's electricity production is substantially lower, for example 0.01067 kg CO_2e per kWh

[37] https://www.ghgenius.ca/

for BC Hydro production (BC Ministry of Environment and Climate Change Strategy, 2022), but inappropriate for calculation of consumption-side intensity.

18.2.1.11. Vehicle cycle

Non-operating emissions attributable to the vehicle cycle are calculated using the emission estimation framework applied in Kannangara et al. (2021), which is consistent with wide practice. The framework in Kannangara et al. is highly parameterized, enabling adaptability, while parameter values are also provided specifically for the BC context. Total vehicle production and end-of-life emissions are summed and then distributed evenly over the lifetime of the vehicle (in km) to generate a per-VKT emission intensity, to which a fixed per-VKT maintenance emission intensity is added.

From Kannangara et al. (2021) – excluding operating phase – total vehicle production and end-of-life emissions (E_V) are parameterized on vehicle (m_V) and battery (m_B) mass, separately for materials, electricity, and end-of-life, and calculated as:

$$E_V = m_V(C_V + C_{El-V} \times EI_E + eol_V) + m_B(C_B + C_{El-B} \times EI_E + eol_B)$$

Lifetime vehicle maintenance emissions are also parameterized on vehicle mass, at a constant rate over the lifetime of the vehicle (Lt): $E_M = Lt \cdot m_V \cdot C_M$. Combining these and dividing by the vehicle lifetime in km, the non-operating vehicle cycle GHG emission intensity (in kg CO_2e per km) is

$$e_{VC} = \frac{E_V + E_M}{Lt} = \frac{m_V}{Lt}(C_V + C_{El-V}EI_E + eol_V) + \frac{m_B}{Lt}(C_B + C_{El-B}EI_E + eol_B) + m_V C_M$$

All parameter definitions and values are given in Table 18-8. The per-km GHG intensity $\left(\frac{E_V+E_M}{L}\right)$ is multiplied by the trip length in km to obtain the upstream emissions attributable to a specific trip.

As shown in Table 18-8, several of the parameter values from Kannangara et al. (2021) (which only included best-selling mid-size gasoline cars in Canada) were modified for better applicability and utilization of the TDD (which included a full spectrum of the vehicle fleet). Firstly, vehicle curb weights by make, model, and year for each vehicle in the TDD were extracted from the comprehensive Canadian Vehicle Specifications (CVS) (Transport Canada, 2021). As with other vehicle datasets, string matching was used for most of the TDD, with manual entry for 248 vehicles that failed matching, using information from a general internet search with the Google search engine (Google, 2022). The CVS curb weight includes traction batteries (for HEV, PHEV, and BEV), and so the traction battery weight (see below) was subtracted to determine m_V.

Only 226 unique vehicles in the TDD (3%) had a traction battery (HEV, PHEV, or BEV), consisting of 93 unique make/model over varying model years. A general internet search with the Google search engine (Google, 2022) was used to determine the traction battery weight and cathode chemistry for each from publicly available information, which were assumed to be constant over model years. Traction battery weight could not be determined for 12 vehicles, for which average battery weights by powertrain and battery type were assumed based on the non-missing data. Battery chemistry could not be determined for 6 vehicles, for which the mode (most common) battery chemistry by powertrain type was assumed based on the non-missing data (nickel-metal hydride (NiMH) for HEV and lithium-ion (Li-ion) for PHEV and BEV).

Table 18-8. Upstream & downstream emissions parameters[1]

Parameter	Units	Description	Value
m_V	kg	Vehicle weight without traction battery	**Vehicle-specific (make, model, year), see below for sources**
m_B	kg	Traction battery weight (=0 for ICE)	**Vehicle-specific (make, model, year), see below for sources**
C_V	kg CO_2e per kg m_V	Emission intensity of vehicle materials and processing for production (without traction battery)	ICEV: 5.294 BEV: 7.813 HEV/PHEV: 5.212+2.602*H
C_B	kg CO_2e per kg m_B	Emission intensity of traction battery materials and processing for production **(added NiMH batteries)**	Li-ion, nickel cobalt aluminum: 11.7 Li-ion, nickel manganese cobalt: 10.9 Li-ion, iron phosphate: 9.49 NiMH: 19.65 **(from Mahmud, 2019)**
C_{El-V}	kWh per kg m_V	Electricity intensity of vehicle production	ICEV/HEV/PHEV: 1.127 BEV: 0.897
C_{El-B}	kWh per kg m_B	Electricity intensity of battery production	16.8
EI_E	kg CO_2e per kWh	Emission intensity of production-phase electricity	0.70
C_M	kg CO_2e/VKT per kg m_V	Emission intensity of vehicle service and maintenance	ICEV, HEV, PHEV: 0.000010 BEV: 0.000008
H	%	Hybridization factor for hybrid vehicles	HEV: 30% PHEV: 60%
Lt	km	Lifetime vehicle kilometres travelled	150,000
eol_V	kg CO_2e per kg m_V	Emissions during end-of-life treatment of vehicle	ICEV: 0.300 HEV: 0.402 PHEV: 0.401 BEV: 0.542
eol_B	kg CO_2e per kg m_B	Emissions during end-of-life treatment of battery	0.5

[1] From Kannangara et al. (2021), unless otherwise indicated **in bold text**

Some TDD vehicles had NiMH traction batteries, which were missing from the Kannangara et al. values/analysis. A value for the GHG intensity of NiMH traction battery material and production (per kg) was taken from Mahmud et al. (2019), supported by earlier findings from Majeau-Bettez et al. (2011). The Kannangara et al. value for battery end-of-life emissions is applied to NiMH as well, based on support from Wang et al. (2021).

Because vehicle lifetime is a critical parameter in the calculations, we undertook additional analysis for the most representative value. A summary of relevant literature values for vehicle lifetimes is given in Table 18-9. Based on this evidence, we decided to apply the value of 150,000 km suggested in Kannangara et al., which was near the center of the distribution reported by a range of sources. A main shortcoming of this assumption, as with previous estimates of vehicle lifecycle emissions, is that the lifetime is not vehicle type or powertrain specific.

Table 18-9. Reference values for vehicle lifetime in vehicle-kilometres travelled (VKT)

Source	Annual VKT	Lifetime VKT	Scope
McElhanney (2018)	9,450	94,500*	Vancouver, 2017
Pardy (2018)	12,000	120,000*	Vancouver, 2025
B.C. Ministry of Environment and Climate Change Strategy (2017)	12,367	123,670*	Vancouver, 2012
Natural Resources Canada (2010)	13,100	131,000*	BC, 2008
Azarafshar and Vermeulen (2020)	13,700	137,000	Canada, 2016 (Ford BEV)
Transport Canada (2020)	14,310	143,100	BC, 2020
Kannangara et al. (2021)	15,000*	150,000	Canada
Sun and Ertz (2021)	14,520	159,720	Canada
Transport Canada (2020)	17,000	170,000	Canada, 2020
Azarafshar and Vermeulen (2020)	17,300	173,000	Canada, 2016 (Ford PHEV)
Statistics Canada (2010)	22,173	221,730*	BC, 2009
Antweiler and Gulati (2015)	12,100	237,160	BC, 2008-2010
Logtenberg et al. (2018)	25,000	250,000	Canada

* Assumes 10 year lifetime, based on other sources

Deadheading

For taxi/ride-hail trips, a deadheading adjustment is applied to each reported trip to account for the induced VKT without the traveller present in the vehicle. The deadheading rate, D_r, is the percent of operating VKT for taxis and ridehail vehicles without a passenger present. Relevant literature reports D_r values of 41% to 61% (Cramer & Krueger, 2016; Li et al., 2020, 2022; San Francisco County Transportation Authority, 2017; Sun & Ertz, 2021). The mean across these studies is $D_r = 55\%$, which we apply to all taxi/ridehail trips in the TRR. The deadheading rate for non-taxi trips is set at $D_r = 0$. The deadheading adjustment of $\left(\frac{1}{1-D_r}\right)$ is only applied to running and upstream (not start) emissions.

Combining the phases

Combining the operating and non-operating phases, per-trip GHG emissions (in kg CO_2e per person-trip) are calculated as:

$$E = \frac{e_s + \frac{\sum_l L}{1 - D_r} e_r MF + e_{FC}\left(f_s + \frac{\sum_l L}{1 - D_r} f_r MF\right) + \frac{\sum_l L}{1 - D_r} e_{VC}}{\theta}$$

where e_{FC} is the upstream (WTT) fuel cycle emissions (in kg CO_2e per unit fuel), f_s and f_r are the start and running fuel consumption rates (derived from MOVES in the same way as e_s and e_r, respectively), and all other variables are as defined above. This equation includes the operating emissions E_o and the non-operating emissions

$$E_{no} = \frac{e_{FC}\left(f_s + \frac{\sum_l L}{1 - D_r} f_r MF\right) + \frac{\sum_l L}{1 - D_r} e_{VC}}{\theta}$$

which combine the fuel and vehicle cycle emission components.

18.3. Public transit trips

This section describes the estimation of emissions associated with uni-modal trips on the main TransLink public transit system, which includes city buses, commuter and rapid rail (Sky Train, West Coast Express), transit ferry (Sea Bus), and paratransit (Handy Dart). Similar methods are also applied to the estimation for public transit segments of multi-modal trips. The 29,236 reported transit trips in the TDD (65% uni-modal) were 55% by Sky Train, 43% by transit bus, and the other 2% divided among West Coast Express, Sea Bus, and Handy Dart.

Emissions for transit trips are calculated as the summation of operating and non-operating (fuel and vehicle lifecycle) components. Operating and non-operating emissions are attributed to transit vehicle operation (per VKT) based on emission and fuel consumption rates and vehicle lifecycle, and then attributed to person-trips by transit based on the transit vehicle passenger occupancy (excluding working drivers).

Operating emissions

18.3.1.1. MOVES emission rate modelling

Per-VKT emission rates for CAC from buses are estimated using MOVES, with the same general model setup and input datasets as described above for automobiles. One additional input required for transit bus emissions estimates was to use the MOVES default fuel formulation for compressed natural gas (CNG), which fueled some of the transit bus fleet but was excluded from the Metro modelling. Fuel type (diesel, gasoline, or CNG) is based on the predominant bus type per line in the TSPR data. Average line speed was taken from the TSPR data as well. Age distributions for buses were based on local MOVES input data from Metro.

18.3.1.2. GHG estimates from transit operator data

Fuel consumption and GHG emissions for transit vehicles are based on TransLink reporting of measured transit fleet fuel consumption data for the year 2019, rather than relying on MOVES estimates. Annual fleet fuel consumption and GHG emissions are attributed equally to annual service km (by mode) using TransLink reported annual operations data (TransLink, 2019, 2020a). The service km exclude deadheading, and so this approach incorporates deadheading emissions into the operations-phase emissions rates.

Table 18-10. Fuel consumption rates by transit service

Transit fleet component	Fuel type	Fuel units	Fuel consumption	Service km	Fuel rate per VKT
Coast Mountain Bus Company	Diesel	litres	31,465,643	49,057,261	0.6414
Coast Mountain Bus Company	CNG	kg	8,469,201	15,939,292	0.5314
Coast Mountain Bus Company	Electricity	kw-hr	32,076,466	23,339,515	1.3744
Community shuttle	Gasoline	litres	3,244,650	13,567,537	0.2391
West Vancouver Transit (bus)	Diesel	litres	1,312,093	2,322,393	0.5650
Sea Bus (transit ferry)	Marine diesel	litres	1,320,272	172,369	7.6596
Handy Dart (paratransit)	Diesel	litres	570,324	2,530,437	0.2256
Handy Dart (paratransit)	Gasoline	litres	1,983,059	7,714,246	0.2570
West Coast Express (commuter rail)*	Diesel	litres	1,328,321	1,377,260	0.9645
SkyTrain, Expo/Millenium lines (rapid rail)*	Electricity	kw-hr	141,620,704	53,274,170	2.6583
Canada Line (rapid rail)*	Electricity	kw-hr	22,859,701	6,531,343	3.5000

* Rail service km are reported in car-km, with typically 2-8 cars per train

Several assumptions were required to match the service km to the fuel consumption, due to aggregation of some fuel types by service. A single aggregate annual service km was given for the three types of fuel used by Coast Mountain Bus Company (CMBC) buses. We disaggregate by assuming relative fuel consumption rates per VKT of 0.8284 and 2.1427 for CNG (in kg CNG per VKT) and electric (in kw-hr per VKT) buses, respectively, relative to litre of diesel per VKT for diesel buses, based on (Pourahmadiyan et al., 2021; TransLink, 2020b). Applying these relative rates to the annual fuel consumption data, we can solve for a VKT distribution of the CMBC fleet of 56% diesel, 18% CNG, and 26% electric. Note that this excludes renewable natural gas buses, which were added to the fleet in 2019 and so do not apply to the 2017 TDD. CNG conversions assume 1 kg CNG is equivalent to 0.0538 GJ CNG.

Similarly, for Handy Dart, the aggregate annual service km were disaggregated by assuming relative fuel consumption rates per VKT of 1.1390 for gasoline buses (in litres per VKT), relative to litre of diesel per VKT for diesel buses, based on (B.C. Ministry of Environment and Climate Change Strategy, 2019). This led to a VKT distribution of 25% diesel and 75% gasoline for Handy Dart service km.

Reported fuel consumption is converted into GHG emissions using the TransLink operations data and BC guidance on fuel emissions intensity (B.C. Ministry of Energy, Mines and Petroleum Resources, 2017; BC Ministry of Environment and Climate Change Strategy, 2022, 2022; (S&T) Squared Consultants Inc., 2022; TransLink, 2020b). CNG feedstock is assumed to be 100% fossil in GHGenius. The GHG intensity of fuels is given in Table 18-11 and the resulting GHG intensity of transit operations are given in Table 18-12.

Table 18-11. GHG intensity of transit fuels

Fuel	Units	Operating (tank-to-wheels) kg CO2e per unit fuel	Upstream (well-to-tank) kg CO2e per unit fuel
Gasoline	litres	2.261	0.8297
Diesel	litres	2.630	0.9128
Marine diesel	litres	2.914	0.9128
Compressed natural gas	kg	3.089	0.5635
Electricity	kw-hr	0	0.0317

Table 18-12. Transit operating GHG emissions rates

Transit fleet component	Fuel type	kg CO_2e per VKT
Coast Mountain Bus Company	Diesel	1.6867
Coast Mountain Bus Company	CNG	1.6415
Coast Mountain Bus Company	Electricity	0.0436
Community shuttle	Gasoline	0.5756
West Vancouver Transit (bus)	Diesel	1.4855
Sea Bus (transit ferry)	Marine diesel	22.3184
Handy Dart (paratransit)	Diesel	0.5928
Handy Dart (paratransit)	Gasoline	0.5813
West Coast Express (commuter rail)*	Diesel	2.5362
SkyTrain, Expo/Millenium lines (rapid rail)*	Electricity	0.0843
Canada Line (rapid rail)*	Electricity	0.1110

* Rail VKT is in car-km, with typically 2-8 cars per train

Fuel type for CMBC buses was determined based on vehicle type by line from the 2019 TSPR data (TransLink, 2019), manually corrected to address line changes (discontinued, renumbered, or introduced) between 2017 and 2019 or missing data in the TSPR before adding the information to the GTFS routing network (described below). Because the TSPR does not distinguish diesel and CNG CMBC buses by line, fuel type proportions were assumed to be equal to annual VKT for each fuel type, and a weighted average GHG emission rate was applied to non-electric CMBC services (1.6751 kg CO_2e per VKT). Similarly, Handy Dart does not distinguish between gasoline and diesel vehicles, and so a weighted average (by annual service VKT) as applied of 0.5841 kg CO_2e per VKT.

18.3.1.3. Transit routing

Transit trip routing was undertaken using the r5r package in R (Pereira et al., 2021) for all modes except Handy Dart trips (the on-demand paratransit service), which were routed using the same procedure as automobile trips. The r5r package executes a least-cost routing algorithm between two points (from an origin to a destination) on a network with link costs conditional on travel mode and departure time. For a detailed description of the r5r algorithm, see (Conway & Stewart, 2019). The transit network is a combination of General Transit Feed Specification (GTFS) links for transit segments (for September 13 through December 13, 2017, corresponding to the TDD dates) and Open Street Maps (OSM) links for access and egress. For routing, the maximum number of transfers was set at 3 (consistent with the TDD), and the default access/egress mode (not recorded in the survey) was set to walk. The link cost function used trip purpose-specific walking, transfer, and waiting time penalties from the Regional Travel Model (RTM) (TransLink, 2018). If trip purpose was missing, the weighted average of non-missing trips was used (2.0, 10.4, and 2.5 times the in-vehicle time for walking, transfer, and waiting time penalties, respectively). Note that we do not know if the traveller took the least-cost path for the reported trip, but we expect relatively small deviations from the least-cost path, resulting in similar in-vehicle and access/egress distances for the trip.

The routing algorithm failed to generate a uni-modal transit route for 442 of the 19,102 uni-modal transit trips. Re-categorizing these as multi-modal transit trips (i.e., allowing a bus segment in a rail trip) produced routes for 206 of the trips, and another 10 were routed with manual mode corrections based on visual inspection. Still no route was found for 179 reported uni-modal transit but trips. For these, we use the TDD reported trip length, and assume walk access and egress comprising a total of 17% of the trip distance, based on the non-missing transit bus routes. Bus emissions for the remaining portion of these trips are assumed to be from CMBC transit buses on urban unrestricted facilities (MOVES Road Type 5), with average speed and occupancy for those vehicles on non-missing routes. For the 47 remaining uni-modal transit rail trips with no route found, we assume a rail line/service based on closest stations to the origin and/or destination. Similar to bus trips, we assume walk access and egress comprising a total of 15% of the trip distance, based on the non-missing transit rail routes. Occupancy for the remaining rail portion of these trips is based on average occupancy by line for non-missing routes with similar segment distance.

Non-operating (upstream & downstream) emissions

Upstream fuel cycle emissions rates are given. For the vehicle cycle, we include the same three elements as for automobiles (manufacture, maintenance, and end-of-life), attributing lifecycle emissions equally across a vehicle's operating life VKT. Figure 18-4 shows the range and mean values in the literature for transit bus vehicle cycle emissions (Chan et al., 2013; M. V. Chester, 2008; Condon & Dow, 2011; Cooney et al., 2013; Lajunen &

Lipman, 2016; Nordelöf et al., 2019; Pourahmadiyan et al., 2021; Spreafico & Russo, 2020; Zhao et al., 2022). Based on this, we assume 116, 27, and 24 g CO2e per VKT for manufacture, maintenance, and end-of-life vehicle cycle emissions, respectively. This approach fails to account for vehicle cycle emission differences by powertrain/fuel type, body type/articulation, and other factors, for which the literature provides insufficient evident to discriminate. The lifetime VKT in the literature ranged from 650,000 to 1,270,000 km.

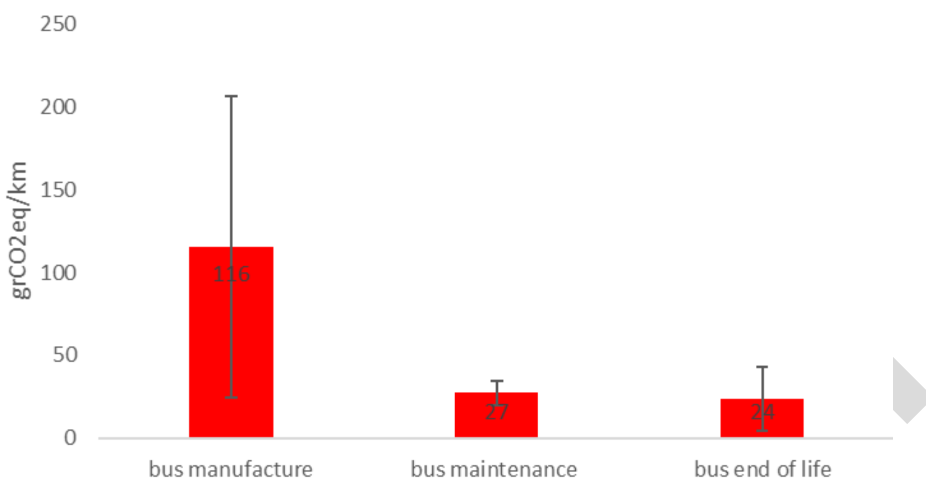

Figure 18-4. Literature values for bus vehicle cycle emissions

Table 18-13 shows the assumed vehicle cycle emissions for rail transit per car-km, based on the limited existing literature reporting applicable values from North America or Europe (M. V. Chester, 2008; Del Pero et al., 2015; Gulcimen et al., 2021; Lederer et al., 2016). No end-of-life information were available for commuter rail, so the light/rapid rail value was applied. Extraction of per-car-km rates for these studies required assumptions about the number of cars per train from transit system information (typically 2-6 cars/train).

Table 18-13. Rail vehicle cycle emissions in g CO_2e per car-km

Vehicle cycle phase	Light/rapid rail (Sky Train)	Commuter rail (West Coast Express)
Manufacture	63	186
Maintenance	15	121
End-of-life	139	111

Transit ferry (Sea Bus) vehicle cycle emissions are also extracted from the literature, although few life-cycle studies have addressed passenger ships (Istrate et al., 2022). Based one particularly relevant study with ferries similar to the Sea Bus, we assume 1405, 301, and -376 g CO_2e per VKT for ferry vehicle cycle emissions (Schmidt & Watson, 2014).

Occupancy

Transit vehicle occupancy is a key factor in the per-PKT emissions intensity of passenger travel. For transit bus and Sea Bus, average peak loads by line-direction are taken from the 2019 TSPR (TransLink, 2019), with missing values imputed from non-missing values for the line. This measure gives the average of the highest number of people on each bus trip, aggregated by line, direction, season, day, and hour. This peak measure can overestimate average loads, but provides a spatial and temporal resolution over these 5 dimensions that is superior to a simple system-average occupancy. The temporal effect of this aggregation is likely small because the measure is hour-specific, and only misses the within-hour variation by line-direction. The larger aggregation effect is with respect to spatial variability along the line (e.g., over-representing occupancy for distal parts of a radial transit line). We note that the proper attribution of line emissions to different segments of that line is arguable, with potential equity impacts of assigning higher emissions to people who must travel farther due to reach the urban core. Also, an occupancy-inflating effect from using this measure would be compensated by the use of average (versus marginal) accounting methods which tend to overestimate the per-passenger emissions impact of transit travel (A. Bigazzi, 2019, 2020). Ultimately, we decided the analytical benefits of using temporally resolved occupancy data outweighed the risks.

Also, this measure would not distort Sea Bus occupancy because it operates between a single station pair.

Rail occupancy was extracted from station boarding and alighting data in the TSPR with a higher spatial resolution of station-by-station rather than line-average (still by line, direction, day, and hour). Because the rail occupancy is by train, train lengths are needed to computer car occupancy for emissions attribution. The Canada and Millennium lines operate 2-car trains, whereas the Expo line runs 4 to 6 cars in each train and West Coast Express runs 3 to 10 bi-level cars per train. Moreover, Millennium and Expo line data are combined in some reference sources because they share stations/track. Lacking dynamic train length data for the Expo line and West Coast Express, we examined the operations data and explored several possible assumptions for train length. Ultimately, we decided to assume a fixed number of cars per train, which implied that car occupancy is proportional to train occupancy. We expect this measure to be more dynamic than real occupancy, because operators would likely provide longer trains for higher-occupancy trips. Average train lengths were inferred from annual service car-km and train frequency data: 4.29 cars/train for Expo and Millennium Lines and 4.56 cars/train for West Coast Express.

18.4. Other modes

Walking, wheelchair, and cycling

Walking trips (33,516) and trips by wheelchair (41) were assumed to have zero GHG impact.

Lifecycle (all upstream) GHG emissions for the 4,266 bicycle trips were calculated from the trip distance using a factor of 10.5 g CO_2e per km, based on (Sun & Ertz, 2021). There was no way to distinguish electric bicycle trips from non-motorized cycles, but they were probably a small portion (<5%) of the reported trips (Hassanpour & Bigazzi, 2023). Bicycle trips were routed on the OSM network using the r5r package in R (Pereira et al., 2021), similar to transit trips, which returned a trip length and duration (using the default 12 km/hr network speed). Cyclist type was set to allow the most permissive use of the network (i.e., tolerant of Level of Traffic Stress 4: Strong and Fearless). For 19 of the 4,266 reported bicycle trips, no route could be found on the OSM network, and so the TDD distance data were used. Figure 18-5 compares the trip duration distributions between the TDD and the routed bicycle trips, showing good agreement.

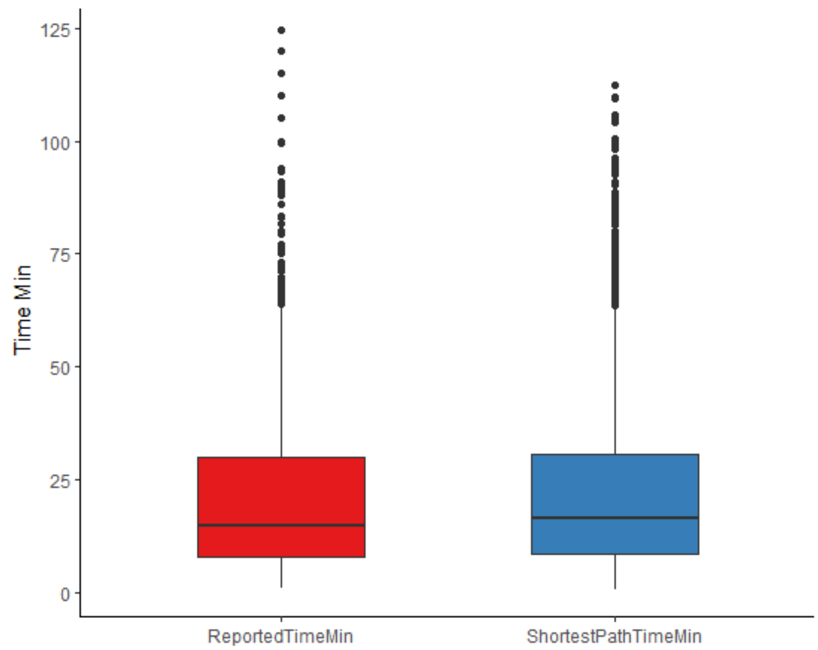

Figure 18-5. Comparison of TDD and routed estimates of trip duration

School bus (609 trips)

School bus emissions rates were generated by MOVES modelling, as described above for automobiles. Routing was based on the automobile network, as well, with access to HOV lanes. However, auto network speeds were found to be substantially higher than those observed for school bus trips reported in the TDD, presumably primarily due to additional stops. Based on the mean travel time ratio, we apply a scaling factor of 0.44 to network link speeds to better represent school bus operating speeds. Lacking local or trip-specific data, school bus occupancy was assumed to be 56 (M. V. Chester, 2008; Vancouver School Bus Charters Inc, 2022). All school bus fuel is assumed to be diesel, although an unknown portion operate on other fuels. Upstream fuel cycle emission rate is the same as for automobile diesel (0.9128 kg CO2e per L). Upstream vehicle cycle emissions are taken as 0.2525 kg CO2e per VKT based on the little available literature (M. V. Chester, 2008; Nordelöf et al., 2019; Zhao et al., 2022).

Motorcycle, moped, and scooter (236 trips)

Motorcycle emissions rates were generated from MOVES using the same general modelling approach described above for automobile trips. Motorcycle, moped, and scooter trips are grouped together in the TDD. Based on 2017 ICBC motor vehicle population data (Insurance Corporation of British Columbia (ICBC), 2020), full-speed motorcycles comprise 92% of the registered motorcycle fleet, with most of the rest limited-speed motorcycles (registered mopeds and scooters). In 2017, we expect a very small portion of reported motorcycle trips were made with other types of scooters or micromobility devices (A. Y. Bigazzi & Hassanpour, 2022; Hassanpour & Bigazzi, 2023). Limited-speed motorcycles in BC have a maximum speed of 70 km/hr; the MOVES motorcycle category includes vehicles capable of travelling at least 25 mi/hr (40 km/hr). Therefore, we are confident modelling reported motorcycle trips reported in the TDD using MOVES emissions rates.

The 236 motorcycle trips were routed on the automobile network, including HOV lanes, which they are allowed to use. Operating emissions were calculated from MOVES using the same method as for automobile trips described above. Occupancy not reported in the TDD was assumed to be 1.15, based on an aggregation of the literature in this area, which ranged from 1 to 1.3 (Bureau of Transportation Statistics, U.S. Department of Transportation, n.d.; M. Chester & Horvath, 2009; de Bortoli, 2021). All motorcycles are assumed to use gasoline fuel, with an upstream fuel cycle emissions intensity of 0.8297 kg CO_2e per litre ((S&T) Squared Consultants Inc., 2022). Based on the literature, the upstream vehicle cycle emissions were set at 0.06403 kg CO_2e per VKT (0.05155 for manufacture + 0.01198 for maintenance + 0.00050 for disposal) (Carranza et al., 2022; M. Chester & Horvath, 2009; Cox & Mutel, 2018; de Bortoli, 2021).

Shuttle and charter bus (105 trips)

Shuttle and charter bus trips are grouped together in the TDD. The local vehicles used as shuttle/charter buses resemble community shuttle buses, with passenger capacity ranging from 11 to 36 persons (Ace Charters Vancouver, 2023; Vancouver Bus Charters, 2021). Operating emission rates are based on MOVES modeling, as described above for automobiles and transit buses. Shuttle/charter vehicles resemble the transit bus fleet, but operate with fewer stops on a non-fixed route with higher average speeds. Therefore, we route on the automobile network, including HOV lanes (only 18 of the routed trips include

HOV lanes), and use auto network speeds (rather than transit bus speeds). Lacking trip-specific occupancy data, we assumed an occupancy of 21 persons, which is the mean occupancy of community shuttle buses (averaging 10 persons) and non-articulated standard transit buses (averaging 32 persons). We also assume an even proportion of VKT by gasoline and diesel buses (i.e., averaging the two emission rates). No deadheading adjustment is made, due to a lack of data. Upstream fuel cycle emissions are consistent with the other modes, with gasoline and diesel upstream rates of 0.8297 and 0.9128 kg CO2e per L, respectively. Upstream vehicle cycle emissions are set equal to transit buses (0.1665 kg CO2e per VKT).

Aqua bus, boat, and tram (47 trips)

Trips by Aqua bus, boat, and tram were reported together in the TDD. The Aqua bus is fixed-route small-vessel ferry service operating in False Creek in Vancouver, running marine diesel on a return route of 6 km at 15 min headways, with 5 daily trips from their 13-vessel fleet over a 15 hr window (Aquabus, 2022). There was no tram or streetcar operating in Metro Vancouver in 2017, so we assume all these trips are in fact by aqua bus or other boat (private or water taxi). With no explicit marine network (other than for Aqua bus), we use trip distance reported in the TDD.

Operating fuel consumption is derived from a 2002 report on BC marine vessel emissions (Levelton Engineering Ltd., 2002). For small vessels "(patrol, rescue, work boats, water taxis, etc.)" they report average power of 300 hp and power load of 30%, which consumes 13.98 kg (16.21 L) of marine diesel per hour. Assuming an average speed of 19.8 km/hr (10.7 knots) from the TDD data, this temporal fuel consumption rate translates to 0.706 kg (0.819 L) of marine diesel per VKT. Using GHG emissions rates from the same report of 3.671 kg CO2e per kg fuel (3.164 kg CO2e per L fuel) yields 2.591 kg CO2e per VKT by Aqua bus or boat. The same report provides CAC emission rates of 7.4, 60.6, 2.4, and 1.2 g per kg fuel for CO, NOx, VOC, and PM respectively.

Upstream fuel cycle emissions are based on a marine diesel rate of 0.9128 kg CO2e per L (B.C. Ministry of Energy, Mines and Petroleum Resources, 2017). Upstream vehicle cycle emissions are based on an aggregation of past studies reporting average annualized marine vessel lifecycle emissions (manufacture, maintenance, and disposal) of 159 kg CO2e (Mio et al., 2022; Pommier et al., 2016). We attribute this to annual VKT for Aqua bus vessels of 10,920 km, based on 30 km per vessel per day over 364 days (Aquabus, 2022), yielding 0.01456 kg CO2e per VKT. Note that these upstream emission rates are comparable to the Sea Bus emissions, scaled down for weight.

The Aqua bus vessels have a passenger capacity of 12. We assume an average passenger load of 30% (4 passengers), which is the average occupancy of Sea Bus (29%) and (land) taxis (31%). Not all the trips in this category in the TDD were made on Aqua bus, but considering the small number of trips, and lacking further information about these trips, we apply the same small vessel emission rates for all 47 trips in this category.

Bowen Island ferry (18 trips)

BC Ferries operates a longer-distance ferry (besides Sea Bus) within metropolitan Vancouver between Horseshoe Bay and Bowen Island (Snug Cove). Travel distance between the ferry terminals was taken from the RTM network, and average ferry occupancy of 80% was assumed, based on (B.C. Ministry of Environment and Climate Change Strategy, 2019). The Queen of Capilano ship that runs this route has an occupancy of 457 (BC Ferries, 2022), and so we assume a passenger load of 366.

Operating emissions are assumed to be 69.936 kg CO2e per VKT, based on a fuel consumption rate of 24 L per VKT (B.C. Ministry of Environment and Climate Change Strategy, 2019). That fuel consumption rate is also used to compute upstream fuel cycle emissions using a rate of 0.9128 kg CO2e per L for marine diesel (B.C. Ministry of Energy, Mines and Petroleum Resources, 2017), yielding 21.907 kg CO2e per VKT.

Upstream vehicle cycle emission factors are based on a study that provides estimates for roll-on/roll-off steel-hull passenger ships (Blanco-Davis et al., 2014). We scale their 25-year lifetime emissions based on displacement weight (down from 20,250 t to 2,500 t) and then attribute to annual VKT of 62,339.2 (assuming 5,566 annual return trips of 11.2 km each, based on BC Ferries operations data). This yields upstream vehicle cycle emissions of 2.673 kg CO2e per VKT (2.301, 0.369, and 0.004 kg CO2e per VKT from manufacture, maintenance, and end-of-life, respectively).

Other/unclassified modes (143 trips)

The primary mode was designated as “Other/unclassified” for 143 uni-modal trips. To infer a mode for these trips, we applied a Support Vector Machine (SVM) classification algorithm with the svm function in R (from the package ‘e1071’), using the parameters 0.1

for gamma, 10 for cost, and a radian kernel based on our previous analysis which required inference of active transport modes (Berjisian & Bigazzi, 2022). The SVM was trained on the following input data:

1. Modal frequency of other uni-modal trips by that person,
2. Automobile availability,
3. Trip distance (km),
4. Mean trip speed (km/hr), and
5. Trip purpose.

The trained SVM successfully predicted 92% of modes for 212,675 single trips in the travel diary. The results of the application of the SVM to the 143 missing-mode trips are shown in Figure 18-6. While these modes might be inaccurate, they are our best estimate of the trip's modal characteristics, preferable to omitting the trips (which would bias the emissions results low). Because they are based on trip attributes (distance, speed, etc.), erroneous labels from the SVM are likely similar to the actual travel modes within the broad categories of automobile, transit, and active transportation (walking, cycling). For example, if the actual travel mode were e-scooter, it would likely be labelled as bicycle by the SVM (which would have similar emissions characteristics).

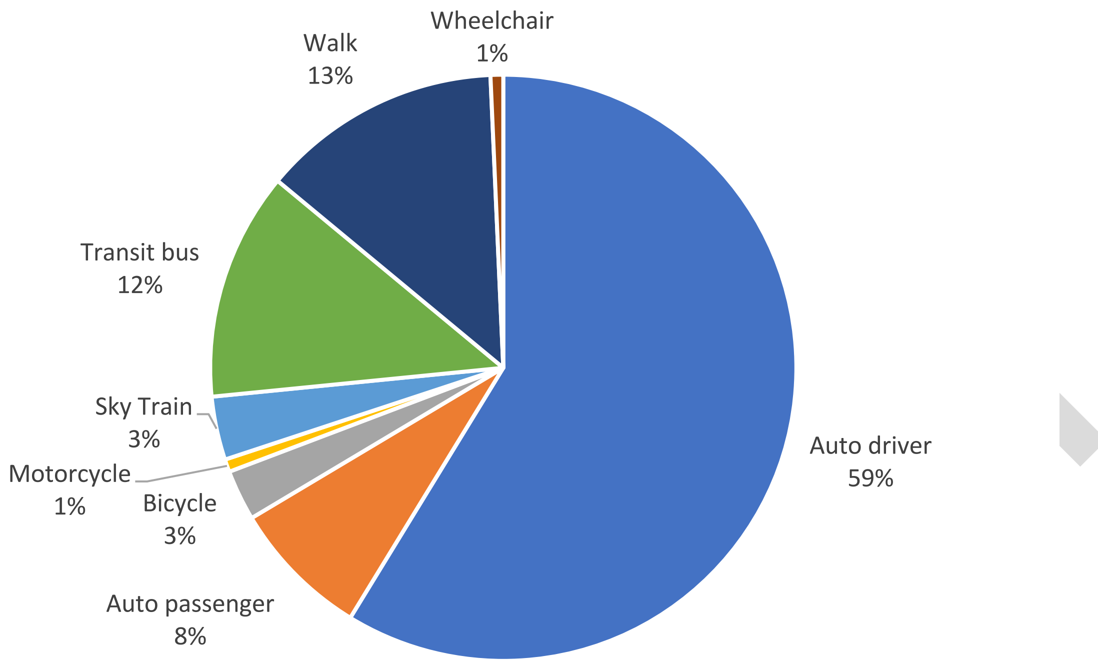

Figure 18-6. SVM-inferred modes for 143 uni-modal trips with mode designated as "Other/unclassified"

18.5. Multimodal trips

The TDD include 10,374 trips (4.6%) reported as multi-modal, but without specific mode-change locations or sub-division of trip attributes such as distance or duration by mode. The designated primary mode for these trips is based on a hierarchy of rail transit, bus transit, then auto modes. We use one of two approaches to disaggregate these trips into uni-modal segments for emissions estimation. For trips including fixed-route services (e.g., rail transit, Sea Bus), we use the r5r routing function in R described above for transit routes, input with the reported mode sequence for the trip. Emissions are then estimated for each of the modal segments comprising the returned route as if the segment were a uni-modal trip, using the methods described above. No valid route was found for 3,197 trips using the reported mode sequence; emissions for these trips were estimated using the method described next for non-fixed-route services.

For trips without fixed-route services, we have no way to confidently infer the modal transitions. For these trips, our approach is to assume that trip segment distances for each mode in a multi-modal trip are proportional to their respective typical trip distances for uni-modal trips, and so aggregate multi-modal trip emissions as a weighted average of each constituent mode. To do this, we first estimate emissions for each trip as if it were a uni-modal trip made by each of the trip's constituent modes $m \in M$, using the methods described above. We then take a weighted average of those emissions, with weights based on the median trip distance for uni-modal trips by each mode, D_m, as $\frac{D_m}{\sum_{m \in M} D_m}$. The median uni-modal trip distances are given in Table 18-14.

Table 18-14. Median trip lengths for uni-modal trips used in weighting for multi-modal trips

Mode	Median uni-modal trip distance (km)
Auto driver	5.88
Auto passenger	4.96
Taxi [1]	4.41
Transit bus	3.52
Sky Train	6.73
West Coast Express	25.21
Sea Bus	3.17
Handy Dart	7.41
Walk (access/egress) [2]	0.32
Wheelchair	0.70
Bicycle	3.18
School bus	6.34
Motorcycle, moped, scooter	4.94
Shuttle/charter bus	9.29
Aqua bus, boat, tram	3.68
Bowen Island Ferry	7.47

[1] Not adjusted for deadheading

[2] Only access/egress for transit trips included here, not exclusive walk trips (which had a median length of 0.76 km)

The TDD includes 9,222 multi-modal trips with the primary mode as transit rail (Sky Train, West Coast Express). The most common other modes in these trips were transit bus

(8,293), auto driver (1,059), and auto passenger (998). The TDD includes 819 multi-modal trips with the primary mode as transit bus. The most common other modes in these trips were auto driver (238), auto passenger (251), and Sea Bus (164).

The TDD includes 213 multi-modal trips with the primary mode as auto driver (142), auto passenger (68), or taxi (3). The most common other modes in these trips were auto driver (68), auto passenger (26), bicycle (43), ferry (30), and other (24). Only a single (highest) occupancy is recorded in the TDD for multi-modal auto trips, which was applied to all auto segments. All other emission estimation processes are as described above for uni-modal auto trips.

For 86 segments of multi-modal trips designated as “Other/unclassified” mode, we use the same SVM algorithm to infer a mode as for uni-modal “Other/unclassified” trips, to avoid introducing negative emissions bias. The results are shown in Figure 18-7.

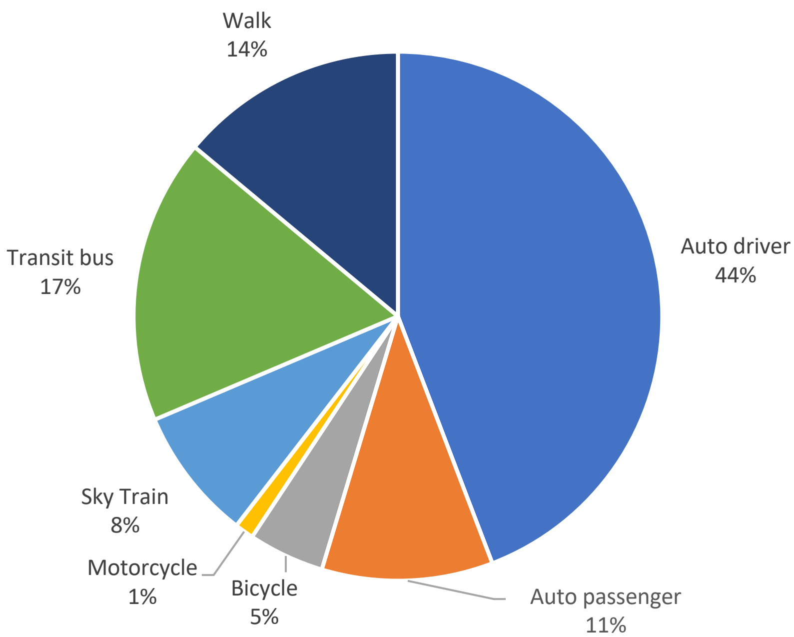

Figure 18-7. SVM-inferred modes for 86 legs of multi-modal trips with mode designated as "Other/unclassified"

18.6. Marginal emissions adjustments

Calculation of marginal adjustment factors

The methods up to this point have used an attributional accounting framework, apportioning vehicle emissions equally across vehicle occupants. To our knowledge, consequential emissions accounting has never been applied to household travel data. We build on previous work that developed a framework for estimating marginal emissions rates for passenger travel (consequential accounting) from average emissions rates (attributional accounting) (A. Bigazzi, 2019). That framework was further developed and applied to city-scale transit systems in Bigazzi (2020), demonstrating the substantial difference (bias) between the apparent climate impacts of travel by each framework.

The estimated emissions attributed to the traveller for each reported person-trip (or person-trip segment) in the TDD using the average-rate (attributional) approach above is:

$$E_P = \frac{E_V}{\theta}$$

where E_V is the trip's total vehicle emissions and θ is the vehicle occupancy in persons. Based on the past work cited above (A. Bigazzi, 2019), the marginal emissions can be calculated:

$$E_P' = \frac{E_V}{\theta}\left(\varepsilon_v^p + \varepsilon_e^\theta - \varepsilon_e^\theta \varepsilon_v^p\right) = E_P\left(\varepsilon_v^p + \varepsilon_e^\theta - \varepsilon_e^\theta \varepsilon_v^p\right)$$

where ε_v^p is the elasticity of VKT to PKT, and ε_e^θ is the elasticity of vehicle fuel or emission rates (per VKT) to vehicle occupancy. We call $\left(\varepsilon_v^p + \varepsilon_e^\theta - \varepsilon_e^\theta \varepsilon_v^p\right)$ the marginal/average emissions ratio, $MAER$.

The MAER was developed based on operating and fuel-cycle emissions. The MAER can also apply to vehicle-cycle emissions that are calculated on a per-VKT basis, because ε_v^p accounts for the marginal change in VKT with PKT. One further assumption is that the sensitivity of operating emissions intensity to passenger loads, represented by ε_e^θ, also applies to vehicle-cycle emissions due to increased wear-and-tear with higher passenger loads. In other words, ε_e^θ is assumed to represent higher per-VKT vehicle-cycle emissions caused by shorter vehicle lifespan in VKT and higher maintenance needs. The relationships between vehicle occupancy and vehicle-cycle emissions needs to be examined in future research; meanwhile, we apply ε_e^θ as the best available estimate.

Local values for ε_v^p can be estimated where dynamic vehicle occupancy data are available. The TDD reports occupancy for automobile trips, and passenger load data are reported for bus and rail services in TransLink's operating (TSPR) data, so we estimate Vancouver-specific values of ε_v^p for automobile, bus, and rail transit trips (as described in the next sub-sections). For other modes and for ε_e^θ, we rely on the U.S.-average values reported in Bigazzi (2019, 2020), as given in Table 18-15.

Table 18-15. Elasticities for calculation of MAER

Mode	ε_e^θ	ε_v^p
Auto driver or passenger	0.040	Calculated from local data
Motorcycle or taxi	0.040	Calculated from local data[1]
Transit bus	0.160	Calculated from local data
SkyTrain	0.050	Calculated from local data
Westcoast Express	0.050	Calculated from local data
School bus	0.160	Calculated from local data[2]
Shuttle	0.100	0.858
SeaBus, Aqua Bus, ferry	0.050	0.431
HandyDart	0.100	0.763
Bicycle, walk, wheelchair	0.000	1.000

[1] Assumed equal to automobile, because motorcycle and taxi trip occupancy not reported in the TDD
[2] Assumed equal to transit bus

Elasticity of vehicle to passenger travel in Vancouver

As shown in Bigazzi (2019, 2020), ε_v^p can be estimated for any system with dynamic vehicle occupancy data using a regression model specified as:

$$\ln(VKT) = \alpha_0 + \alpha_1 \ln(PKT) + \beta_j X_j + \gamma_j \ln(PKT)\, X_j$$

where X_j are covariates over which we may want to allow the elasticity to vary (such as service type, time period, or household attributes). From the estimated parameters, elasticity is calculated as

$$\varepsilon_v^p = \alpha_1 + \gamma_j X_j$$

Longitudinal data can be used to measure long-term elasticity of vehicle to passenger travel, including major service changes such as the introduction of new transit services or routes. Cross-sectional data can be used as well, but may not capture dimensions of transport system dynamics that change over a long time scale.

For automobile trips, we apply the model at the household level, which is typically considered the main decision-making unit for private vehicle travel (Ortuzar and Willumsen, 2011). Trip segments with a mode of Auto driver or Auto passenger are aggregated up to the household for daily PKT by summing segment length for reported person-trips, and for daily VKT by summing person-trip segment lengths divided by segment vehicle occupancy. This approach attributes VKT equally across vehicle occupants, due to a lack of more specific information about agency in trip generation. Summary data for the 21,430 households with automobile travel are reported in Table 18-16. The model is estimated using household weights from the TDD.

Table 18-16. Summary of data used to estimate vehicle to passenger travel elasticity

Travel variable	Minimum	First quartile	Median	Mean	Third quartile	Maximum
Auto PKT per day	0.1	21.4	46.8	71.4	93.7	1459.6
Auto VKT per day	0.0	17.0	36.8	55.7	73.1	1019.7
Bus passengers per hour	0.1	20.5	71.0	192.4	205.4	5587.7
Bus vehicles per hour	0.5	1.3	2.0	2.5	3.0	19.7
Rail passengers per hour	4	400	800	1221	1700	14900
Rail vehicles per hour	1.0	9.0	10.0	13.1	18.0	31.0

The automobile elasticity model reveals whether households with higher automobile PKT produce proportionally higher automobile VKT $\left(\varepsilon_v^p = 1\right)$, or whether increasing PKT is partially accommodated by increased ride sharing (higher occupancy), leading to $\varepsilon_v^p < 1$ and $MAER < 1$. To understand the elasticity patterns, we test household characteristics as moderating variables (X_j), including household size and composition, vehicle availability, housing type and tenure, and household income. We also examine separate elasticities for Auto driver and Auto passenger modes. Note that the model could not be applied to motorcycle or taxi trips because trip-level occupancy data for these modes were not reported in the TDD.

For bus transit trips, we estimate the model using cross-sectional data from the 2019 TSPR of bus trips and boardings per hour, which are reported by line, direction, day type (workday or weekend/holiday), season (fall or summer), time period (0-4 hr, 4-6 hr, 6-9 hr, 9-15 hr, 15-18 hr, 18-21 hr, and 21-24 hr). A multi-level (mixed effects) model is estimated with random effects by line for 216 unique lines, with a total of 12,315 complete observations. Because the TSPR reports trips, not kilometres travelled, this model neglects possible systematic changes in trip lengths with passenger volumes. Tested moderating variables include day type, season, and time period.

For rail transit trips, we estimate the model using cross-sectional data from the 2019 TSPR of train passenger volumes per hour, which are reported by service (Millennium/Expo lines, Canada line, West Coast Express), station, direction, day type (workday or weekend/holiday), and hour of the day (over 21 service hours). The TSPR data are augmented with average train (vehicle) trips per hour over the same segmenting variables, derived from the GTFS data for September through December 2019. A multi-level (mixed effects) model is estimated with random effects by station for 55 unique stations, with a total of 6,268 complete observations. Tested moderating variables include day type and service.

All elasticity models are estimated using the plm package in R (Croissant & Millo, 2008), with heteroscedasticity-consistent standard errors estimated using the lmtest package (Zeileis & Hothorn, 2002).

Application to TDD emissions estimates

After estimating modal elasticities of vehicle to passenger travel from local data, modal MAER are calculated as $\left(\varepsilon_v^p + \varepsilon_e^\theta - \varepsilon_e^\theta \varepsilon_v^p\right)$. These MAER are applied to the segment-level total lifecycle CO_2e emissions estimates based on segment mode by multiplication. The segment-level marginal lifecycle CO_2e emission estimates are then summed to the trip, person, and household levels.

18.7. Results of emissions estimates

This section summarizes the emission estimation results for the observed trips in the TDD. Unless stated otherwise, this section reports estimation results with unweighted summary values (i.e., without applying sampling or expansion weights), and so are not representative of regional emissions.

18.7.1. Segment emissions

Table 18-17 gives the cumulative estimated GHG emissions by segment mode, disaggregated by emissions component (operating, non-operating). The vast majority of the travel in the TDD is by auto drivers or passengers, and those two modes comprise the bulk of the estimated emissions. Most emissions are generated directly from vehicle operations (running), followed by non-operating fuel and vehicle cycle emissions. Figure 18-8 shows these results visually, with emissions normalized to PKT for each segment mode to represent GHG intensity.

Table 18-17. Cumulative GHG emissions by segment mode (kg CO_2e)

Segment mode	Segment length (km)	Operating (running)	Operating (start)	Non-operating (fuel)	Non-operating (vehicle)	Total
Aqua Bus	318	18	0	12	1	31
Auto Driver	1,250,340	257,796	13,617	98,817	88,547	458,777
Auto Passenger	279,765	25,734	1,746	9,974	9,402	46,856
Bicycle	20,370	0	0	0	214	214
Ferry	762	146	0	46	6	197
Handy Dart	1,266	565	15	204	160	944
Motorcycle	2,409	488	25	188	134	834
School bus	6,567	108	2	37	30	176
Sea Bus	2,020	375	0	117	22	514
Shuttle	2,738	108	2	38	21	169
Sky Train	160,499	0	0	676	1,696	2,372
Taxi	4,274	457	28	143	824	1,451
Transit bus	127,377	5,455	92	1,709	708	7,964
Walk	57,201	0	0	0	0	0
West Coast Express	11,999	340	0	119	58	517
Wheelchair	104	0	0	0	0	0
Total	1,928,010	291,589	15,525	112,079	101,824	521,017

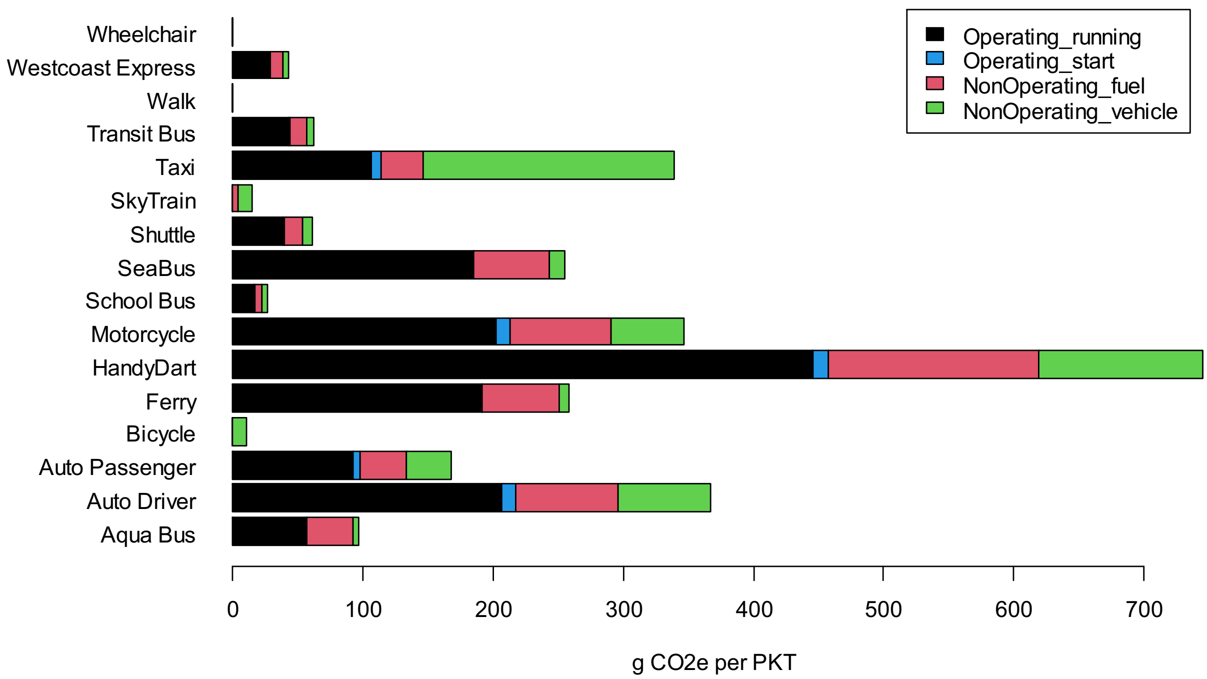

Figure 18-8. Mean emissions intensity per PKT by segment mode

Table 18-18 summarizes the segment-level occupancy, PKT, and emissions intensity by segment mode. The values are aggregated across segments (not weighted by distance). Start and running emissions are combined to give per-PKT operating emissions. The table shows that emissions intensity varies widely across trips, especially for the automobile and main transit modes (bus and rail), for which dynamic occupancy values were used. Occupancy is a key determinant of per-PKT emissions intensity. Per-VKT emission rates vary as well, depending on vehicle type, fuel, congestion level, and other factors (varying across modes). The varying emissions intensities within modes is a strength of this analysis, which produced emissions estimates more sensitive to trip attributes than the more common approach of applying fixed per-PKT emissions rates by mode.

Table 18-18. Occupancy, PKT, and GHG intensity by segment mode

Segment mode	Occupancy (persons/vehicle)		PKT		Operating (g CO2e/PKT)		Non-operating fuel (g CO2e/PKT)		Non-operating vehicle (g CO2e/PKT)	
	mean	s.d.[1]	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Auto driver	1.38	0.68	10.04	11.52	257.53	216.11	91.83	71.46	69.28	26.09
Auto passenger	2.45	0.85	8.60	10.93	121.97	141.48	43.15	44.07	33.03	10.38
Taxi	1.24	0.00	7.28	8.91	130.03	24.36	37.37	5.70	192.73	0.00
Motorcycle	1.15	0.00	9.81	13.53	243.60	74.84	88.39	25.65	55.68	0.00
Transit bus	35.26	16.29	4.67	5.07	42.38	43.76	13.05	12.27	6.13	5.32
School bus	56.00	0.00	10.37	12.53	18.97	11.28	6.36	3.68	4.52	0.00
Shuttle	21.37	0.00	13.49	22.76	38.80	4.15	13.63	1.45	7.77	0.00
SkyTrain	40.19	31.89	8.54	6.79	0.00	0.00	3.90	4.03	9.70	10.02
Westcoast Express	120.47	71.70	19.95	14.92	19.70	18.34	8.28	6.38	6.96	10.84
SeaBus	124.82	23.39	2.78	1.10	185.46	36.81	58.10	11.53	11.05	2.19
Aqua Bus	4.00	0.00	5.87	7.15	56.34	0.00	36.51	0.00	3.64	0.00
Ferry	366.00	0.00	11.12	8.56	191.08	0.00	59.86	0.00	7.30	0.00
HandyDart	1.31	0.00	7.96	5.60	467.97	60.00	161.40	0.00	126.72	0.00

[1] standard deviation

18.8. Trip emissions

Table 18-19 gives GHG emissions estimates per trip by primary mode. Figure 18-9 illustrates these values normalized by PKT to illustrate GHG intensity by primary mode. Note that the trip-aggregated values include emissions from other modal segments in the trips. For example, the Sky Train generates no operating emissions, but Sky Train trips that are accessed by automobile or transit bus include those operating emissions.

Table 18-19. Mean GHG emissions per trip by primary mode (g CO2e)

Primary mode	Number of trips	PKT	Operating (running)	Operating (start)	Non-operating (fuel)	Non-operating (vehicle)	Total
Auto Driver	123021	10.1	2079	109	797	714	3699
Auto Passenger	31404	8.6	785	52	304	287	1428
Taxi	521	7.3	790	47	247	1408	2491
Transit bus	12686	7.8	310	7	101	52	471
Sky Train	15980	15.1	300	15	145	176	635
West Coast Express	230	36.1	1668	77	605	456	2806
Sea Bus	187	8.6	996	30	338	197	1560
Handy Dart	153	8.1	3579	95	1296	1019	5988
School bus	630	10.6	206	5	70	54	335
Bike	4271	4.5	1	0	0	48	49
Walk	33516	1.0	0	0	0	0	0
Other mode	591	11.0	1379	54	526	366	2325
Total	223190	8.6	1306	70	502	456	2334

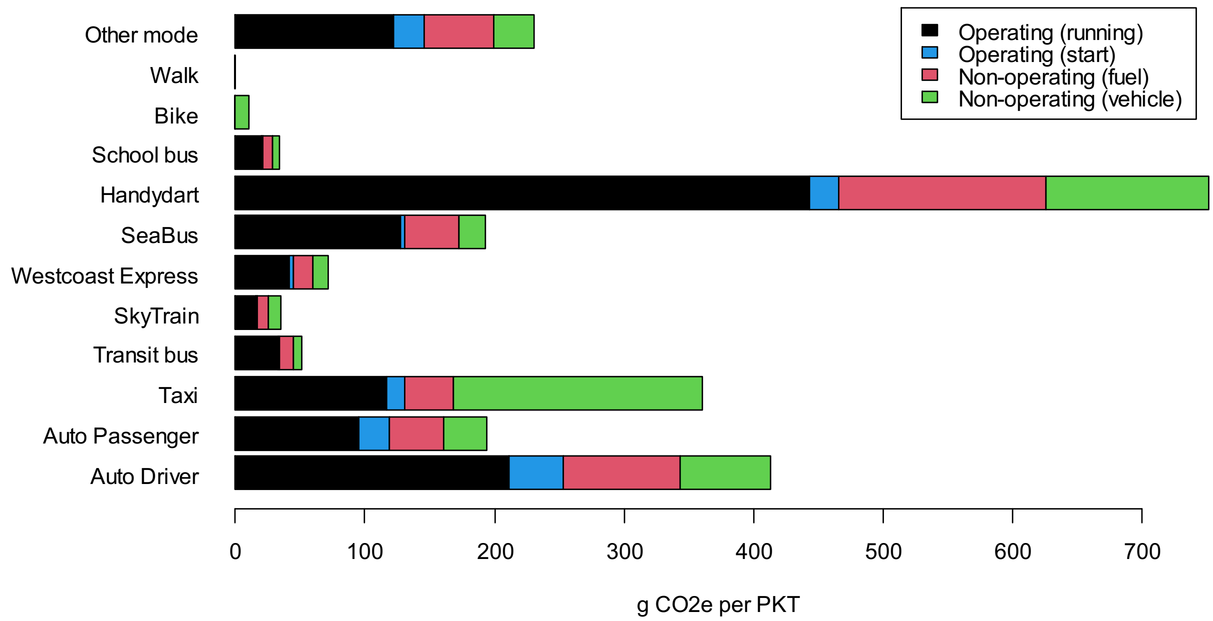

Figure 18-9. Average emissions intensity per PKT by primary mode

Table 18-20 gives average CAC emissions per trip by the same set of primary modes – again aggregating emissions from all trip segments.

Table 18-20. Average trip CAC emissions (g) by primary mode

Primary mode	CO	NOx	VOC	$PM_{2.5}$
Auto Driver	21.905	2.011	1.311	0.097
Auto Passenger	6.220	0.469	0.362	0.034
Taxi	2.987	0.165	0.204	0.073
Transit bus	1.825	0.786	0.125	0.027
Sky Train	2.195	0.572	0.145	0.022
West Coast Express	8.344	0.638	0.493	0.037
Sea Bus	4.541	0.419	0.288	0.022
Handy Dart	107.546	14.212	6.391	0.437
School bus	0.850	1.011	0.223	0.097
Bike	0.007	0.000	0.000	0.000
Walk	0.000	0.000	0.000	0.000
Other mode	41.020	2.402	4.649	0.090
Total	13.414	1.280	0.809	0.063

18.9. Person and Household emissions

Table 18-21 reports summary statistics for further aggregated emissions up to the person and household levels, as both total daily GHG and GHG intensity per PKT. Emissions rates across the TDD sample vary widely, with interquartile ranges larger than the mean values. The 75th percentile persons and households are generating 8 to 10 times the daily emissions of the 25th percentile persons and households. Some of this is due to higher PKT, but emissions intensity (g CO2e per PKT) also varies by a factor of 3 to 5.

Table 18-21. Person- and household-level aggregate GHG measures

Measure	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Person-level total PKT	0.10	11.47	26.01	40.02	51.92	672.33
Household-level total PKT	0.16	21.59	47.95	73.10	96.60	1,463.80
Person-level total daily GHG (g CO2e)	0	1,347	5,483	10,814	14,158	396,433
Household-level total daily GHG (g CO2e)	0	3,502	11,964	19,753	26,562	589,654
Person-level GHG intensity (g CO2e per PKT)	0	82	232	251	385	2,700
Household-level GHG intensity (g CO2e per PKT)	0	122	269	265	388	2,406

Applying the TDD person and household sampling weights, the weighted mean daily PKT is 36.91 per person and 91.39 per household, generating weighted mean emissions of 10.18 kg CO_2e per person and 25.21 kg CO_2e per household. Weighted mean GHG intensity of travel is 251.6 or 276.6 g CO_2e per PKT, averaged at the person or household levels, respectively. The weighted median daily PKT is 21.22 per person and 61.80 per household, generating weighted median emissions of 3.90 kg CO_2e per person and 16.12 kg CO_2e per household. Weighted median GHG intensity of travel is 234.2 or 283.3 g CO_2e per PKT, averaged at the person or household levels, respectively. The household weighting has a greater impact than person weighting, due to a stronger relationship between weights and emissions at the household level. Household and person weights both range from 0.169 to 808.696, with median values of 26.087 and 24.453 and mean values of 47.736 and 39.569 for person and household weights, respectively. Person weights have a correlation of 0.052 with person-level GHG, whereas household weights have a correlation of 0.202 with household-level GHG. In other words, the sampled households are expected to generate less travel-related GHG than the region overall.

18.10. External comparisons

As an external validation, in Figure 18-10 we compare our running emissions estimates to the emission rates from BC's Provincial emission factors by vehicle type and fuel type, which applied in 2017 (BC Ministry of Environment and Climate Change Strategy, 2022). Upstream fuel cycle emissions are included for battery electric and hybrid vehicles only, for comparability to the reference BC data. The central values are similar, but with greater variation in our estimates due to the inclusion of additional influencing factors (vehicle make, speed, road type, etc.).

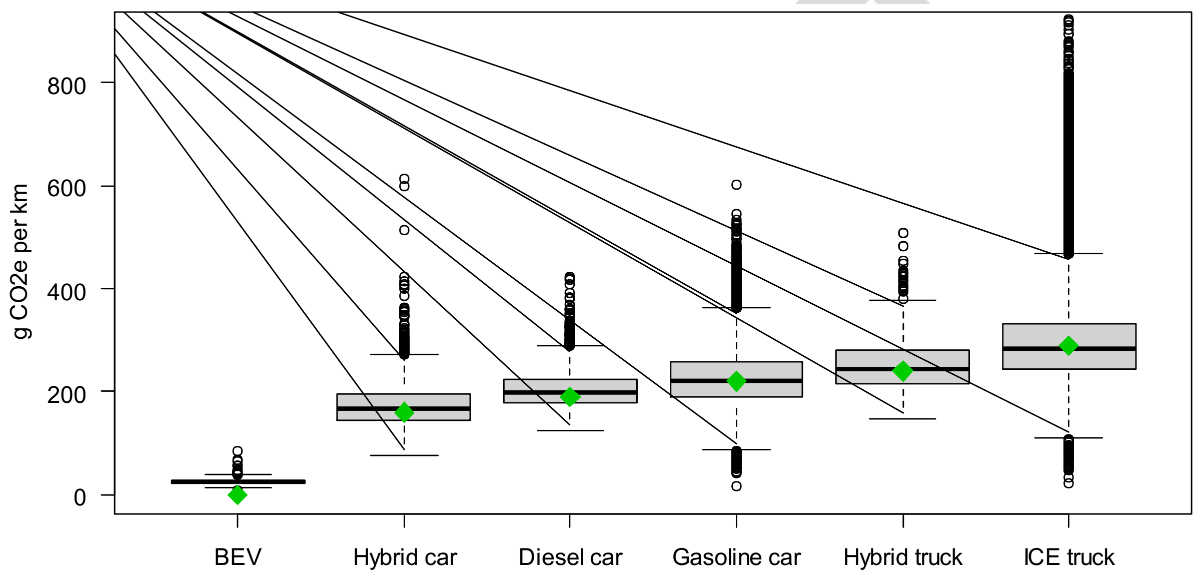

Figure 18-10. Comparison of our emission estimates for automobile trips (boxplots) to rates in BC Provincial guidance (green diamonds); including upstream fuel cycle emissions for BEV and hybrid powertrains for comparability

As another external validation, Wang et al. (2023) computed daily GHG emissions for the sample of trips in Toronto's 2016 household travel survey data. They report median personal daily GHG emissions from travel of 6.5 kg CO2e, and median GHG intensity of travel of 210 g CO2e per PKT. In comparison, we calculate median values of 5.5 kg CO2e/person/day and 232 g CO2e per PKT for the TDD. These values are similar, providing a good external validation on the estimates, despite different regions of analysis (Toronto is a larger but less dense region). In addition, there were several important differences in the estimation methods, including:

1. We include vehicle cycle emissions while they do not,
2. We include vehicle make/model adjustments to MOVES-modeled fuel efficiency by vehicle class/fuel, which they do not,

3. We use vehicle-specific fuel and powertrain types (gasoline, diesel, HEV, PHEV, and BEV) rather than assuming all passenger vehicles are gasoline-fuelled and all buses are diesel-fuelled,
4. We include dynamic passenger occupancy for automobile (from the TDD) and the primary transit modes (from operational data) rather than fixed occupancy by mode and time period (extracted from a travel demand model),
5. Our transit emission factors (per VKT) are based on measured fuel consumption data, rather than MOVES estimates (petrol buses) or manufacturer information (electric buses and trains),
6. We use a fixed GHG intensity for Provincial electricity *consumption*, rather than a dynamic GHG intensity for Provincial electricity *production*,
7. We attribute automobile emissions equally to all vehicle occupants, rather than only to the driver, and
8. We estimate emissions from all reported trips (with necessary assumptions) rather than excluding “other” modes.

Note also that due to skewed distributions and varying trip lengths and household sizes, these aggregate measures vary greatly if using mean versus median values, or aggregating by trip, person, or household. For further comparisons, mean daily GHG emissions per person from travel has been reported as 6.8 kg CO2e in Quebec City in the early 2000’s (Barla et al., 2011a), and just 0.6 kg CO2e in Xiamen City, China in 2015 (L. Xu et al., 2018).

18.11. Marginal emissions

Regression model estimates are given in

Table 18-22 for all three modes. Adjusted R-squared values for the models were 0.931 for automobile, 0.717 for bus transit, and 0.364 for rail transit. The individual (versus idiosyncratic) error component was 58% and 38% of the total error for bus transit and rail transit, respectively, in the random effects models.

Table 18-22. Elasticity regression model results

Model	Parameter[1]	Estimate	Standard error[2]
Automobile	Intercept	-0.152	0.0125
Automobile	Passenger travel	0.977	0.0032
Bus transit	Intercept	-0.799	0.0423
Bus transit	Passenger travel	0.365	0.0090
Rail transit	Intercept	0.300	0.1043
Rail transit	Passenger travel	0.323	0.0152

[1] Dependent variables were vehicle travel; dependent and independent variables were log-transformed
[2] All significantly different from both 0 and 1 at $p<0.05$

The parameters of interest in are the estimates for Passenger travel, which indicate the elasticity of vehicle to passenger travel, ε_v^p. As explained in the literature, ε_v^p is expected to be between 0 and 1 (A. Bigazzi, 2019). A ε_v^p of 0 indicates that the quantity of vehicle travel is independent of the quantity of passenger travel, and increasing passenger trips are accomplished through higher vehicle occupancy (and vice versa). A ε_v^p of 1 indicates that the quantity of vehicle travel increases proportionately with the quantity of passenger travel, resulting in (or a consequence of) a fixed vehicle occupancy. The elasticity of vehicle to passenger travel for automobile trips in

Table 18-22 is 0.977, indicating that 98% of the variation PKT by household is matched with variation in household VKT (the rest is accommodated by varying occupancy). The elasticity of vehicle to passenger travel for bus and rail transit in

Table 18-22 is 0.365 and 0.323, respectively, indicating that variation in transit vehicle trips is about 1/3rd the magnitude of variation in transit passenger trips (higher for bus than rail). Hence, VKT is much less sensitive to variation in passenger PKT for transit than automobile trips – consistent with past analysis of data from the USA (A. Bigazzi, 2019).

We explored a range of household and transit system co-variates to understand the moderators of vehicle to travel elasticity, ε_v^p. Higher elasticity indicates that the quantity of vehicle travel is more sensitive to passenger demand, and that vehicle occupancy is less sensitive. For automobile trips, elasticity increases (significantly at $p<0.05$) for households with fewer people, no family members co-habituating, less vehicle availability, higher income, and for renters (vs. owners). Although statistically significant, the magnitude of these moderating effects is small, changing elasticity by <0.07. These results indicate that vehicle occupancy is more dynamic (i.e., lower ε_v^p) in households with more potential for coordination of automobile trips among household members. Elasticity was not sensitive ($p>0.05$) to housing type (single detached or not).

For transit trips, elasticity increases for weekday (vs. weekend) and for daytime (vs. 21 hr to 4 hr) services. The magnitudes of these differences are around 0.03. Rail transit elasticity is also substantially higher for SkyTrain (0.332) than West Coast Express (0.135) services. Given these differences, we apply separate elasticities to SkyTrain and West Coast Express trips in the analysis below. These results are consistent with expectations, with peak-period and higher-ridership services being more demand-sensitive and so having higher elasticity (A. Bigazzi, 2020).

As a comparison, past analysis applying similar modelling methods to national-level household travel survey data from the USA reported lower vehicle to passenger elasticity for automobile trips of 0.90 (versus 0.98 here) (A. Bigazzi, 2019). A key conceptual and methodological difference between the studies is the aggregation of VKT to households; the USA analysis assigned VKT based on the household of the vehicle driver, whereas we assign VKT proportionately to all vehicle occupants. We believe our method is a better approximation of the unknown distribution of agency for trip production among vehicle occupants. Note that if the vehicle occupants are from the same household, the results are equivalent. Re-estimating our elasticity model with all VKT assigned to the vehicle driver's household results in an elasticity of 0.914, which is closer to the results of the USA analysis. We believe this approach gives passengers in another household's automobile an emissions “free ride”, and underestimates the sensitivity of VKT to PKT. In addition to this methodological difference, the difference in elasticities is likely also due to the data scope, with the USA national data including more households in low-density suburban and rural contexts, which would correspond with factors that were shown above to decrease elasticity (larger, family households with more vehicles in owned housing).

Past analysis applying similar modelling methods to national-level transit system data from the USA reported similar vehicle to passenger elasticity for bus transit of 0.38 (versus 0.37 here), but much higher elasticity for rail transit of 0.83 (versus 0.32 here) (A. Bigazzi, 2020). In addition to the different national context, a major difference between these models is the scale, with the local model representing changes in VKT with ridership for the TransLink system within a given year, and the USA model representing changes at the metropolitan scale over time. Hence, the previous analysis would represent long-term elasticity, include changes such as new rail lines, whereas the local analysis would represent short-term elasticity within a relatively fixed system extent. Given the very low GHG emissions rate for SkyTrain segments (on par with bicycles), the selection of an elasticity value to calculate MAER for SkyTrain ultimately have little impacts on the results. Still, the contextual factors influencing vehicle to passenger travel elasticity for rail transit require further investigation with a composite set of transit data from diverse cities.

Applying the estimated local elasticities with the previous assumptions in Table 18-23. MAER applied to the TDD emissions estimates we generate the MAER (marginal to average emissions ratios). The MAER scaling factors are applied to trip segments by mode (multiplying by the previously-calculated attributional g CO_2e), and then summed to trip total consequential (marginal) emissions estimates in g CO_2e.

Table 18-23. MAER applied to the TDD emissions estimates

Mode	ε_e^θ	ε_v^p	MAER
Auto driver or passenger	0.040	0.977[1]	0.978
Motorcycle or taxi	0.040	0.977[1]	0.978
Transit bus	0.160	0.365[1]	0.467
SkyTrain	0.050	0.332[1]	0.365
Westcoast Express	0.050	0.135[1]	0.178
School bus	0.160	0.365[1]	0.467
Shuttle	0.100	0.858	0.872
SeaBus, Aqua Bus, ferry	0.050	0.431	0.459
HandyDart	0.100	0.763	0.787
Bicycle, walk, wheelchair	0.000	1.000	1.000

[1] From local data; others from Bigazzi (2019, 2020)

Figure 18-11 and Figure 18-12 illustrate the consequential versus attributional (i.e., marginal versus average rate) emissions estimates by segment and trip, respectively. Since the MAER are applied by segment mode, segments by each mode form a line at a slope corresponding to the MAER. The trip-level comparison aggregates the segment-level differences of multi-modal trips. This aggregation is particularly relevant for transit trips with substantial (high-emitting) access and egress segments.

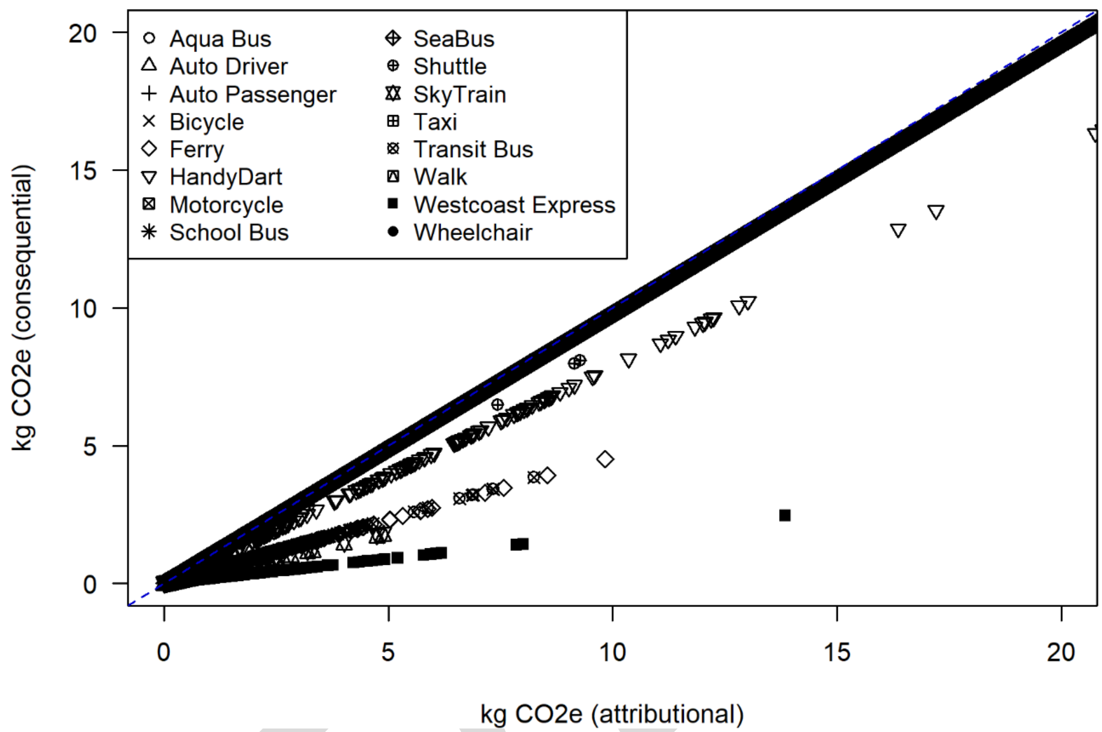

Figure 18-11. Segment-level attributional (average-rate) versus consequential (marginal-rate) emissions by segment mode; bounds truncated for legibility; blue dashed line denotes equivalent values

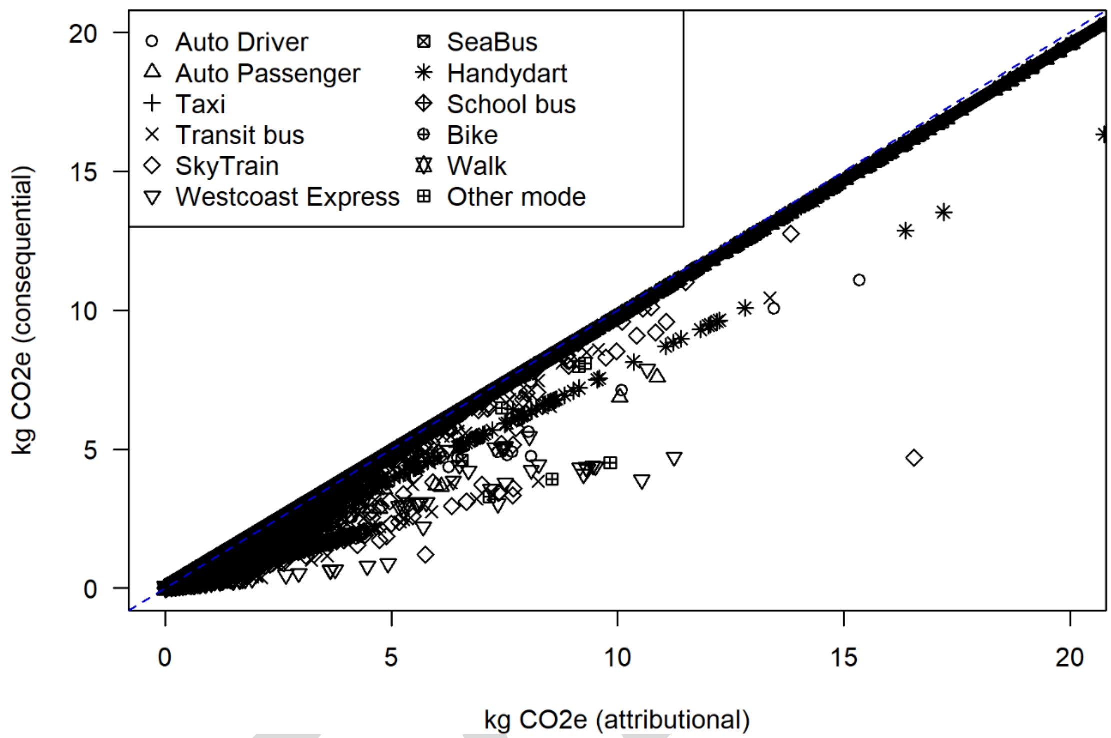

Figure 18-12. Trip-level attributional (average-rate) versus consequential (marginal-rate) emissions by primary trip mode; bounds truncated for legibility; blue dashed line denotes equivalent values

Figure 18-12 shows that the consequential and attributional accounting frameworks generate substantially different emissions estimates for some but not all trips. The ratio of consequential to attributional emissions estimates by trip averages 0.91 (0.97 if emissions-weighted) and ranges from 0.18 to 1.00, with 25th, 50th, and 75th percentile values of 0.98 (due to the preponderance of automobile trips).

Given the variability in the effect of accounting framework on trip-level emissions, we estimate a regression model to examine the relationships between person and household-level factors and the difference between the two types of emissions estimates. The model is specified with person and household variables as independent variables and estimated using person and household weights from the TDD. Two different dependent variables are investigated: 1) the difference in emissions (in g CO2e) estimated by a consequential versus an attributional framework (i.e., $E_P' - E_P$), and 2) the percent difference in emissions estimated by a consequential versus an attributional framework (i.e., $\frac{2(E_P'-E_P)}{E_P'+E_P} * 100\%$).

Model estimation results are given in Table 18-24. The results show that applying a consequential versus an attributional framework disproportionately impacts the apparent climate impacts of travel systematically with person and household attributes including age, gender, income, and vehicle ownership. The differences are larger for people and households who use more low-MAER modes (particularly transit). A consequential framework disproportionately decreases the estimated climate impacts of travel for non-senior adult travellers (19-64 y), renters, larger households, and households with lower vehicle ownership or detached housing. The model results are inconsistent for some factors because the magnitudes of the two measures of difference depend on the total amount of VKT and the proportion by transit. For example, higher income households have significantly more transit VKT but even more automobile VKT. More transit travel produces a negative effect of income on total consequential GHG, but a smaller proportion of household VKT from transit produces a positive effect of income on the percent difference between the two GHG measures. This contrast is illustrated in Figure 18-13, which shows the mean consequential and attributional daily household GHG by income tier. Higher income households have a larger absolute differential between their consequential and attributional GHG estimates, but that difference is smaller on a percentage basis.

Table 18-24. Model of personal factors influencing difference between consequential and attributional emissions estimates

Variable	Difference model[1]	Percent difference model[2]
Intercept	-413.35*	-37.52*
Age <19 yr	315.21*	22.16*
Age 65+ yr	179.69*	2.08*
Male	-59.06*	0.08
Licensed driver	-8.92	22.78*
Carshare member	23.17*	-4.52*

[1] Dependent variable: difference between consequential and attributional estimates (g CO_2e)
[2] Dependent variable: percent difference between consequential and attributional estimates (%)
* $p < 0.05$

Table 18-25. Model of household factors influencing difference between consequential and attributional emissions estimates

Variable	Difference model[1]	Percent difference model[2]
Intercept	-178.97*	-5.85*
Persons of age 5+ (up to 6)	-202.27*	-0.29*
Vehicles ≥ adults	-28.94	2.70*
Detached housing	-92.95*	0.18
Renting housing	-12.67	-0.91*
Income middle ($50k-$100k)	-100.85*	0.53*
Income high (>$100k)	-243.77*	0.59*
Cohabitating with 1+ family member	-3.62	0.94*

[1] Dependent variable: difference between consequential and attributional estimates (g CO_2e)
[2] Dependent variable: percent difference between consequential and attributional estimates (%)
* $p < 0.05$

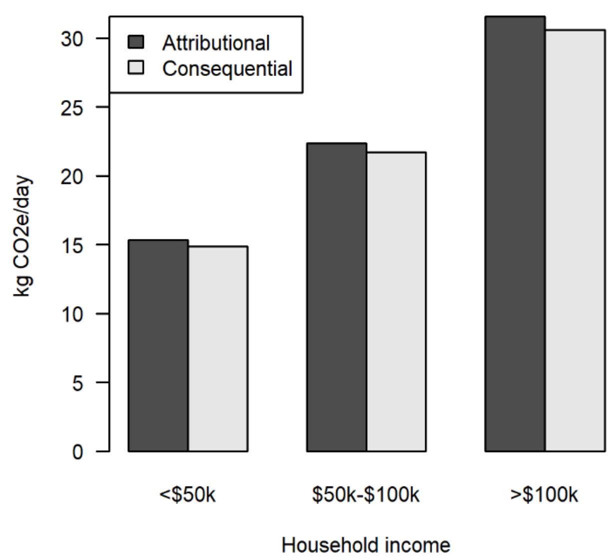

Figure 18-13. Mean consequential and attributional daily household GHG by income tier

18.12. Analysis of statistical relationship between emissions and walkability

Study sample and study variables

The Walkability Index is a composite measure of neighbourhood walkability, comprised of four component variables (net residential density, commercial floor area, intersection density, and land use mix). Within this current analysis, the walkability value for each household was defined as the composite index value within a 1-kilometre network buffer, which follow a walkable road network, surrounding the location of the home (as defined by home 6-digit postal code). The values for each component measure were calculated beginning at the home postal code location and were then converted to z-scores to calculate the overall walkability index. The 1-km network buffer size was selected to represent the distance individuals could reasonably travel in a 10–15-minute walking trip and has been previous used to define the home "neighbourhood" area. (Colabianchi et al., 2007).

In addition to neighbourhood walkability, regional accessibility and sidewalk connectivity were calculated at the 6-digit postal code level and linked to the residential location. These values were calculated for both vehicle travel, which provides an estimation of peak travel time from the home location if traveling by vehicle, as well as for transit travel, which conversely provides as estimation of peak travel time from the home if traveling by transit. Additionally, sidewalk connectivity, a measure of the completely of the pedestrian infrastructure, was calculated using methods similar to the walkability index in the 1-km network buffer surrounding the home.

Individual and household demographic data were obtained from the TDD. For this current analysis the following variables were utilized and categorized as follows: gender (dichotomized as female or male), age (categorized as child/youth [age 5-18], adult [age 19-64], and older adult [65+]), driver's license status (dichotomous yes/no), car share status (continuous 0-4, the number of car share membership participants reporting having), employment status (categorized as 'full time employed', 'full time student', 'part time worker or student, or self-employed' or 'non-worker/non-student'), household income (categorized as <$50,000, $50,000-100,000, and >$100,000), household size (continuous 1-10), number of household bicycles (continuous 0-10), number of vehicles per adult in the home (dichotomized as less vehicles than adults [vehicles < adults] and 1 or more vehicle per adult in the home [vehicles > = adults]).

Statistical analysis

Adjusted associations and 95% confidence intervals (CI) were calculated using linear regression and three iterations of adjustment variables. Three adjustment models were developed based on existing literature and conceptual understanding of individual and environmental factors associated with travel behaviour. Multi-level (mixed effects) models were developed to account for the hierarchical nature of the TDD (e.g., multiple participants living in the same household). A two-level model was used to account for clustering of participants within households. Additionally, survey weights obtained from the TDD were utilized in these analyses.

Table 18-26 through Table 18-30 show the association between individual, household, and built environment factors and individual emissions (CO_2, CO, NOX, $PM_{2.5}$, VOC) across trips reported in the TDD. Across each emission analyzed, a trend emerged of reduced emissions associated with living in more walkable areas. Walkability results are presented as change in travel related emissions generated compared to the reference least walkable areas. A graded relationship (dose-response) was shown across walkability bins for CO_2 emissions – with each increase in walkability associated with further reductions in CO_2 emissions, all of which were statistically significant. The results for consequential and attributional CO_2 emissions are similar, with a slightly stronger relationship between walkability and CO2 emissions when using the consequential estimates. For $PM_{2.5}$ and NOX, more walkable (e.g., all walkability bins compared to the reference "least walkable" level) neighbourhoods were associated with statistically significant reduction in emissions. However, although CO emissions were reduced across all walkability bins compared to the reference level, this reduction in CO emissions were no longer significant in the most walkable bin. A similar pattern was shown for VOC emissions, where more walkable areas were associated with lower emissions, however these results did not remain statistically significant at the two most walkable bins.

Across all models and emissions, reporting female gender (compared to male) was associated with lower emissions, as was being in the youngest age group (5-18). Having a driver's licence, and higher ratio of vehicles to adults living in the home was associated with significantly higher emissions estimates across all models. Higher household income tended to be associated with higher emissions, however these results were not consistently significant. Additionally, being a full-time student, or a non-worker/non-student was associated with significantly lower emissions across all models compared to full-time workers.

These results are consistent with previous findings in other locations which tended to find both individual and neighbourhood factors were associated with the individual emissions generated for daily travel purpose. Previous work across multiple locations have found that individuals and households living in more walkable neighbourhoods tended to generate lower travel related emissions, which may be attributed to the features of these neighbourhoods promoting the use of active travel modes, as opposed to private vehicles, being used to make daily trips (Darwish et al., 2023; L. D. Frank, Jr, et al., 2000, p. 200; Rickwood et al., 2008; Steemers, 2003). Additionally, these current results found similar patterns in individual characteristics which tended to be associated with emissions generates, including that higher income households tend to produce higher travel based emissions, which has previously been attributed to these households making more driving trips and owning more household vehicles (Barla et al., 2011b; Brand & Preston, 2010; Kahn, 1998; Ko et al., 2011; Sider et al., 2013).

In conclusion, both individual and neighbourhood characteristics were associated with travel related emissions estimates. When controlling for other individual, household, and neighbourhood factors, living in more walkable areas was associated with generating lower travel related emissions.

Table 18-26. Estimated model of individual daily g CO_2e emissions (attributional) from travel

Variable	Model 1	95% CI	Model 2	95% CI	Model 3	95% CI
Gender (reference: male)						
Female	**-4511.80**	**-4796, -4228**	**-4490.43**	**-4774, -4207**	**-4500.78**	**-4785, -4217**
Age (reference: 19-64)						
5-18	**-2904.20**	**-3683, -2126**	**-3112.33**	**-3890, -2334**	**-3214.63**	**-3992, -2437**
65+	-245.73	-904, 413	-463.88	-1122, 195	-537.02	-1195, 121
Driver's License						
Yes	**12294.72**	**11741, 12848**	**12037.38**	**11484, 12591**	**11892.29**	**11339, 12446**
Car share						
+1	**-652.38**	**-1267, -38**	-461.19	-1074, 152	-223.51	-837, 390
Status (reference: full-time employed)						
Full time student	**-5460.86**	**-6109, -4813**	**-5555.48**	**-6203, -4908**	**-5607.68**	**-6254, -4961**
Part time or self-employed	**-2680.23**	**-3182, -2179**	**-2864.64**	**-3366, -2363**	**-2946.09**	**-3447, -2445**
Non-worker/non-student	**-11006.51**	**-11562, -10451**	**-11196.14**	**-11752, -10641**	**-11322.57**	**-11878, -10767**
Household income						
\$50,000 - \$100,000	**1685.85**	**855, 2517**	**1249.66**	**421, 2078**	**1044.57**	**218, 1871**
>\$100,000	**3336.48**	**2435, 4238**	**2389.88**	**1476, 3304**	**2021.93**	**1110, 2934**
Household size						
+1	**-563.56**	**-825, -303**	**-506.82**	**-820, -301**	**-686.09**	**-947, -425**
Household vehicles						
Vehicles > = Adults	-		**3438.15**	**1006, 5870**	**3054.38**	**630, 5479**
Bicycles						
+1	-		**1024.67**	**450, 1599**	**862.31**	**2886, 1436**
Regional Accessibility						
Vehicle	-		32.47	-40, 105	**73.85**	**0, 147**
Transit	-		**102.96**	**78, 127**	**58.53**	**32, 85**
Sidewalk connectivity					-1113.23	-2912, 685
Walkability (reference level 1)						
2	-		-		**-1656.90**	**-2677, -637**
3	-		-		**-3167.94**	**-4357, -1979**
4	-		-		**-4393.76**	**-5868, -2919**
5	-		-		**-4561.15**	**-6710, -2413**
Greenness (reference level 1)						
2	-		-		**1331.10**	**246, 2416**
3	-		-		**1236.04**	**284, 2188**
4	-		-		**2679.11**	**1588, 3771**
5	-		-		**3356.95**	**2376, 4338**

Notes: bolded results indicate statistical significance at $p<0.05$

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

Table 18-27. Estimated model of individual daily g CO emissions from travel

Variable	Model 1	95% CI	Model 2	95% CI	Model 3	95% CI
Gender (reference: male)						
Female	**-19.83**	**-21.73, -17.94**	**-19.66**	**-21.55, -17.77**	**-19.68**	**-21.57, -17.79**
Age (reference: 19-64)						
5-18	**-18.29**	**-23.48, -13.10**	**-19.46**	**-24.65, -14.27**	**-19.80**	**-24.99. -14.61**
65+	-1.76	-6.19, 2.67	-2.65	-7.08, 1.79	-2.91	-7.35, 1.52
Driver's License						
Yes	**58.02**	**54.32, 61.73**	**56.68**	**52.97, 60.38**	**56.16**	**52.45, 59.86**
Car share						
+1	**-7.86**	**-12.00, -3.73**	**-6.90**	**-11.03, -2.76**	**-6.03**	**-10.17, -1.89**
Status (reference: full-time employed)						
Full time student	**-24.88**	**-29.20, -20.56**	**-25.38**	**-29.70, -21.06**	**-25.59**	**-29.91, -21.27**
Part time or self-employed	0.67	-2.69, 4.02	-0.36	-3.71, 3.00	-0.66	-4.01, 2.69
Non-worker/non-student	**-41.78**	**-45.50, -38.06**	**-42.84**	**-46.56, -39.11**	**-43.33**	**-47.06, -39.61**
Household income						
$50,000 - $100,000	**8.00**	**2.24, 13.77**	5.14	-0.62, 10.90	4.30	-1.46, 10.07
>$100,000	**7.67**	**1.39, 13.95**	1.45	-4.94, 7.83	-0.13	-6.52, 6.25
Household size						
+1	**-3.39**	**-5.22, -1.56**	**-3.12**	**-4.94, -1.29**	**-3.60**	**-5.44, -1.76**
Household vehicles						
Vehicles > = Adults	-		**38.76**	**21.86, 55.66**	**37.20**	**20.31, 54.08**
Bicycles						
+1	-		**8.20**	**4.20, 12.20**	**7.34**	**3.34, 11.34**
Regional Accessibility						
Vehicle	-		0.25	-0.25, 0.75	0.44	-0.06, 0.95
Transit	-		**0.51**	**0.34, 0.68**	**0.31**	**0.13, 0.49**
Sidewalk connectivity			-		-4.19	-16.64, 8.27
Walkability (reference level 1)						
2	-		-		**-9.57**	**-16.68, -2.45**
3	-		-		**-19.32**	**-16.68, -2.45**
4	-		-		**-17.47**	**-27.75, -7.18**
5	-		-		-12.71	-27.67, 2.24
Greenness (reference level 1)						
2	-		-		0.21	-7.30, 7.72
3	-		-		-0.14	-6.74, 6.45
4	-		-		**8.63**	**1.07, 16.18**
5	-		-		**11.07**	**4.27, 17.87**

Notes: bolded results indicate statistical significance at $p<0.05$

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

Table 18-28. Estimated model of individual daily g NO_x emissions from travel

Variable	Model 1	95% CI	Model 2	95% CI	Model 3	95% CI
Gender (reference: male)						
Female	**-3.01**	**-3.30, -2.72**	**-2.99**	**-3.28, -2.70**	**-2.99**	**-3.28, -2.69**
Age (reference: 19-64)						
5-18	**-4.08**	**-4.88, -3.29**	**-4.25**	**-5.04, -3.45**	**-4.29**	**-5.09, -3.49**
65+	-0.32	-1.00, 0.35	-0.46	-1.13, 0.22	-0.48	-1.16, 0.19
Driver's License						
Yes	**4.11**	**3.55, 4.68**	**3.92**	**3.35, 4.49**	**3.86**	**3.29, 4.43**
Car share						
+1	**-1.48**	**-2.11, -0.85**	**-1.33**	**-1.95, -0.70**	**-1.21**	**-1.84, -0.58**
Status (reference: full-time employed)						
Full time student	**-0.10**	**-0.76, 0.57**	**-0.17**	**-0.83, 0.50**	**-0.19**	**-0.85, 0.47**
Part time or self-employed	**0.33**	**-0.18, 0.85**	**0.19**	**-0.32, 0.70**	**0.15**	**-0.36, 0.66**
Non-worker/non-student	**-3.24**	**-3.81, -2.68**	**-3.39**	**-3.96, -2.82**	**-3.45**	**-4.02, -2.88**
Household income						
$50,000 - $100,000	**0.65**	**-0.19, 1.50**	**0.29**	**-0.56, 1.14**	**0.19**	**-0.66, 1.04**
>$100,000	**0.37**	**-0.55, 1.29**	**-0.40**	**-1.33, 0.53**	**-0.58**	**-1.51, 0.36**
Household size						
+1	**-0.42**	**-0.69, -0.16**	**-0.39**	**-0.65, -0.12**	**-0.41**	**-0.68, -0.15**
Household vehicles						
Vehicles > = Adults	-		**5.58**	**3.09, 8.07**	**5.33**	**2.85, 7.82**
Bicycles						
+1	-		**0.79**	**0.21, 1.38**	**0.67**	**0.08, 1.26**
Regional Accessibility						
Vehicle	-		-0.03	-0.11, 0.04	**0.00**	**-0.07, 0.08**
Transit	-		**0.09**	**0.06, 0.11**	**0.06**	**0.03, 0.08**
Sidewalk connectivity			-		-2.33	-4.07, -0.39
Walkability						
2	-		-		**-1.68**	**-2.73, -0.64**
3	-		-		**-2.14**	**-3.36, -0.92**
4	-		-		**-2.01**	**-3.52, -0.50**
5	-		-		**-1.13**	**-3.33, -1.08**
Greenness						
2	-		-		-0.25	-1.36, 0.85
3	-		-		0.10	-0.88, 1.07
4	-		-		1.10	-0.11, 2.13
5	-		-		1.40	0.40, 2.41

Notes: bolded results indicate statistical significance at $p<0.05$

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

Table 18-29. Estimated model of individual daily g $PM_{2.5}$ emissions from travel

Variable	Model 1	95% CI	Model 2	95% CI	Model 3	95% CI
Gender (reference: male)						
Female	**-0.12**	**-0.13, -0.11**	**-0.12**	**-0.13,-0.11**	**-0.12**	**-0.13, -0.11**
Age (reference: 19-64)						
5-18	**-0.14**	**-0.17, -0.12**	**-0.15**	**-0.18, -0.12**	**-0.15**	**-0.18, -0.13**
65+	-0.02	-0.05, -0.00	**-0.03**	**-0.06, -0.01**	**-0.03**	**-0.06, -0.01**
Driver's License						
Yes	**0.26**	**0.24, 0.28**	**0.25**	**0.23, 0.28**	**0.25**	**0.23, 0.27**
Car share						
+1	**-0.03**	**-0.05, -0.01**	-0.02	-0.05, -0.00	-0.02	-0.04, 0.01
Status (reference: full-time employed)						
Full time student	**-0.09**	**-0.12, -0.07**	**-0.10**	**-0.12, -0.07**	**-0.10**	**-0.12, -0.07**
Part time or self-employed	**-0.07**	**-0.09, -0.05**	**-0.08**	**-0.10, -0.06**	**-0.08**	**-0.10, -0.06**
Non-worker/non-student	**-0.24**	**-0.26, -0.22**	**-0.25**	**-0.27, -0.23**	**-0.25**	**-0.27, -0.23**
Household income						
\$50,000 - \$100,000	**0.04**	**0.01, 0.07**	0.03	-0.00, 0.06	0.02	-0.00, 0.05
>\$100,000	**0.08**	**0.05, 0.11**	**0.05**	**0.02, 0.08**	**0.04**	**0.01, 0.07**
Household size						
+1	**-0.02**	**-0.03, -0.01**	**-0.02**	**-0.03, -0.01**	**-0.02**	**-0.03, -0.01**
Household vehicles						
Vehicles > = Adults	-		**0.12**	**0.03, 0.20**	**0.11**	**0.02, 0.19**
Bicycles						
+1	-		**0.03**	**0.01, 0.05**	**0.03**	**0.01, 0.05**
Regional Accessibility						
Vehicle	-		0.00	-0.00, 0.00	0.00	-0.00, 0.01
Transit	-		0.00	0.00, 0.00	0.00	0.00, 0.00
Sidewalk connectivity					-0.07	-0.14, -0.01
Walkability (reference level 1)						
2	-		-		**-0.07**	**-0.10, -0.03**
3	-		-		**-0.09**	**-0.13, -0.05**
4	-		-		**-0.11**	**-0.16, -0.05**
5	-		-		**-0.10**	**-0.17, -0.02**
Greenness (reference level 1)						
2	-		-		0.02	-0.02, 0.06
3	-		-		0.02	-0.02, 0.05
4	-		-		**0.06**	**0.02, 0.10**
5	-		-		**0.08**	**0.05, 0.12**

Notes: bolded results indicate statistical significance at $p<0.05$

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

Table 18-30. Estimated model of individual daily g VOC emissions from travel

Variable	Model 1	95% CI	Model 2	95% CI	Model 3	95% CI
Gender (reference: male)						
Female	**-1.33**	**-1.49, -1.16**	**-1.31**	**-1.48, -1.15**	**-1.31**	**-1.48, -1.15**
Age (reference: 19-64)						
5-18	**-1.17**	**-1.62, -0.73**	**-1.25**	**-1.69, -0.80**	**-1.27**	**-1.71, -0.82**
65+	0.24	-0.14, 0.62	0.18	-0.20, 0.56	0.17	-0.21, 0.55
Driver's License						
Yes	**2.97**	**2.65, 3.29**	**2.88**	**2.57, 3.20**	**2.86**	**2.54, 3.18**
Car share						
+1	**-0.75**	**-1.10, -0.39**	**-0.68**	**-1.04, -0.33**	**-0.64**	**-1.00, -0.29**
Status (reference: full-time employed)						
Full time student	**-1.07**	**-1.44, -0.70**	**-1.10**	**-1.47, -0.73**	**-1.11**	**-1.48, -0.74**
Part time or self-employed	**0.31**	**0.02, 0.59**	0.24	-0.05, 0.53	0.23	-0.06, 0.51
Non-worker/non-student	**-2.06**	**-2.38, -1.74**	**-2.13**	**-2.45, -1.81**	**-2.15**	**-2.47, -1.83**
Household income						
$50,000 - $100,000	0.35	-0.15, 0.84	0.16	-0.33, 0.66	0.13	-0.37, 0.62
>$100,000	0.04	-0.50, 0.58	-0.36	-0.90, 0.19	-0.43	-0.98, 0.12
Household size						
+1	**-0.22**	**-0.37, -0.06**	**-0.19**	**-0.35, -0.04**	**-0.21**	**-0.36, -0.05**
Household vehicles						
Vehicles > = Adults	-		**3.02**	**1.57, 4.47**	**2.93**	**1.48, 4.38**
Bicycles						
+1	-		**0.51**	**0.16, 0.85**	**0.46**	**0.11, 0.80**
Regional Accessibility						
Vehicle	-		0.02	-0.02, 0.06	0.03	-0.01, 0.08
Transit	-		0.03	0.02, 0.04	0.02	0.00, 0.03
Sidewalk connectivity			-		-0.62	-1.69, 0.45
Walkability (reference level 1)						
2	-		-		**-0.67**	**-1.29, -0.06**
3	-		-		**-1.01**	**-1.72, -0.30**
4	-		-		-0.79	-1.67, 0.09
5	-		-		-0.09	-1.37, 1.19
Greenness (reference level 1)						
2	-		-		-0.09	-0.73, 0.56
3	-		-		-0.19	-0.75, 0.38
4	-		-		0.25	-0.40, 0.90
5	-		-		0.55	-0.03, 1.13

Notes: bolded results indicate statistical significance at $p<0.05$

Vehicle regional accessibility = AM vehicle trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations; Transit regional accessibility = AM transit trip weighted mean minutes to Metro Vancouver and Fraser Valley destinations

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metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

E2

To: Regional Planning Committee

From: Edward Nichol, Senior Planner, Regional Planning and Housing Services

Date: March 13, 2024 Meeting Date: April 5, 2024

Subject: **Metro 2050 Climate Policy Enhancement Study - Recommendations**

RECOMMENDATION

That the MVRD Board direct staff to prepare a bylaw to amend *Metro 2050* for consideration based on the following recommendations and as described in Table 2 of the report dated March 13, 2024, titled "*Metro 2050* Climate Policy Enhancement Study – Recommendations" to:

a) develop a revised definition for the regional Rural land use designation;
b) encourage the protection and restoration of trees and other ecosystems on lands with a non-urban regional land use designations and lands outside the Urban Containment Boundary;
c) require environmental and climate change-related analyses as part of all *Metro 2050* amendment applications;
d) encourage the development of local hazard and risk data that meets key requirements;
e) add new climate-related performance monitoring metrics; and
f) increase intersection density and permeability of the urban street grid.

EXECUTIVE SUMMARY

In response to MVRD Board direction, new and enhanced climate-related policy actions have been developed for *Metro 2050*. An initial list of policy ideas was presented at two workshops with subject matter experts in early 2023, and the feedback received was used to inform six draft recommendations. These draft recommendations were presented at a joint workshop with the Climate Action Committee and Regional Planning Committee in November 2023, and the feedback received was considered and applied to staff's recommendations. The six recommendations represent potential policy changes that are actionable, effective, important for climate action, and closely connected to the intent and scope of *Metro 2050*.

PURPOSE

To provide the Regional Planning Committee and MVRD Board with recommendations to strengthen climate change policies in *Metro 2050*.

BACKGROUND

At its meeting on January 29, 2021, the MVRD Board endorsed the recommendations of the *Metro 2040 Climate Change and Natural Hazards Policy Review* (Reference 1) as the basis for updating the climate change and natural hazard-related policies in the regional growth strategy. As a result, *Metro 2050* contains stronger climate change policies as compared to *Metro 2040* (Reference 2). Notwithstanding these stronger climate-related policies, at its meeting on March 25, 2022, while considering first and second readings of the *Metro 2050* bylaw (Reference 3), the MVRD Board passed the following resolution:

> *Given the urgent need to respond to climate change and prepare for extreme weather events, direct staff to undertake work and engagement with an aim to proposing an early amendment to Metro 2050 post-adoption to strengthen climate action language and policy including the intent to improve integration of climate action into other Metro 2050 priorities.*

At its May 27, 2022 meeting, the MVRD Board received a report titled "Process to Consider Stronger Climate Action Language and Policy for Metro 2050" (Reference 4). That report set out a high-level process for how staff would respond to the March 25, 2022 Board direction.

At its February 10, 2023 meeting, the Regional Planning Committee received a report titled "Metro 2050 Climate Policy Enhancement Study – Project Initiation" (Reference 5); the same report was provided to the Climate Action Committee for information at its meeting on March 9, 2023. That report provided greater detail on the proposed scope of work and the engagement process for the study. *Metro 2050* was adopted as bylaw by the MVRD Board on February 24, 2023.

At its November 2, 2023 meeting, the Climate Action Committee hosted a Joint Discussion with the Regional Planning Committee. Participants of this session received a Backgrounder on the *Metro 2050* Climate Policy Enhancement Study (Reference 6) and provided feedback that has been considered in the development of the final recommendations presented in this report.

POLICY APPROACHES OF METRO 2050 AND CLIMATE 2050

Land Use Planning is Climate Action

Land use planning decisions can significantly influence the spatial arrangements of communities, transportation systems, building typologies, and protect natural areas which, in turn, affect the amount of energy consumed, greenhouse gases (GHGs) emitted, and carbon stored. Land use planning can also be a powerful catalyst for enhancing resilience by ensuring that residents, property, infrastructure, and ecosystems are safeguarded from the impacts of climate change and natural hazards. Land use planning and decision making is foundational to advancing climate action and sustainability in the region over the long term.

Starting with a Strong Foundation

Metro 2050 contains regional GHG emission reduction targets that align with the global targets set by the Intergovernmental Panel on Climate Change and those of *Climate 2050*, as well as strategies and actions to help meet those targets. *Metro 2050* contains climate policies across all five goal areas and supports Metro Vancouver and its member jurisdictions in focusing projected growth in a network of transit-oriented urban centres, and building compact, complete communities that offer amenities close to home. This approach to focusing growth has three key GHG emission reduction benefits:

1) reduces development pressures in areas that naturally store carbon (such as the region's agricultural and natural areas);

2) reduces emissions by supporting more sustainable, low carbon transportation options such as walking, cycling, and public transit and by reducing the distances people typically have to drive for essential trips; and
3) encourages multi-unit development forms which are generally more energy-efficient than single-detached homes.

Where and how the region accommodates growth also determines the degree to which residents, businesses, and infrastructure are exposed to the risks associated with climate change and natural hazards. To improve resilience, *Metro 2050* includes policy actions that:

- protect natural areas and other important lands that are essential to buffering communities from climate change impacts and natural hazards;
- establish a role for Metro Vancouver to develop and share information related to hazard, risk, and vulnerability; and
- encourage the protection of existing communities and discourage new growth in at-risk areas.

Mutually Supportive Plans
Metro 2050 was developed in accordance with the provisions of the *Local Government Act* and sets out actions and directions for Metro Vancouver, member jurisdictions, and TransLink. The process to develop and approve a regional growth strategy necessitates a high degree of consensus and acceptance across the regional federation. Member jurisdictions demonstrate alignment between their local Official Community Plans and *Metro 2050* through the completion of Regional Context Statements.

Climate 2050, the regional climate action strategy, is intended to guide climate change policy and action for all stakeholders in the region over the next 30 years. It is implemented through a series of ten “Roadmaps” (organized by topic area) that are ultimately endorsed by the MVRD Board. The *Climate 2050 Land Use and Urban Form Roadmap* (LUUF), which is currently being developed, includes content related to land use planning, urban form, and growth management that is consistent and supportive of *Metro 2050*. Table 1 below outlines the rationale for land use-related policy ideas to be included in either: a) the Metro 2050 Climate Policy Enhancement Study recommendations, or b) the *Climate 2050 Land Use and Urban Form Roadmap*.

Table 1. Rationale Used to Direct Policy Ideas

Metro 2050 **Climate Policy Enhancement Study**	**Climate 2050 LUUF Roadmap**
• Policies that do not require additional studies or research • Policies that could be implemented in the short-term as a result of a *Metro 2050* amendment	• Policies that are exploratory and study-focused, which could inform future amendments to *Metro 2050*
• Policies that would be most effectively implemented in *Metro 2050* (e.g., by signatories)	• Policies that could be effectively implemented regardless of *Metro 2050*

• New policies that strengthen the overall suite of climate change policies in *Metro 2050*	• Includes context (non-policy) sections that communicate the climate change benefits of existing policies in *Metro 2050* • Policies that are informed by, supportive of, and supplemental to the principles and actions of *Metro 2050* • New policy directions, including a series of 'Big Moves'
• Policy changes within scope of a Type 2 or Type 3 amendment to *Metro 2050*	• Policies and concepts that are exploratory, politically-sensitive, or less well-established • Policies that would not be appropriate for *Metro 2050* due to legislative or regulatory constraints

METRO 2050 CLIMATE POLICY ENHANCEMENT STUDY

The *Metro 2050* Climate Policy Enhancement Study addresses the MVRD Board's direction to bring forward stronger climate change policy options for consideration.

Engagement Summary

To avoid engagement fatigue and maximize efficiency, the *Metro 2050* Climate Policy Enhancement Study and the LUUF Roadmap project teams prepared a joint engagement plan. A policy idea shortlist developed by Metro Vancouver staff was presented at two workshops held in early 2023 to gather feedback about how to advance climate action through land use and growth management planning. Attendees of the workshops included staff from government agencies, other regional and non-governmental organizations, and youth. Local First Nations were also invited to participate in the two workshops, to meet directly with project staff separately, and to provide written input on the draft lists of actions and policies; funding was made available to support the involvement of First Nations. To date, Squamish Nation staff have met with project staff directly to provide feedback.

On November 2, 2023, staff presented the draft recommendations at a joint Climate Action and Regional Planning Committee meeting. Attendees expressed general support for the recommendations, and provided additional feedback for staff consideration.

Recommendations

During the engagement phase, many policy amendment options were considered and explored. Following engagement, staff refined the list of climate change policy option recommendations for *Metro 2050* into two categories. Table 2 below outlines the core (staff) recommendations, and Table 3 below outlines additional policy options for consideration to amend *Metro 2050* that could also advance climate action, but do not have as strong a connection with the goals and strategies of *Metro 2050*. Additional context and rationale related to the recommendations is included in each table.

Table 2. Climate Policy Enhancement Study Recommendations

a)	**That Metro Vancouver work collaboratively with member jurisdictions to develop an updated *Metro 2050* definition, intent and appropriate uses for the Rural regional land use designation, to provide needed clarity and consistency, and articulate the importance of Rural lands for:** • **Supporting regional urban containment objectives;** • **Protecting the region's ecosystems and agricultural lands;** • **Sequestering and storing carbon; and** • **Buffering the impacts of climate change and natural hazards.** **The intent of this recommendation is not to amend policy action 1.4.3 or 6.9.1.** <u>*Rationale/Anticipated Outcomes:*</u> • *While other regional land use designations are more clearly defined by specific criteria, Rural designated lands are ambiguously defined in Metro 2050;* • *Rural designated lands are not intended for urban expansion, which is made clear in the policy directions of Metro 2050 that limit extension of regional sewer servicing outside the Urban Containment Boundary;* • *The current ambiguity related to the definition and intent of Rural lands complicates the review of Metro 2050 amendment applications for lands with a Rural regional land use designation, confuses the assumption of their long-term purpose, and may work counter to the urban containment objectives and Guiding Principles of Metro 2050;* • *A significant portion of the region's Rural designated lands are within or adjacent to floodplains and steep slopes, support agricultural production, contain Sensitive Ecosystems with high carbon storage value, and have areas with high water tables and sensitive groundwater aquifers. Because of these characteristics, much of the region's designated Rural lands are also unsuitable for urban forms of development, and protecting existing Rural lands for their current use is a cost-effective climate action given the ecosystem services they already provide and the implicit climate change benefits (reducing GHGs and enhancing resilience) associated with urban containment;* • *Revising the definition of Rural designated lands and providing additional information in an Implementation Guideline would clarify the role and servicing intent of Rural lands, and will serve to reduce speculation and development pressures faced by member jurisdictions. The need for this clarity is critical, given that servicing needs and requirements are interrelated with development intensity; and* • *Revising the definition of Rural designated lands will provide consistent messaging for member jurisdictions, landowners / developers, First Nations, agency partners, and the public, and will improve transparency.*
b)	**Add new policies to Strategies 1.4, 2.3, and 3.1 of *Metro 2050* for Metro Vancouver to work with key partners to encourage the protection and restoration of trees and other natural ecosystems on lands with a non-urban regional land use designation (i.e., Rural, Agricultural, Conservation and Recreation), and on lands outside the Urban Containment Boundary.** <u>*Rationale/Anticipated Outcomes:*</u> • *Trees and other ecosystems provide important climate-related ecosystem services by storing carbon, providing shading and cooling, and absorbing stormwater runoff;*

	• *Metro 2050 contains a target for tree canopy cover within the Urban Containment Boundary but not for lands outside the UCB;* • *Metro 2050 includes an ecosystem protection target for 50% of the region's total land base;* • *Agricultural, Rural, and Conservation and Recreation designated lands provide opportunities to protect natural ecosystems and increase tree canopy cover - this will be essential to supporting Metro 2050's 50% protected areas target;* • *70% of Sensitive and Modified Ecosystem loss between 2014 and 2020 occurred within the Agricultural, Conservation and Recreation, and Rural regional land use designations; and* • *71% of Sensitive and Modified Ecosystem loss between 2014 and 2020 occurred on lands outside the Urban Containment Boundary.*
c)	**Add a new policy to Section F of *Metro 2050* requiring Metro Vancouver and member jurisdictions to include additional climate-focused analysis in *Metro 2050* amendment applications. This would be implemented by a) requiring Metro Vancouver to work with member jurisdictions to provide relevant environmental and climate change data and analysis and b) requiring member jurisdictions to demonstrate that the proposed amendment does not conflict with applicable commitments in OCPs / accepted Regional Context Statements pertaining to the following topic areas:** • **Carbon storage levels in natural areas;** • **Tree canopy cover;** • **Impervious surfaces;** • **Ecosystem protection, including Sensitive and Modified Ecosystems;** • **Agricultural land; and** • **Green infrastructure and ecosystem connectivity.** <u>*Rationale/Anticipated Outcomes:*</u> • *Policy action 3.2.2 a) of Metro 2050 establishes Metro Vancouver's role to collect and report on the gains and losses for relevant environmental data;* • *Policy action 3.2.7 of Metro 2050 requires member jurisdictions to report on tree canopy cover, protected areas, and sensitive ecosystems in Regional Context Statements;* • *Implementing this recommendation will provide consistent messaging for member jurisdictions, landowners / developers, First Nations, agency partners, the public, etc., improve transparency on all Regional Growth Strategy amendment requests, and reinforce the connection between local planning and regional environment and climate change targets (and shared objectives) of Metro 2050;* • *Implementing this recommendation would contribute towards Action 3.3 of the MVRD Board-endorsed Climate 2050 Nature and Ecosystems Roadmap and Action 1.7 of the MVRD Board-endorsed Climate 2050 Agriculture Roadmap;* • *Implementing this recommendation would contribute towards Strategy 2.2 of the MVRD Board-adopted Ecological Health Framework; and* • *Implementing this recommendation would support Metro 2050 performance monitoring.*
d)	**Update policy action 3.4.5 of *Metro 2050* to encourage member jurisdictions to develop local-scale hazard and risk datasets and, where they already exist, endeavour to:** • **keep them up-to-date;**

	• **include future climate change scenarios;** • **include both probable and severe scenarios; and** • **incorporate them into Official Community Plans, zoning, and other land use regulations, as appropriate.** *Rationale/Anticipated Outcomes:* • *While policy action 3.4.5 of Metro 2050 requires member jurisdictions to adopt Regional Context Statements that: a) minimize risks to existing communities and, b) discourage new development in at-risk areas, those decisions might not be made with current hazard and risk information;* • *Based on results from surveyed municipalities, it is estimated that less than 50% of local hazard datasets in the Metro Vancouver region were developed in the last 10 years;* • *International guidance – such as the Sendai Framework for Disaster Risk Reduction and the United Nations Disaster Resilience Scorecard for Cities – emphasize developing and periodically updating risk-based information (including risk maps), and incorporating risk scenarios that are regularly updated;* • *International guidance materials – such as the United Nations Disaster Resilience Scorecard for Cities – note that risk scenarios should identify hazards, exposures and vulnerabilities in at least the "most probable" and "most severe" (i.e., "worst-case") scenarios; and* • *This recommendation aligns with the new Emergency and Disaster Management Act requirement to incorporate climate change information into local risk assessments.*
e)	**Add new climate-related performance monitoring metrics to Section G of *Metro 2050* for:** **i. The percentage of new growth (dwelling units and employment) in known and unmitigated hazard areas** *Rationale/Anticipated Outcomes:* • *Introducing this new metric will improve performance monitoring for Goal 3 - Metro Vancouver currently has no performance monitoring metrics to track progress on Strategy 3.4 of Metro 2050 (to Advance land use, infrastructure, and human settlement patterns that improve resilience to climate change impacts and natural hazards);* • *Table 4 of Metro 2050 stipulates that new or reclassified Urban Centres and FTDAs must not be located in known, unmitigated hazard areas, and policy action 3.4.5 of Metro 2050 discourages member jurisdictions from developing in current and future hazardous areas;* • *Tracking this metric is a critical first step to setting a regional baseline of data, and to inform future Regional Growth Strategy policy changes pertaining to growth and development in hazardous areas;* • *Tracking this metric will utilize Metro Vancouver's regional multi-hazard mapping data; and* • *Tracking this data will involve developing a shared definition of "known and unmitigated hazard areas".* **ii. Percentage of lands within the Urban Containment Boundary that contain impervious surfaces**

	<u>*Rationale/Anticipated Outcomes:*</u> • *Imperviousness is a key indicator to measure progress related to green infrastructure implementation and flood resilience;* • *Metro Vancouver currently gathers this data and it is made available on the Metro Vancouver open data portal, but it is not monitored and reported out as a performance indicator for any Metro 2050 policies;* • *Policy action 3.2.2 a) of Metro 2050 identifies Metro Vancouver's role to collect and maintain data related to imperviousness, and this data will be collected and updated every 5- 6 years; and* • *Tracking this metric is a critical first step to setting a regional baseline of data, and to inform future policy changes to the Regional Growth Strategy.* **iii. New performance metrics within Urban Centres, Frequent Transit Development Areas, and Major Transit Growth Corridors including:** • **Tree canopy cover;** • **Impervious surfaces;** • **Sensitive and Modified ecosystems;** • **Walkability; and** • **Cooling and clean air centres.** <u>*Rationale/Anticipated Outcomes:*</u> • *The proposed metrics could be utilized as indicators for successful climate action within Urban Centres and FTDAS and considered when identifying a new (or reclassifying an existing) Urban Centre or FTDA; and* • *The data could inform future policies related to new requirements for Urban Centres, FTDAs, and MTGCs.*
f)	**Add a new policy action to Strategy 5.1 of *Metro 2050* for member jurisdictions to develop strategies and policies that increase intersection density and permeability of their urban street grid.** <u>*Rationale/Anticipated Outcomes:*</u> • *Implementing this policy during neighbourhood planning and redevelopment projects will shorten trip distances, facilitate better bike and pedestrian connections, improve walkability, and reduce average block length.*

During the engagement phase many policy amendment options were considered and explored. Two additional policy options to amend *Metro 2050* received significant support. These are shown in Table 3 below. These action would also advance climate action, but they do not have as strong a connection with the goals and strategies of *Metro 2050*. If supported by the Regional Planning Committee and MVRD Board, these additional policy actions can be combined with the recommendations in Table 2 via Alternative 2 below.

Table 3 – Additional Climate Policy Enhancement Study Recommendations for Consideration

g)	**i. Amend Table 3 of *Metro 2050* (*Guidelines for Urban Centres and Frequent Transit Development Areas*) to include cooling and clean air centres within the list of "General Expectations/Attributes" for all Urban Centres and FTDAs; and** **ii. Add a new policy to Strategy 1.3 of *Metro 2050* requiring member jurisdictions to adopt Regional Context Statements that support cooling and clean air centres in appropriate locations that are accessible to more vulnerable populations.** _Rationale/Anticipated Outcomes:_ • *Metro Vancouver's Climate Projections indicate that the region will face considerably warmer temperatures year-round and an increase in wildfire risk by the year 2050;* • *The 2021 heat dome event resulted in 619 heat-related deaths in British Columbia, the majority of which occurred inside people's homes that lacked air conditioning and adequate ventilation or alternative place to go to cool down;* • *68% of the region's residential growth and 77% of the region's employment growth is targeted to Urban Centres and FTDAs by the year 2041, which will be in primarily multi-unit buildings;* • *This direction supports Action 6.3 of the Climate 2050 Buildings Roadmap (Expand the Network of Public Buildings that can serve as Cool, Clean Air Centres) and supports the implementation of policy actions 3.4.2 c) and 3.4.7 of Metro 2050; and* • *The Metro Vancouver Sustainable Innovation Fund Project AirCnC – Cooler 'n' Cleaner Air Centres, which will assist member jurisdictions in identifying and implementing cooling and clean air centres, can support implementation of this policy idea.*
h)	**Add a new policy action to Strategy 5.1 of *Metro 2050* for:** **i. Metro Vancouver to advocate to other levels of government for targeted funding to support zero-emission bus depot infrastructure;** **ii. TransLink to work with member jurisdictions to identify locations for zero-emission bus depots; and** **iii. Member jurisdictions to facilitate construction of these facilities with streamlined municipal approvals.** _Rationale/Anticipated Outcomes:_ • *The lack of zero-emission bus infrastructure and the length of time required for approvals and permitting is bottlenecking the region's ability to expand and replace the fossil fuel bus fleet and meet our collective short and long-range GHG emission reduction targets.*

ALTERNATIVES

1. That the MVRD Board direct staff to prepare a bylaw to amend Metro 2050 for consideration based on the following recommendations and as described in Table 2 of the report dated March 13, 2024, titled "Metro 2050 Climate Policy Enhancement Study – Recommendations" to:
    a) develop a revised definition for the regional Rural land use designation;

   b) encourage the protection and restoration of trees and other ecosystems on lands with a non-urban regional land use designations and lands outside the Urban Containment Boundary;
   c) require environmental and climate change-related analyses as part of all Metro 2050 amendment applications;
   d) encourage the development of local hazard and risk data that meets key requirements;
   e) add new climate-related performance monitoring metrics; and
   f) increase intersection density and permeability of the urban street grid.

2. That the MVRD Board direct staff to prepare a bylaw to amend *Metro 2050* for consideration based on the following recommendations and as described in Tables 2 and 3 of the report dated March 13, 2024, titled "Metro 2050 Climate Policy Enhancement Study – Recommendations" to:
   a) develop a revised definition for the regional Rural land use designation;
   b) encourage the protection and restoration of trees and other ecosystems on lands with a non-urban regional land use designations and lands outside the Urban Containment Boundary;
   c) require environmental and climate change-related analyses as part of all *Metro 2050* amendment applications;
   d) encourage the development of local hazard and risk data that meets key requirements;
   e) add new climate-related performance monitoring metrics;
   f) increase intersection density and permeability of the urban street grid;
   g) support cooling and clean air centres in appropriate locations; and
   h) support the development of zero-emission bus depots.

3. That the MVRD Board receive for information the report dated March 13, 2024 titled "Metro 2050 Climate Policy Enhancement Study - Recommendations" and provide alternate direction to staff.

FINANCIAL IMPLICATIONS

There are no financial implications associated with this report. All work was developed internally within the Regional Planning work program and was considered as part of the 2023 and 2024 Board-approved budgets. If the MVRD Board approves Alternative 1 or 2 below a *Metro 2050* amendment bylaw will be prepared for Board consideration. Other climate change-related studies and projects underway may consider some of these options and continue to inform future policy changes to *Metro 2050* over time.

CONCLUSION

As directed by the MVRD Board, Regional Planning staff have undertaken a *Metro 2050* Climate Policy Enhancement Study to explore opportunities to strengthen climate change policy in *Metro 2050*. Developed in close coordination with the process to develop the *Climate 2050 Land Use and Urban Form Roadmap,* a policy shortlist was presented at two workshops held in early 2023 to gather and refine ideas about how to advance climate action through land use and growth management planning. The feedback received from the workshops informed draft recommendations for new climate policies in *Metro 2050,* which were presented to attendees of the joint Climate Action and Regional Planning Committee meeting on the *Metro 2050* Climate

Policy Enhancement Study in November, 2023. Following that engagement, this report presents staff's revised recommendations for consideration. Staff recommend Alternative 1.

ATTACHMENT

1. Presentation re: Metro 2050 Climate Policy Enhancement Study - Recommendations

REFERENCES

1. Metro 2040 Climate Change and Natural Hazards Policy Review – Recommendations
2. Comparison of Climate Related Policies of Metro 2040 and Metro 2050
3. Consideration of Metro Vancouver Regional District Regional Growth Strategy Bylaw No. 1339
4. Process to Consider Stronger Climate Action Language and Policy for Metro 2050
5. Metro 2050 Climate Policy Enhancement Study – Project Initiation
6. Climate Action Committee and Regional Planning Committee Joint Discussion on the Metro 2050 Climate Policy Enhancement Study

56950990

Attachment 1

Metro 2050 Climate Policy Enhancement Study - Recommendations

Edward Nichol

Senior Planner, Regional Planning and Housing Services

Regional Planning Committee Meeting | April 5, 2024

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RECOMMENDATION A

Develop a revised definition for the regional Rural land use designation

- Work with member jurisdictions to update the definition, intent, and appropriate uses for lands
- Reinforce the importance of these lands for:
  - supporting urban containment objectives
  - protecting the region's ecosystems / agricultural lands
  - sequestering and storing carbon
  - buffering impacts of climate change / natural hazards

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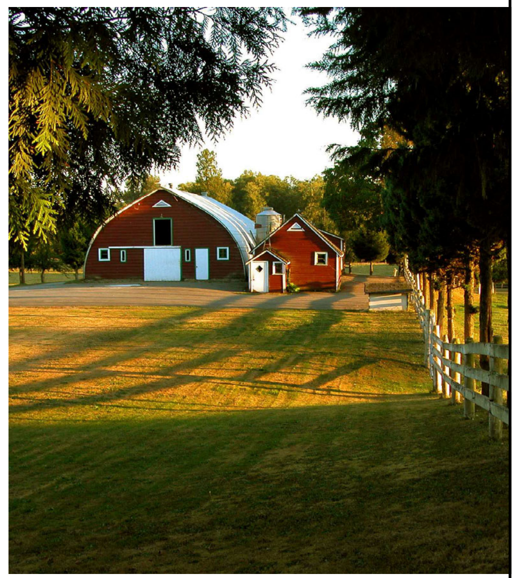
RECOMMENDATION B

Encourage the protection and restoration of trees and other ecosystems

- Work with partners to encourage the protection and restoration of trees and other ecosystems in areas outside the Urban Containment Boundary



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RECOMMENDATION C

Require environmental / climate-related analyses for Metro 2050 amendment applications

- Demonstrate no conflict with applicable commitments in OCPs / accepted RCSs pertaining to:
  - Carbon storage levels in natural areas
  - Tree canopy cover
  - Impervious surfaces
  - Ecosystem protection
  - Agricultural land
  - Green infrastructure / ecosystem connectivity

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RECOMMENDATION D

Encourage the development of local hazard and risk data

- Develop hazard datasets, and where they already exist:
  - Keep them up-to-date
  - Include future climate change scenarios
  - Include both probable and severe scenarios
  - Incorporate them into OCPs, zoning, and other land use regulations

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RECOMMENDATION E

Add new climate-related performance metrics

- % of new growth in known and unmitigated hazard areas
- % of lands within the UCB that contain impervious surfaces
- In Urban Centres and FTDAs:
  - Tree canopy cover
  - Impervious surfaces
  - Sensitive and Modified ecosystems
  - Walkability
  - Cooling and clean air centres

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RECOMMENDATION F

Increase intersection density and permeability of the urban street grid

- Through strategies and policies

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ADDITIONAL CONSIDERATIONS

G) Require the identification of cooling and clean air centres:

- Include these within the list of "General Expectations / Attributes" for Urban Centres and FTDAs
- Requiring member jurisdictions to identify, locate and support these in appropriate locations that are accessible to vulnerable populations

H) Support zero emission bus depot infrastructure:

- MV to advocate to other levels of government for targeted funding
- TransLink to work with member jurisdictions to identify locations
- Member jurisdictions to support and facilitate construction with streamlined municipal approvals

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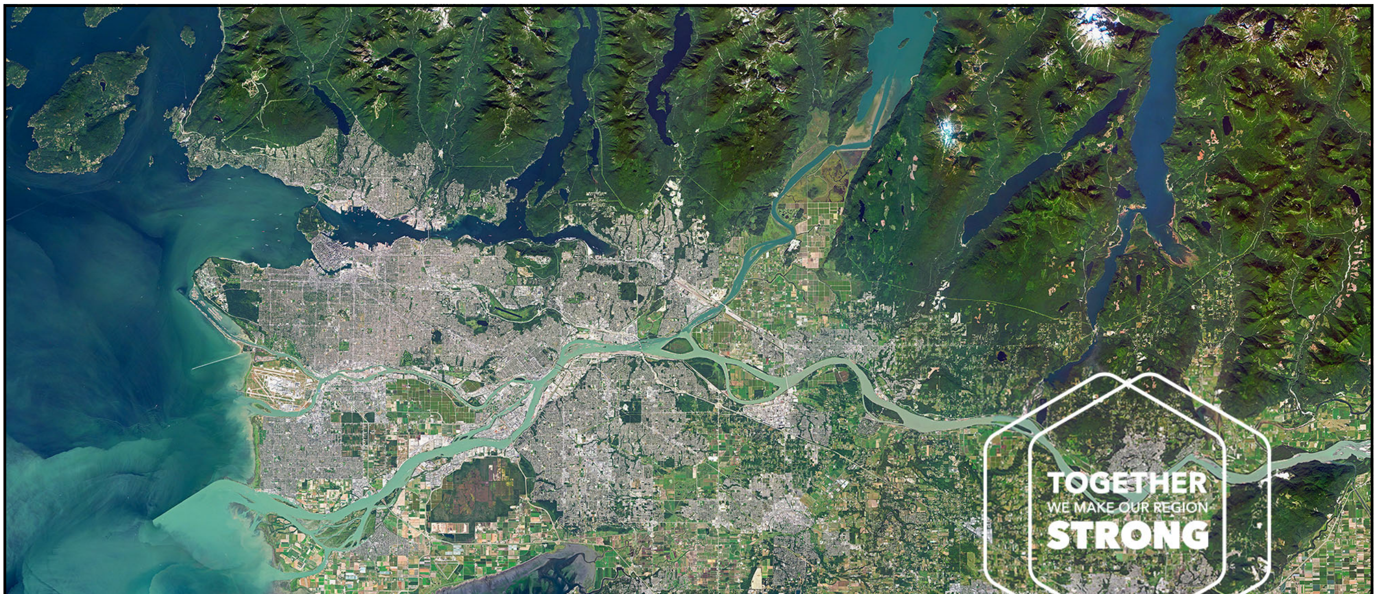

Thank you

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SERVICES AND SOLUTIONS FOR A LIVABLE REGION

E3

To: Regional Planning Committee

From: Laurie Bates-Frymel, Senior Planner, and Agatha Czekajlo, Senior Policy and Planning Analyst, Regional Planning and Housing Services

Date: March 15, 2024 Meeting Date: April 5, 2024

Subject: **Tree Canopy Cover and Impervious Surface – 2020 Update**

RECOMMENDATION

That the MVRD Board:

a) receive for information the report dated March 15, 2024 titled "Tree Canopy Cover and Impervious Surface – 2020 Update"; and
b) share the findings and datasets with member jurisdictions with an offer of a staff presentation to Council upon request.

EXECUTIVE SUMMARY

In 2020, impervious surface covered 54 percent of lands within Metro 2050's Urban Containment Boundary. This represents an increase of 4 percent since 2014, with most jurisdictions seeing an increase in imperviousness. In 2020, tree canopy covered 31 percent of lands within the Urban Containment Boundary. This represents a decrease of 1 percent since 2014, with the majority of jurisdictions experiencing loss, primarily associated with greenfield development and densifying urban areas. Increased growth and intensification pressures, as well as implementation of the new provincial housing legislation allowing greater intensification of urban lots, will likely lead to further tree canopy cover losses and impervious surface increases. However, with the implementation of progressive tree retention and urban forest expansion strategies, it is possible to offset these losses.

With the adoption of *Metro 2050*, a regional target was introduced to increase the total regional tree canopy cover within the Urban Containment Boundary to 40 percent by the year 2050. *Metro 2050* also includes an action for Metro Vancouver to collect tree canopy cover and impervious surface data and share it with member jurisdictions. Regional tree canopy cover, impervious surface, and potential planting area datasets have been updated based on the most recent regional data from 2020 and compared with measurements taken in 2014.

PURPOSE

To provide the Regional Planning Committee and MVRD Board with the latest data update on the status of tree canopy cover and impervious surface across the urban part of the region.

BACKGROUND

Adopted by the MVRD Board in February 2023, *Metro 2050* commits Metro Vancouver to collect and maintain tree canopy cover and imperviousness data, and to share these datasets with member jurisdictions. *Metro 2050* also includes a regional target to "increase the total regional tree canopy cover within the Urban Containment Boundary from 32% to 40% by the year 2050".

2020 REGIONAL TREE CANOPY COVER AND IMPERVIOUS SURFACE REPORT

Tree canopy refers to the leaves and branches, and their coverage can be identified by the ground area they cover when viewed from above. Impervious surface, such as paved roads and buildings, are hard surface areas that allow very little or no water to pass through.

Using 5 metre resolution land cover classification data from 2020 (the most recent regional land cover data available), Metro Vancouver has summarized tree canopy cover and impervious surface for various geographies in a technical report titled "2020 Regional Tree Canopy Cover and Impervious Surface in Metro Vancouver" (Reference 1). The 2020 tree canopy cover and impervious surface data were compared to the previous regional datasets to assess change between 2014 and 2020. In addition, the technical report includes projections of future tree canopy cover levels as greenfield and infill development continue, as well as a number of recommendations to retain and enhance tree canopy cover while reducing impervious surface. The technical report and associated data will be posted on Metro Vancouver's website and Open Data Portal after the Board receives them. It is noted that several Metro Vancouver member jurisdictions have conducted finer-resolution tree canopy analyses within their boundaries, and some have also reported change over time. Metro Vancouver's analysis complements this work and provides a consistent regional-scale assessment that fills data gaps for municipalities that do not currently have local mapping.

Why are Tree Canopy Cover and Impervious Surface Measurements important?

Trees provide a range of important ecosystem services that benefit humans such as shading, cooling, carbon sequestration, stormwater management, and physical, mental, and social well-being (References 2 and 3). Aside from monitoring progress towards the urban tree canopy target of *Metro* 2050, measuring tree canopy cover is a simple way to determine the extent of the region's urban forest and the magnitude of services it provides; this is particularly important to measure in the context of this rapidly urbanizing region. In contrast, impervious surface is associated with many of the negative effects of urbanization, such as higher temperatures (i.e., the 'Urban Heat Island' effect) and increased flood risk, hydrological cycle disruptions, and poor water quality, all of which can impact ecological and human health. Measuring the level of impervious surface across a landscape gives an indication of the potential extent of these negative effects.

Although tree canopy cover and imperviousness are ecological health indicators, their connection to factors such as urban temperatures and stormwater management also means they are good indicators of how resilient communities may be to climate change-related impacts. Looking more closely at whether these indicators are distributed equitably can also help to identify communities or populations that may be more vulnerable to risks and receiving fewer ecosystem service benefits.

Tree Canopy Cover and Impervious Surface Levels and Change Since 2014

The technical report analyzes change since 2014 has draws the following key conclusions:

- In 2020, tree canopy covered 31 percent of lands within the Urban Containment Boundary (UCB).
- Most of the urban tree canopy cover was located within residential areas (38 percent) and recreation, open space and protected natural areas (36 percent).

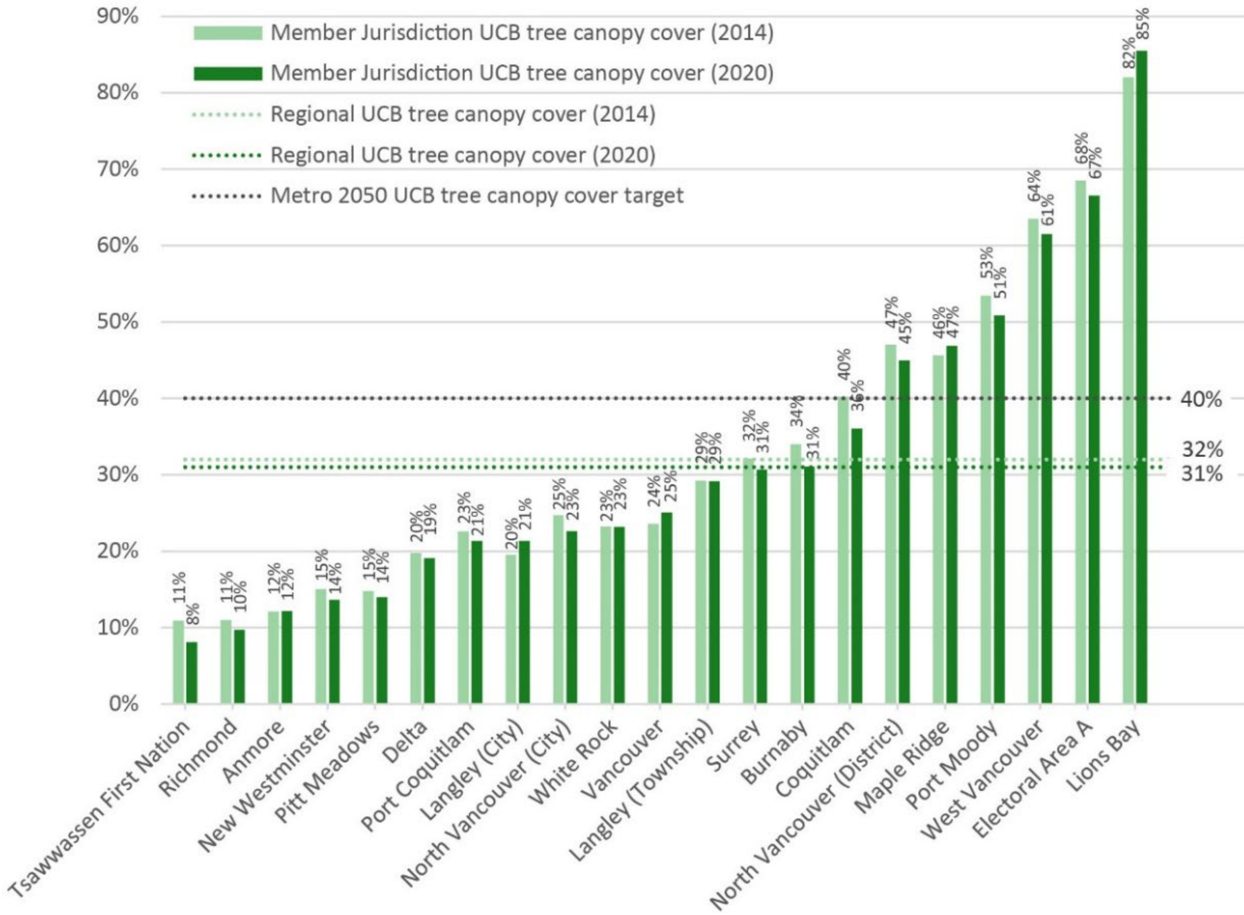
- Private lands had a relatively low tree canopy coverage (27 percent), but the majority of tree canopy cover in the UCB (57 percent) was found on private land – primarily because the majority of land in the UCB (69 percent) is privately-owned.
- Between 2014 and 2020, **tree canopy cover decreased by 1 percent** within the UCB (from 32 to 31 percent). Some member jurisdictions saw increases in tree canopy cover, but most experienced loss (Figure 1). Concentrated areas of loss generally corresponded with planned greenfield development and densifying urban areas.
- In 2020, impervious surface covered 54 percent of lands within the UCB.
- Most of the UCB's impervious surface was located within residential areas (39 percent) and road rights-of-way (27 percent). Impervious surface on private lands was relatively high (57 percent).
- Between 2014 and 2020, **impervious surface increased by 4 percent** within the UCB (from 50 to 54 percent). Some member jurisdictions saw reductions in impervious surface, but impervious surface increased for most. Similar to areas that observed tree canopy cover loss, areas of increasing impervious surface generally corresponded to greenfield and industrial development.
- Approximately 21 percent of the tree canopy cover and 19 percent impervious surface within the UCB was found within single-detached residential neighbourhoods.

If the region's remaining greenfield lands within the UCB are developed and single-detached housing stock is redeveloped as expected over the next 20-30 years, tree canopy cover is projected to continue to decrease from 31 percent to 29 percent over this timeframe. However, this estimate did not consider implementation of the newly-adopted provincial housing legislation (see 'Potential Impact of the New Provincial Housing Legislation' section below).

Tree Planting to Offset Losses and Achieve the Metro 2050 Tree Canopy Cover Target
Municipalities, including several Metro Vancouver member jurisdictions, often use tree planting programs and policies as a way to maintain or expand tree canopy, which can also help to offset anticipated future losses from development and redevelopment. However, to offset the projected decline in UCB tree canopy cover over the next 20-30 years it is estimated that roughly 1,990 hectares of land within the UCB would have to be dedicated to tree planting. An additional 8,000 hectares (a total of 9,900 ha) of tree canopy cover would be required to achieve the *Metro 2050* UCB tree canopy cover target (i.e., 40 percent).

Achieving the *Metro 2050* UCB tree canopy cover target will be challenging. Metro Vancouver's analysis indicates that about 30,000 hectares of land within the UCB is currently potentially available for tree planting. This includes non-tree vegetation, soil patches, barren surfaces, and pavement that does not fall on roads, which under the right circumstances, could be modified to increase tree canopy cover. Further site-level assessments would be needed to determine what areas have the greatest potential to increase tree canopy cover through tree planting.

Figure 1. Tree Canopy Cover within the Urban Containment Boundary by member jurisdiction in 2020 and 2014, compared to the *Metro 2050* target



Note: Belcarra and Bowen Island are not included because they fall outside the UCB. Lions Bay was removed from the UCB in 2021.

Potential Impact of the New Provincial Housing Legislation

More information about the pace and scale of uptake is needed to fully assess the potential impacts on tree canopy cover from the intensification of single-detached neighbourhoods and transit-oriented areas required by the recently-adopted provincial housing legislation. However, it is anticipated that the recent legislative changes will make it even more challenging for the region to achieve its urban tree canopy target. That will continue to be monitored and will likely be a key consideration during the next update of the tree canopy cover and impervious surface dataset. Staff are considering how best to track intensification trends and will continue to monitor and report out on change over time.

Discussions with Member Jurisdiction Staff

The "2020 Regional Tree Canopy Cover and Impervious Surface in Metro Vancouver" technical report was shared with the Regional Planning Advisory Committee - Environment Subcommittee during its meeting on February 15, 2024, and the Regional Planning Advisory Committee on March 15, 2024. Member jurisdiction staff expressed serious concerns about limited space for trees, particularly in light of other competing space requirements (e.g., stormwater management, utility infrastructure, housing intensification). They also recognized challenges associated with young tree mortality during drought conditions. Member jurisdiction staff were encouraged to consider the best practices and alternatives provided in the Metro Vancouver Tree Regulations Toolkit, which was recently updated with land use / zoning-related examples and is being presented in a separate staff report on this Regional Planning Committee meeting agenda (Reference 4), as well as Metro Vancouver's Urban Forest Climate Adaptation resources for advice about tree species climate suitability, necessary soil volumes, and other considerations (Reference 5).

NEXT STEPS

It is recommended that the Tree Canopy Cover and Impervious Surface report findings and data should be forwarded to staff from member jurisdiction CAOs and City Managers. Staff will also promote the findings via social media and staff are also available to present the report and findings to Councils upon request. The main objective of the social media outreach will be to increase public awareness about the important benefits of urban forests such as shading, cooling, carbon sequestration, stormwater management, and physical, mental, and social well-being.

The 2020 tree canopy cover and impervious surface data is the most recent regional-scale data available. Regular updates of the data are important to track long-term trends and to support *Metro 2050*'s performance monitoring. Regional remote sensing data is collected every 6 years and therefore the next tree canopy cover and impervious surface update is planned for 2026. The collation of remote sensing data from across the region, generation of the regional land cover classification dataset, select site validation, and spatial analysis takes time. Based on previous update timelines, staff anticipate that the next report will be completed in 2028.

ALTERNATIVES

1. That the MVRD Board:
   a) receive for information the report dated March 15, 2024 titled "Tree Canopy Cover and Impervious Surface – 2020 Update"; and
   b) share the findings and datasets with member jurisdictions with an offer of a staff presentation to Council upon request.

2. That the MVRD Board receive for information the report dated March 15, 2024 titled "Tree Canopy Cover and Impervious Surface – 2020 Update" and provide alternate direction to staff.

FINANCIAL IMPLICATIONS

There are no financial implications to this report. Work associated with measuring these indicators was completed as part of the Regional Planning annual work program.

CONCLUSION

The 2020 "Regional Tree Canopy Cover and Impervious Surface in Metro Vancouver" technical report concludes that in 2020 tree canopy covered 31 percent of the lands within the UCB, with variations among neighbourhoods and land use types. Impervious surface covered 54 percent of the lands within the UCB. Since 2014, regional tree canopy cover has decreased by 1 percent and impervious surface has increased by 4 percent within the UCB.

As the region's remaining greenfield lands are developed and single-detached housing stock is redeveloped and intensified over the next 20-30 years, tree canopy cover in the UCB is projected to decrease from 31 to 29 percent. However, with the implementation of progressive tree retention and urban forest expansion strategies, it is possible to offset these losses and work towards the 40 percent tree canopy cover target for the region's urban areas, as set out in *Metro 2050*. Changes to tree canopy cover and impervious surface will continue to be monitored and reported.

ATTACHMENT

1. Presentation re: Tree Canopy Cover and Impervious Surface – 2020 Update

REFERENCES

1. 2020 Regional Tree Canopy Cover and Impervious Surface in Metro Vancouver - Technical Report
2. The Urban Forest and Ecosystem Services: Impacts on Urban Water, Heat, and Pollution Cycles at the Tree, Street, and City Scale
3. Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews
4. Metro Vancouver Tree Regulations Toolkit
5. Metro Vancouver's Urban Forest Climate Adaptation Resources

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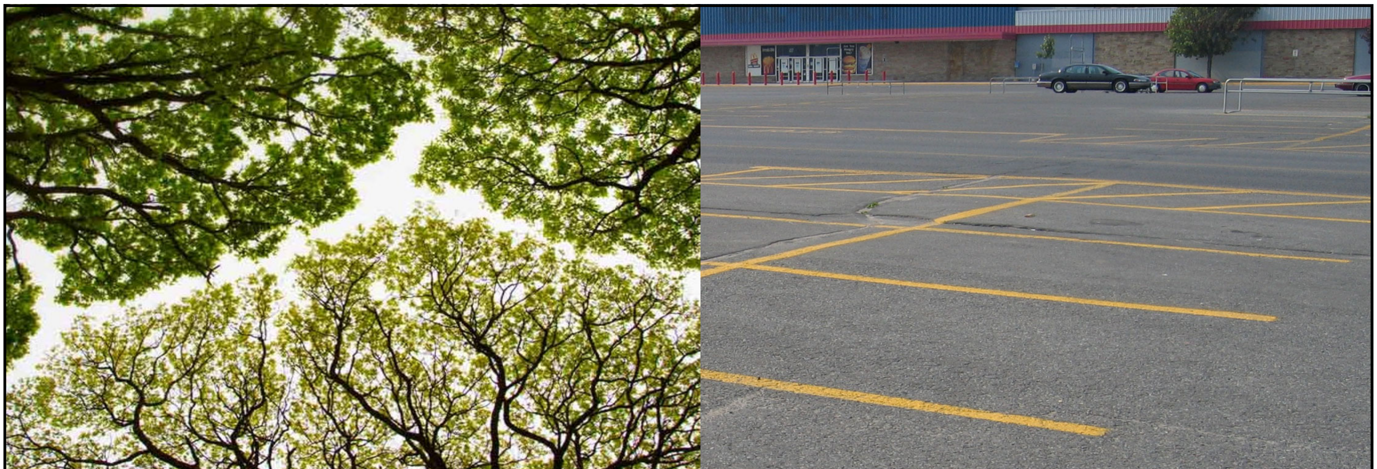
Attachment 1



Tree Canopy Cover, Impervious Surface, and Tree Regulations

DATASET AND TOOLKIT UPDATE

Laurie Bates-Frymel
Senior Planner (Environment),
Regional Planning & Housing Services

Agatha Czekajlo
Senior Policy and Planning Analyst,
Regional Planning & Housing Services

Edward Nichol
Senior Planner,
Regional Planning & Housing Services

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Regional Planning Committee – April 5, 2024
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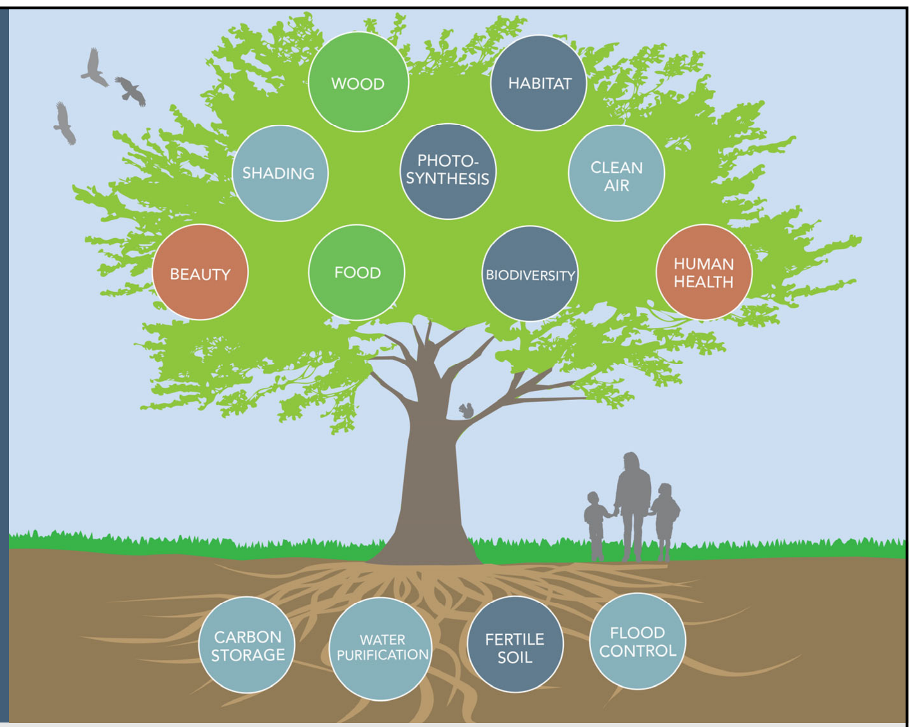
Why measure 'tree canopy cover' and 'impervious surface'?



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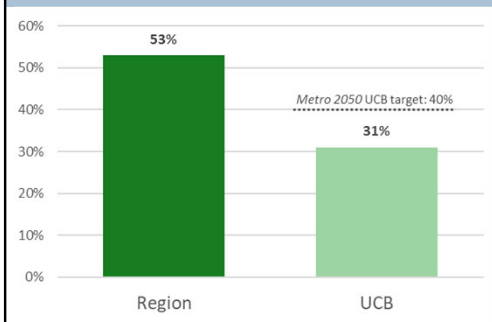
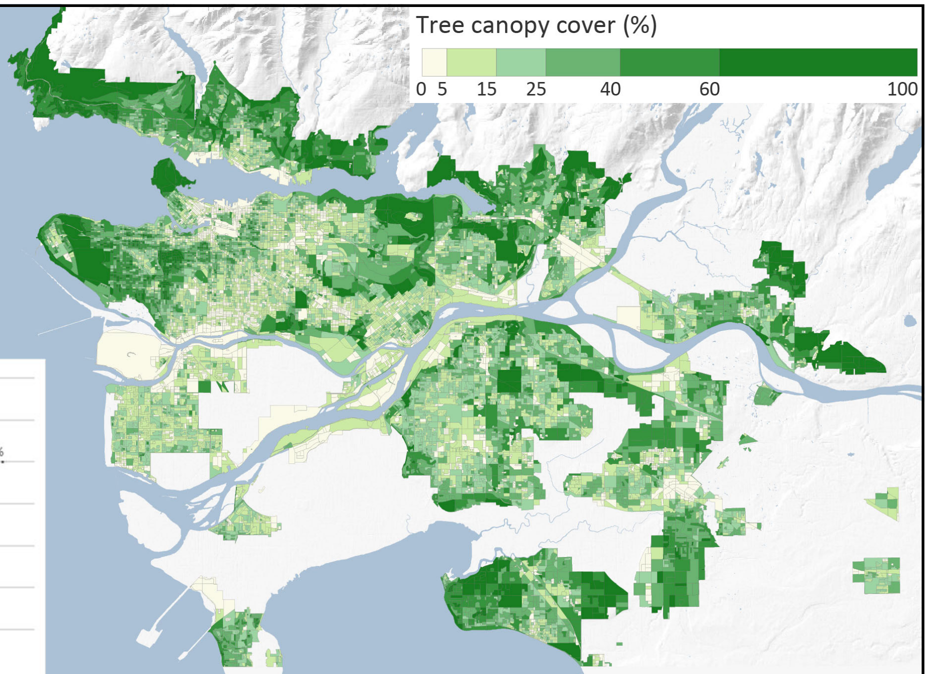
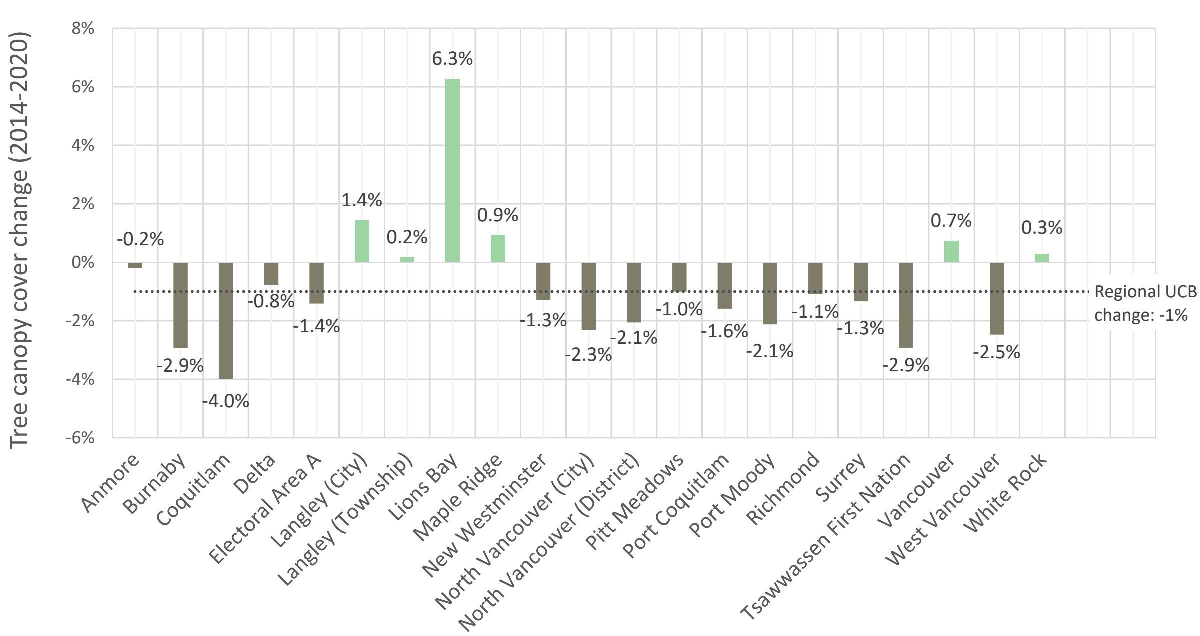
Areas of lower tree canopy cover:

- Urbanized, denser and newly developed areas
- Commercial and industrial lands
- Some jurisdictions greener than others

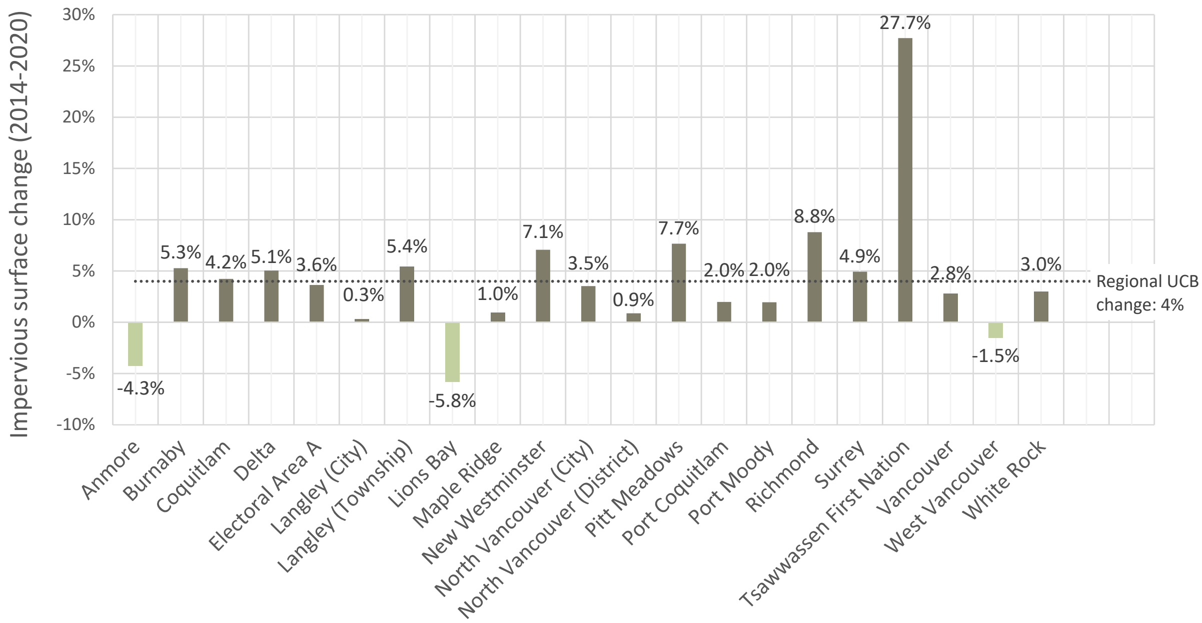




2020 Tree Canopy Cover – Within UCB



Tree Canopy Cover Change (2014-2020) – Within UCB



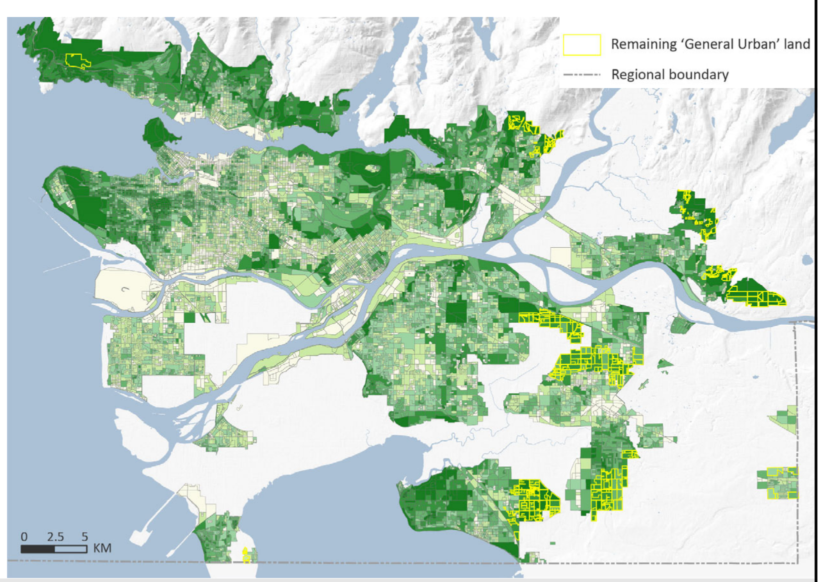
Impervious Surface Change (2014-2020) – Within UCB

FUTURE PROJECTIONS OF TREE CANOPY COVER

Tree canopy cover is projected to ***decrease*** from 31% to 29% due to continued development within the UCB

+1,990 ha of tree planting required to offset projected loss

+8,000 ha of tree planting required to reach *Metro 2050*'s UCB tree canopy cover target of 40%



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DATA SUMMARY

- Tree canopy cover in the Urban Containment Boundary (UCB)
  - **Decreased by 1%** between 2014 and 2020 (32% to 31%)
  - In 2020 - 38% on Residential lands, 21% on single detached
- Impervious surface in the UCB
  - **Increased by 4%** between 2014 and 2020 (50% to 54%)
  - In 2020 - 39% on Residential lands, 19% on single detached
- Tree Canopy Cover Future Projections for the UCB
  - Expected to **decrease from 31% to 29%***
  - 9,900 ha of tree planting in the UCB needed to offset this loss and reach *Metro 2050*'s UCB 40% tree canopy cover target

TREE REGULATIONS TOOLKIT UPDATE

- **Toolkit Purpose**:
  - Guidance on regulatory tools that influence the preservation and growth of trees and tree canopy
- **Structure:**
  - Higher-level plans
  - Tools regulating land use
  - Tools regulating trees

TREE REGULATIONS TOOLKIT UPDATE

New Information On:

- Land use trends and tree canopy cover
- Considerations for canopy cover targets
- Land use bylaws and development permit areas
- Development, subdivision, and servicing bylaws
- Worksheets to assess regulatory framework and identify opportunities for improvement

Thank you

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To: Regional Planning Committee

From: Edward Nichol, Senior Planner, Regional Planning and Housing Services

Date: March 8, 2024 Meeting Date: April 5, 2024

Subject: **Metro Vancouver Tree Regulations Toolkit Update**

RECOMMENDATION

That the MVRD Board:

a) receive for information the report dated March 8, 2024, titled "Metro Vancouver Tree Regulations Toolkit Update"; and
b) forward the "Metro Vancouver Tree Regulations Toolkit Update" to member jurisdictions for information with an offer of a presentation to Councils upon request.

EXECUTIVE SUMMARY

This report highlights the updated Metro Vancouver Tree Regulations Toolkit. The findings indicate that, as the region develops, it is critical to require adequate space to retain or grow trees post-development, and that regulatory tools such as land use bylaws, development permit areas, and development, subdivision, and servicing bylaws, can support the foundation for long-term protection and growth of trees.

Originally developed by Diamond Head Consulting in 2021, the Toolkit provides guidance on regulatory tools that can be used to protect trees and increase tree canopy cover at the local level. In response to the ongoing challenges associated with preserving trees in this rapidly growing urban region, and working towards the regional urban tree canopy cover target in *Metro 2050*, Metro Vancouver again retained Diamond Head Consulting in 2023 to update the Toolkit with more robust information in the land use-focused sections of the document. That work has now been completed.

PURPOSE

To provide the Regional Planning Committee and MVRD Board with the updated Metro Vancouver Tree Regulations Toolkit.

BACKGROUND

Healthy trees provide communities with important ecosystem services, including shading and cooling, stormwater absorption, habitat, and carbon storage. Collectively, the trees within the public and private lands of a community (including the trees in parks, around buildings, along streets and in backyards) make up the urban forest. Since 2016, Metro Vancouver has supported local urban forestry efforts across the region by providing data and resources, convening practitioners, and advocating for innovative approaches that improve the health and resilience of the region's urban forests, with the first iteration of the Tree Regulations Toolkit being completed in 2021. The Metro Vancouver Tree Regulations Toolkit has now been updated (Attachment 1).

TOOLKIT UPDATE

At its June 9, 2021 meeting, the Regional Planning Committee received the report "Metro Vancouver Tree Regulations Toolkit" (Reference 1). That report introduced the first iteration of the Toolkit, and noted that it may be updated in the future to add more substantial content to the land use-focused sections of the document.

The 2021 Toolkit focused on tools that primarily regulate trees (e.g., tree bylaws); additional content on tools that primarily regulate land use was included as supplemental information. In 2023 Metro Vancouver retained Diamond Head Consulting, the consultant behind the 2021 iteration, to update the Toolkit with more information on the land use-focused sections. The update was undertaken in response to the ongoing challenges associated with preserving trees in this rapidly growing urban region, and with the objective of updating the information to incorporate current best practices.

Urban Tree Canopy Cover and Impervious Surfaces

In 2024, Metro Vancouver's Tree Canopy Cover and Impervious Surfaces dataset was updated; this update is also being presented in a separate report to the Regional Planning Committee in this meeting's agenda package. The results show a decrease of 1 percent tree canopy cover within the region's Urban Containment Boundary from the years 2014-2020. Metro Vancouver's tree canopy cover is currently projected to continue to decline within the Urban Containment Boundary, primarily due to urban growth, development, and the intensification of land uses. These projections, in combination with the tree canopy loss observed between 2014-2020, highlight the need for innovative regulatory and supportive approaches to protect and retain trees at the local level through land use and development processes. This work will be critical for the region to reverse the current trends and move us towards a path to achieving the ambitious 40 percent tree canopy cover target set out in *Metro 2050.*

Toolkit Overview

The Metro Vancouver Tree Regulations Toolkit provides guidance on selecting and using regulatory tools that can help preserve trees and increase tree canopy cover based on best practices. Earlier iterations of the Toolkit were informed by survey results from consulting arborists and local staff across the region, as well as a review of scientific literature, practitioner guides, and bylaws from across Canada and the United States. Information is included on higher-level plans (such as regional growth strategies and official community plans), tools that regulate land use and influence the space available to retain or replace trees (such as zoning bylaws and subdivision and servicing bylaws), and tools that regulate trees as their primary purpose (such as covenants and tree bylaws).

The updated Metro Vancouver Tree Regulations Toolkit complements and supports several Metro Vancouver initiatives, plans, and policies, including:

- The *Board Strategic Plan 2022 - 2026,* which includes a priority action to support member jurisdictions to develop and implement effective policies and tools that will help the region achieve its targets to protect 50 percent of lands for nature and achieve 40 percent urban tree canopy (Reference 2);

- The *Climate 2050 Nature and Ecosystems Roadmap*, which includes an action for Metro Vancouver to provide data and resources to support urban forest management (Reference 3); and
- *Metro 2050,* which includes an action for member jurisdictions to adopt Regional Context Statements that include policy statements that: enable the retention and expansion of urban forests using various tools, such as local tree canopy cover targets, urban forest management strategies, tree regulations, development permit requirements, land acquisition, street tree planting, and reforestation or restoration policies, with consideration of resilience (Reference 4).

New Information Included in the Update
The section of the Toolkit dedicated to tools that primarily regulate land use has been updated. This section now includes new information on:

- current land use trends across the region and the implications for tree canopy cover and impervious surfaces;
- considerations for setting tree canopy cover targets;
- land use bylaws and development permit areas (including zoning bylaws, form and character development permit areas, climate change and energy conservation development permit areas, screening and landscaping bylaws, and development procedure bylaws);
- development, subdivision, and servicing bylaws; and
- worksheets to assess a local government’s regulatory framework for protecting urban trees and to identify opportunities for improvement.

The Toolkit is organized based on relevancy for the public and private realms, and for tree retention and planting goals. Key bylaw components are described by their general purpose, core (recommended) components, and additional bylaw component options for consideration. Examples of bylaw components that have been successfully implemented by other jurisdictions are also included. The updated Toolkit includes icons and callout boxes to highlight the anticipated impacts and implications of recent provincial housing legislation changes on relevant bylaw components, where applicable.

Since the recent provincial housing legislation changes were announced towards the end of the Toolkit update process, additional work may be required in the future to better understand the impacts of the region’s increased intensification of single-detached residential neighbourhoods, and determine how the housing legislation can be implemented in a way that maximizes tree retention.

NEXT STEPS
Staff will promote and share the Toolkit broadly throughout the region as a resource to inform urban forest planning and management, and encourage its use to update and strengthen local policies and regulations. It is recommended that copies of this staff report with the attached updated Metro Vancouver Tree Regulations Toolkit be forwarded to member jurisdictions for information with an offer of a presentation to Council upon request. The final report will also be posted on the Metro Vancouver website for download.

The Toolkit may be updated in the future, as needed. Metro Vancouver will continue to provide data and resources, convene with regional partners and practitioners, and advocate for innovative approaches to ensure a healthy and resilient regional urban forest.

ALTERNATIVES

1. That the MVRD Board:
   a) receive for information the report dated March 8, 2024, titled "Metro Vancouver Tree Regulations Toolkit Update"; and
   b) forward the "Metro Vancouver Tree Regulations Toolkit Update" to member jurisdictions for information with an offer of a presentation to Councils upon request.

2. That the MVRD Board receive for information the report dated March 8, 2024 titled "Metro Vancouver Regulations Toolkit Update and provide alternative direction to staff.

FINANCIAL IMPLICATIONS

This work was undertaken as part of Regional Planning's regular work program and the MVRD Board-approved 2023 Regional Planning budget. The project cost was $18,000.

CONCLUSION

The first iteration of the Metro Vancouver Tree Regulations Toolkit was developed by Diamond Head Consulting for Metro Vancouver in 2021. The Toolkit was developed to provide guidance on regulatory tools that can help protect trees and increase tree canopy cover at the local level. Metro Vancouver again retained Diamond Head Consulting in 2023 to update the Toolkit with more substantial information in the land use-focused sections of the document. As a next step, Metro Vancouver will promote and share the updated Toolkit broadly throughout the region as a resource to support urban forest planning and management.

ATTACHMENT

1. "Metro Vancouver Tree Regulations Toolkit – Second Edition", dated March 2024

REFERENCES

1. Metro Vancouver Tree Regulations Toolkit, Regional Planning Committee Report dated May 14, 2021
2. Regional Planning Priority Actions in the Board Strategic Plan 2022-2026
3. Action 4.2 of the *Climate 2050 Nature and Ecosystems Roadmap*
4. Policy action 3.2.7. c) ii of *Metro 2050*

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Attachment 1

Metro Vancouver Tree Regulations Toolkit

Second Edition

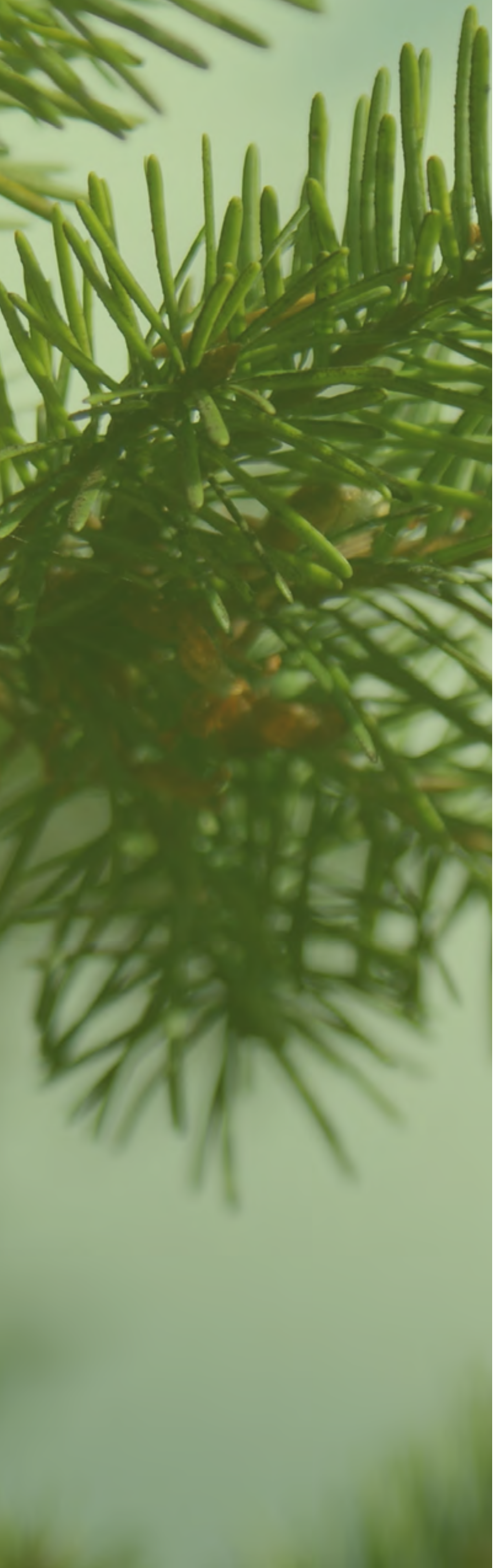
March 2024

Prepared by:

DIAMOND HEAD

Commissioned by Metro Vancouver

metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION



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Acknowledgements

Thank you to all the municipal staff and consulting arborists who answered our surveys in the fall of 2020. Thank you also to Edward Nichol and Marcin Pachcinski of Metro Vancouver, and Dr. Julian Dunster for their thorough review and comments on this Toolkit. The *Metro Vancouver Tree Regulations Toolkit* benefited from your input, guidance, and care.

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RECOMMENDED CITATION

Metro Vancouver. (2024). *Tree Regulations Toolkit - Second Edition.* Contract report prepared by Diamond Head Consulting.

1.0 Introduction

Trees provide Metro Vancouver communities with shade and cooling, intercept stormwater, store carbon, create habitat, and make our cities beautiful. Healthy forests in both urban and natural areas are an essential component of regional livability and resilience to climate change. However, the area covered by trees in Metro Vancouver's urban areas (i.e., within the Urban Containment Boundary) is expected to decline from 32% to 28% over the next 20 to 30 years (Metro Vancouver, 2019). This canopy loss is anticipated due to development and lower density housing areas being re-developed as part of the region's planned growth. At the same time, the urban forest is vulnerable to climate change, and unexpected canopy loss could occur in the region because of heat, drought, extreme weather events or pest and disease outbreaks. As a result, approaches to preserve trees and grow canopy cover need to consider a wide range of factors, from the impact of land use on the availability of permeable land to grow trees to the future climate suitability of tree species.

The *Metro Vancouver Tree Regulations Toolkit* (Toolkit) provides guidance for Metro Vancouver member jurisdictions on how they can develop comprehensive policy and regulations to preserve trees and grow tree canopy within British Columbia's current legislative framework. Municipalities in British Columbia can use legislative tools to off-set or prevent canopy loss and contribute to achieving *Metro 2050*'s 40% tree canopy cover target by 2050.

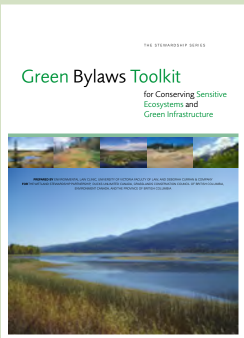
This Toolkit is a resource for municipal staff, decision makers and other practitioners, including planners, arborists, biologists, engineers and landscape architects, on using regulatory tools that influence the preservation and growth of trees and tree canopy. This Toolkit provides a framework for selecting regulatory tools to help achieve municipal tree preservation or canopy growth objectives.

No single best practices approach to regulating trees was identified during this review. The Toolkit therefore presents guidance based on best practices when available and recommends alternatives and options for consideration. Deciding on the most appropriate regulatory approach will require consideration of the community's values and canopy cover objectives, as well as the budgetary implications for local governments and permit applicants.

This Toolkit is not legal advice. Users must conduct their own legal review of any bylaws, regulations, or policies developed using this Toolkit.

ADDITIONAL TOOLKITS AND GUIDANCE DOCUMENTS

There are several other useful guides and toolkits that may help readers and inform the development of a comprehensive set of bylaws to manage natural assets, including:



- The **Green Bylaws Toolkit for Conserving Sensitive Ecosystems and Green Infrastructure** (Stewardship Centre BC, 2021) provides guidance on tools for local governments to protect green infrastructure (natural and engineered).
- **Environmental Development Permit Areas: In Practice and in Caselaw** (Britton-Foster, Grant, & Curran, 2016) provides information about using Environmental Development Permit Areas to protect riparian and terrestrial ecosystems. This report provides information about key components of environmental development permit areas (DPAs) and their judicial treatment in British Columbia.
- **Enhancing Climate Resilience of Subdivision and Development Servicing (SDS) Bylaws in the Columbia Basin: A Guidance Document** (Nelitz, Cooke, Curran, & Glotze, 2013) provides information to guide the update of subdivision and development servicing bylaws for the purpose of increasing climate resiliency and reducing the cost of building and operating infrastructure.
- The **Topsoil Bylaws Toolkit** (Curran, Dumont, Low, & Tesche, 2012) provides information and guidance for local governments to create effective topsoil policies that support rainwater management and reduce the impact of development.

1.1 STRUCTURE OF THE TOOLKIT

This Toolkit provides:

1. An overview of the available approaches to regulating trees in British Columbia
2. Considerations for selecting the right tools for your community
3. Descriptions of each tool including:
   a. **Higher-level plans** that can support tree preservation or canopy growth through their vision and policy guidance (regional growth strategies and official community plans)
   b. **Tools regulating land use** that influence the space available to retain or replace trees (land use bylaws and development permit areas and development, subdivision, and servicing bylaws)
      i. The Toolkit provides information about:
         - Key components to retain or plant trees on private and public land
         - The core tool(s) commonly used and purpose of each component to achieve tree preservation and growth
   c. **Tools regulating trees** as their primary purpose (environmental development permit areas, covenants, and tree bylaws)
      i. The Toolkit provides detailed information about:
         - Key components listed in typical bylaw sections
         - The purpose of each component within the bylaw
         - Options for each component, either as a recommended best practice or a list of alternatives for readers to select from based on their community context

The majority of the content in this Toolkit is focused on tools regulating trees as their primary purpose because Metro Vancouver had identified a gap in regional guidance on this topic. In 2024, this Toolkit was updated to provide additional information about higher-level plans and tools regulating land use that provide the foundation for long term preservation of trees and growth of tree canopy in the region. Readers seeking to preserve trees and grow canopy cover should begin with higher-level plans and tools regulating land use before selecting tools to regulate trees. Callout boxes throughout this Toolkit provide examples, external resources, and findings from the practitioner surveys conducted for the development of this Toolkit.

1.2 TOOLKIT DEVELOPMENT

The Toolkit was developed with input from a practitioner survey of municipal staff and consulting arborists in the region. In addition, the project team conducted a review of scientific literature, practitioner guides and bylaws from several regions across Canada and the United States to explore best practices for regulating trees and tree canopy.

In 2020, practitioners in Metro Vancouver were surveyed to better understand regional perceptions of the strengths and needs for improvement of tree regulations. Two practitioner surveys were sent, the first targeting municipal staff involved in tree bylaw implementation, and the second targeting consulting arborists who have experience working through the development process (listed on the International Society of Arboriculture's list of consulting arborists for municipalities in Metro Vancouver).

Fourteen staff from Metro Vancouver member jurisdictions with private tree bylaws answered the municipal survey. Twenty-nine consulting arborists (who have experience preparing arborist reports on development projects across Metro Vancouver) answered the consulting arborist survey. Appendix 1 contains the 2020 survey results. The project team conducted a review of academic literature and practitioner guides to identify components of successful tree regulations and key considerations for governance, planning and implementation supporting effective regulations. Appendix 2 contains the literature review.

Several Canadian tree bylaws were reviewed to inform the tree bylaws section. In Canada, only some provinces have legislation that explicitly enables the regulation of trees on private property. Municipalities in Ontario, Québec and British Columbia have private tree bylaws. Although bylaws from Ontario, Québec and the US were reviewed, British Columbia bylaws were selected for comparison in the Toolkit because of their legal compatibility with legislation in the Metro Vancouver region. Similarly, bylaws presented as examples in the land use section primarily come from British Columbia to ensure their applicability in the region, with a few examples from elsewhere included to provide inspiration from neighbouring jurisdictions.

2.0 British Columbia's Institutional Framework for Regulating Trees

British Columbia's institutional framework provides a range of policy and regulatory tools to preserve or grow trees in forest stands and urban areas. Figure 1 summarizes how tree and tree canopy considerations can be incorporated into British Columbia's available regulatory tools, including:

1. Higher-level plans:
   a. Regional Growth Strategy
   b. Official Community Plans and neighbourhood plans
2. Tools regulating land use and therefore the space available for tree retention and replacement:
   a. Land use bylaws and development permits areas, including zoning bylaws, screening and landscaping bylaws, development procedures bylaws, and form and character or energy efficiency development permit areas
   b. Development, subdivision, and servicing bylaws
3. Tools primarily regulating trees:
   a. Environmental development permit areas
   b. Covenants
   c. Tree bylaws

These tools provide opportunities to regulate trees in British Columbia but may not be applicable in all instances; the relevance of each tool depends on each jurisdiction's context and the trees that are the focus of regulation. Figure 1 includes examples for how each tool can be used to regulate trees growing on private (blue headings) and public (red headings) land for two types of canopy: naturalized stands and urban areas. Each column on the figure indicates if and how a tool would typically apply to this type of public or private tree canopy. For example, Figure 1 does not list content for 'Regional Growth Strategies' under private yard trees and private trees in a development because they are not typically addressed by that tool.

In addition to the regulations represented in Figure 1, some bylaws can stand alone or have their content addressed within zoning bylaws, subdivision and servicing bylaws or development permit areas. These bylaws include:

- **Runoff control bylaws** | Runoff control bylaws can establish maximum percentage areas covered by impermeable surfaces varied by land use, zones, geography and size of paved areas

- **Soil removal and deposit bylaws** | Sometimes called sediment and erosion bylaws, these bylaws regulate grading, soil removal and deposition, soil storage and erosion control guidelines

- **Watercourse protection bylaws** | Watercourse protection bylaws can regulate specific activities and development in riparian setback areas

HOW REGULATORY TOOLS CAN BE USED TO PRESERVE TREES AND GROW TREE CANOPY IN THE REGION

	PRIVATE FOREST	MUNICIPAL FOREST
REGIONAL GROWTH STRATEGIES (OCP* must be consistent with RGS*)	Encourage development patterns that avoid urban sprawl, minimize risks from natural hazards, protect environmentally sensitive areas (ESAs) and water quality.	Encourage preserving, creating and linking urban and rural open spaces including parks and recreation areas.
OFFICIAL COMMUNITY PLANS & NEIGHBOURHOOD PLANS (Other bylaws must be consistent with OCP*)	Direct development away from ESAs* and environmental hazards. Policies supporting preservation, protection, and enhancement of tree stands and wildlife trees, clustering and density bonusing in exchange for conservation covenants.	Policies supporting the preservation, protection and enhancement of tree stands and wildlife trees. Policies that support clustering and density bonusing in exchange for parkland.
ZONING BYLAWS (Or contained in related land use bylaws for runoff control, parking, landscaping etc.)	Require setbacks from riparian areas and ESAs*, enable clustering and density bonusing, set out standards for preserving, protecting, enhancing and restoring ESAs.	At rezoning, parkland acquisitions can be negotiated through density bonusing.
DEVELOPMENT, SUBDIVISION, AND SERVICING BYLAWS	Sets standards for drainage and onsite stormwater management that can be made low impact.	Sets standards for drainage and onsite stormwater management that can be made low impact.
ENVIRONMENTAL DEVELOPMENT PERMIT AREAS	Establish riparian setbacks, ESA* soil and vegetation protection and restoration guidelines, environmental assessment requirements.	DPAs on private land can enhance connectivity, restoration and enhancement of natural areas adjacent to municipal forest.
COVENANTS	Protect natural areas and sensitive ecosystems on title and place maintenance or restoration requirements and restrict actions that could damage the protected features.	
TREE BYLAWS	Regulate all trees in ESAs*, on slopes and significant trees. Specify assessment, protection, replacement standards.	Regulate all municipal trees. Specify assessment, protection, compensation standards.

***Short forms:** ESA – Environmentally Sensitive Area | OCP – Official Community Plan | RGS – Regional Growth Strategy

Figure 1. The key regulatory tools in BC that can be used to protect or grow urban forest canopy types.

2 | Trees in Urban Areas

MUNICIPAL STREET & PARK TREES	PRIVATE YARD TREES	PRIVATE TREE IN A DEVELOPMENT
Develop settlement patterns that minimize the use of automobiles and encourage walking, cycling and the efficient use of public transit.		
Policies and targets supporting parkland amenity contributions, new parkland, expansion of the urban forest, treed character of streets and areas, integration with goals such as stormwater management, biodiversity, energy conservation and walkability.	Policies supporting the treed character of new landscaping in land uses and neighbourhoods.	Policies and targets supporting tree and canopy retention, protection and enhancement.
At rezoning, negotiate amenity contributions for new parkland. Require setbacks of above and below ground structures, signage and weather protection favourable for street trees.	Require lot sizes, trees per lot, impermeable/ permeable cover, off-street parking, screening | and landscaping, favourable to yard trees.	IMPORTANT: The tree bylaw may not apply to the extent necessary to allow a permitted use or density.
Set standards for boulevard trees, spacing, soil volume, planting standards, access, utilities favourable for street trees.	Set standards for access and utilities placement favourable to yard trees.	Set standards for access and utilities placement favourable to retaining private trees.
	Promote energy conservation, water conservation and reduction of greenhouse gas emissions using trees.	
		Protect trees or tree groups on developing properties, place maintenance requirements and restrict actions that could damage the protected features.
Regulate all municipal trees. Specify assessment, protection, compensation standards.	Regulate certain trees and require a minimum number of trees/canopy per lot. Specify assessment and replacement standards.	Regulate certain trees and require a minimum number of trees/canopy per lot. Specify assessment, protection, replacement standards.

Tree types: Forest stands and naturalized areas | Urban trees

Jurisdiction: Public | Private

***Short forms:** ESA – Environmentally Sensitive Area | OCP – Official Community Plan | RGS – Regional Growth Strategy

3.0 Selecting the Right Tools and Options for your Community

This Toolkit provides options for content that municipalities could include in policy and regulatory tools to preserve trees and grow tree canopy. For a municipality considering what tool(s) to select, an urban forest governance lens may be helpful to identify the decision-making factors. Urban forest governance refers to the processes, interactions, organizations, and decisions that lead to the establishment and maintenance of urban forest resources and benefits (Lawrence, De Vreese, Johnston, Konijnendijk, & Sanesi, 2013). Applying an urban forest governance lens means defining the governance approach used by a specific municipality and using that information to help inform decisions about which tool(s) are likely to be most successful.

The paper "*Urban forest governance: Towards a framework for comparing approaches*" (Lawrence, De Vreese, Johnston, Konijnendijk, & Sanesi, 2013) defines a set of variables for systematically analysing urban forest governance. This Toolkit poses a set of analysis questions related to urban forest governance; these questions can be used to help define the relevant focus, level of effort, extent of change, key actors, capacity, and processes for developing new tree regulations.

Urban forest governance analysis questions

1. **Community context:**
   - ◊ What are the urban forest canopy types that are the target of canopy preservation or growth: canopy in forest stands and naturalized areas, canopy in urban areas, or canopy in both naturalized forest stands and urban areas? Please refer to Figure 1 for the canopy types and how they might be regulated with different tools.
   - ◊ What level of administration and enforcement effort can be supported by the jurisdiction's population size and geographic area?
   - ◊ What level of regulation would align with community values?

2. **Institutional frameworks:**
   - ◊ What types of policies, plans and regulations are already in place and how could they be enhanced or complemented with updates or new regulation?
   - ◊ Will new policies or plans be required to support new regulation?
   - ◊ What urban forest canopy or tree targets exist in policies and plans, and how could new regulations be used to achieve them?

3. **Actors and coalitions:**
   - ◊ Who are the key internal and external stakeholders who need to be consulted?
   - ◊ Who needs to support the decision and who will make the final decision?

4. **Resources:**
   - ◊ Will funding and staffing need to increase to support the new regulation?
   - ◊ What new technical information will need to be provided to internal and external stakeholders?
   - ◊ Can other policies, programs or staff be used to implement the changes more effectively?

5. **Processes:**
   - ◊ What are the narratives, conflicts and framing that justify the changes being made?
   - ◊ What are the specific ways that actors and stakeholders will be consulted, engaged, involved, and empowered in decisions and implementation?
   - ◊ What are the performance targets[1] for the change? How will success be measured and reported in relation to targets?

Answering these questions will help choose the right tools and options for your community. Your answers will inform the selection and design of policy and regulatory tools that will be appropriate for the community's governance context; and help identify the engagement and resourcing required to support their effective implementation.

[1] Examples of measurable targets include metrics such as canopy cover, rate of tree removal and replacement, replacement tree survival rates, or pervious cover.

Higher-level plans are established for a regional, municipal or neighbourhood planning scale. The plans set goals, targets and policies that guide planning and development at that planning scale, making them an important driver for tools that regulate land use and trees.

4.0 Higher-level Plans

The higher-level plans described in this section include Regional Growth Strategies, Official Community Plans and Neighbourhood Plans. Regional Growth Strategies are an agreement across local governments on the future, population in the region and employment projections, and targets, policies and actions, for example for the reduction of greenhouse gas emissions (Local Government Act, RSBC 2015, c 1, 2015). A Regional Growth Strategy describes objectives for and ways to protect environmentally sensitive areas. Local governments are required to include a regional context statement within Official Community Plans (OCPs) to demonstrate consistency with matters in the regional growth strategy. Since the publication of the first edition of the Tree Regulations Toolkit, Metro Vancouver published *Metro 2050*, the new Regional Growth Strategy.

METRO 2050

In 2023, Metro Vancouver adopted its new Regional Growth Strategy, Metro 2050. The Strategy shares the vision for the region's projected growth in population, housing, and jobs for the next 30 years. Strategy 3.2 focuses on the protection, enhancement, restoration, and connection of ecosystems. It includes a target to increase tree canopy cover within the Urban Containment Boundary from 32% to 40% by 2050.

Official Community Plans are comprehensive plans that can include environmental protection policies. They provide the policy support for the bylaws adopted in the community. Official Community Plans can also define settlement patterns that guide development and avoid sprawl, map key areas, and designate development permit areas and guidelines for development permits responsible for tree protection and replacement (Stewardship Centre BC, 2016). Official Community Plans can establish goals and indicators related to the preservation and growth of a community's urban forest and support the implementation of community-supported bylaws and policies for that purpose. More specifically, Official Community Plans can set policies related to the natural environment with regard to the protection of stands of trees and ecosystems. They can also provide guidance on equity components to ensure access to all community members and to recognize and support the rights of Indigenous Peoples regarding urban forest resources. Official Community Plans should also guide land acquisition for the purpose of preserving and growing tree canopy and support climate resilience of our communities through strategic use of tree canopy benefits and of urban forests in the face of changing growing conditions. Finally, they can guide the best use of trees for urban design and livability.

Neighbourhood Plans can be a helpful accompanying policy tool to set out targets for canopy cover. They can also and define policy objectives and character elements of importance for the urban forest and neighbourhood character. This smaller planning scale enables more consideration to be given to the local land use and unique context of each neighbourhood within a municipality. To supplement this section of the Toolkit, practitioners can refer to Appendix 3 for a worksheet that helps local governments assess their Official Community Plan and Neighbourhoods Plans.

LOOKING BEYOND BRITISH COLUMBIA: WASHINGTON STATE'S REGULATORY FRAMEWORK FOR NO NET LOSS OF HABITAT

Municipalities in Metro Vancouver follow the rules set by the Province of British Columbia. However, looking at other jurisdictions, including Washington State, could offer new ideas for urban forest management. Washington State's Growth Management Act requires all municipalities and counties to adopt critical areas' regulations for the protection of the natural environment, wildlife habitats, and sources of drinking water. The municipal and county regulations must first avoid, then minimize and mitigate development impacts on critical areas. The State requires a no net loss approach which requires local governments to maintain the same quantity and quality of critical areas over time. As a result, cities like Bellingham have adopted a Critical Areas Ordinance to implement the no net loss framework that applies to both public and private lands. These requirements have resulted in significant investments in restoration, including stream daylighting, forest and wetland restoration, and now the development of a mitigation bank to direct compensation funds towards ecologically appropriate and functional mitigation for impacts anticipated to occur over the next 10 years.

Land use regulations create the foundation for long-term protection and growth of trees. These regulations control where trees can exist and how much space is available for them to grow in a particular land use type as it develops.

It will be ineffective to implement a tree bylaw or an environmental development permit area to protect trees or grow tree canopy if land use regulations do not require adequate space to retain or grow trees post-development.

5.0 Tools Regulating Land Use

Land use regulations significantly impact on tree preservation and growth because they influence the space available to retain or replace trees with development. As such, these tools will be critical to achieving Metro Vancouver's target to increase tree canopy cover to 40% within the Urban Containment Boundary (UCB) by 2050.

The availability of space to retain or replace trees varies widely across both public and private land uses. As urbanization and density increase in Metro Vancouver, the space available to grow trees tends to decrease. More specifically, studies have found that canopy cover declines significantly when median site coverage or housing density increases (Hilbert et al. 2019; Landry & Pu 2010; Troy et al. 2007). Local governments will need innovative land use policies to maintain and enhance tree canopy (where possible) and mitigate tree canopy loss in densely populated areas.

The land use bylaw components presented in this section contribute to tree preservation and growth because they influence the space available to retain or replace trees on private or public land. Practitioners can evaluate their current regulations to determine how much space they make for trees and how landscaping and tree retention mechanisms contribute to desired tree canopy cover outcomes.

Practitioners can use the following regulatory tools to address the components listed in this section:

- **Land use bylaws and development permit areas:** zoning bylaws can set rules for lot sizes, setbacks, building coverage, and how land can be used, which can, in turn, affect land cover and where tree canopy (and associated environmental benefits such as urban heat mitigation and stormwater interception) is distributed (Wilson, Clay, Martin, Stuckey, & Vedder-Risch, 2003). Zoning bylaws, screening bylaws, or 'form and character' and 'climate change' development permit areas can also regulate or provide guidelines for landscaping, retaining important trees, and promoting landscaping strategies for passive solar gain and cooling.

- **Development procedures bylaw:** can allow staff to approve minor variances to retain trees.

- **Development, subdivision and servicing bylaw:** can control the placement of trees and vegetation in streets and the landscaping design criteria and construction standards.

In a 2020 survey, the majority of municipal staff survey respondents indicated that they thought their zoning bylaws were not currently effective for preserving or growing canopy cover.

While some best practices for regulatory components influence tree canopy outcomes, others are more variable and context-specific. The following subsections provide detailed information about key bylaw components, including:

- Purpose of the bylaw component
- A recommendation for each component, either as:
  - ◊ Recommended components – central to the approach presented for tree retention or planting
  - ◊ Options – listed for every community's consideration based on the specific land use or context
- Examples of where those regulatory components are being implemented in existing regulations

Before providing an overview of the regulatory components, the toolkit includes context about how land use influences the region's tree canopy cover and impervious surface.

5.1 CURRENT LAND COVER AND CONSIDERATIONS FOR SETTING LAND USE CANOPY COVER TARGETS

This subsection presents information about the distribution of land uses in the Metro Vancouver region and their contributions to tree canopy and impervious surface cover. Land cover information provides context for which land uses have the greatest influence on tree canopy cover in Metro Vancouver.

Largest land uses in Metro Vancouver

Figure 2 illustrates the land use composition of the region's UCB in 2020. The most abundant land uses were low-rise housing (single detached and small-scale, multi-unit housing), parks and greenspaces, road rights-of-way, and commercial and industrial uses. Nearly 40% of the region's land area is in publicly managed parks and roads, while private land uses account for 60%. Therefore, when developing land use regulations to influence canopy cover, local governments must carefully consider how regulating their most extensive land uses can best support canopy preservation and growth.

Land uses across the region are not static and will continue to change. For instance, since 2014, the proportion of low-rise housing decreased as urban centres have densified. In addition, recently introduced Provincial regulations will result in all single-detached housing in the Urban Containment Boundary transitioning towards small-scale, multi-unit housing

LAND USE AREA WITHIN THE URBAN CONTAINMENT BOUNDARY

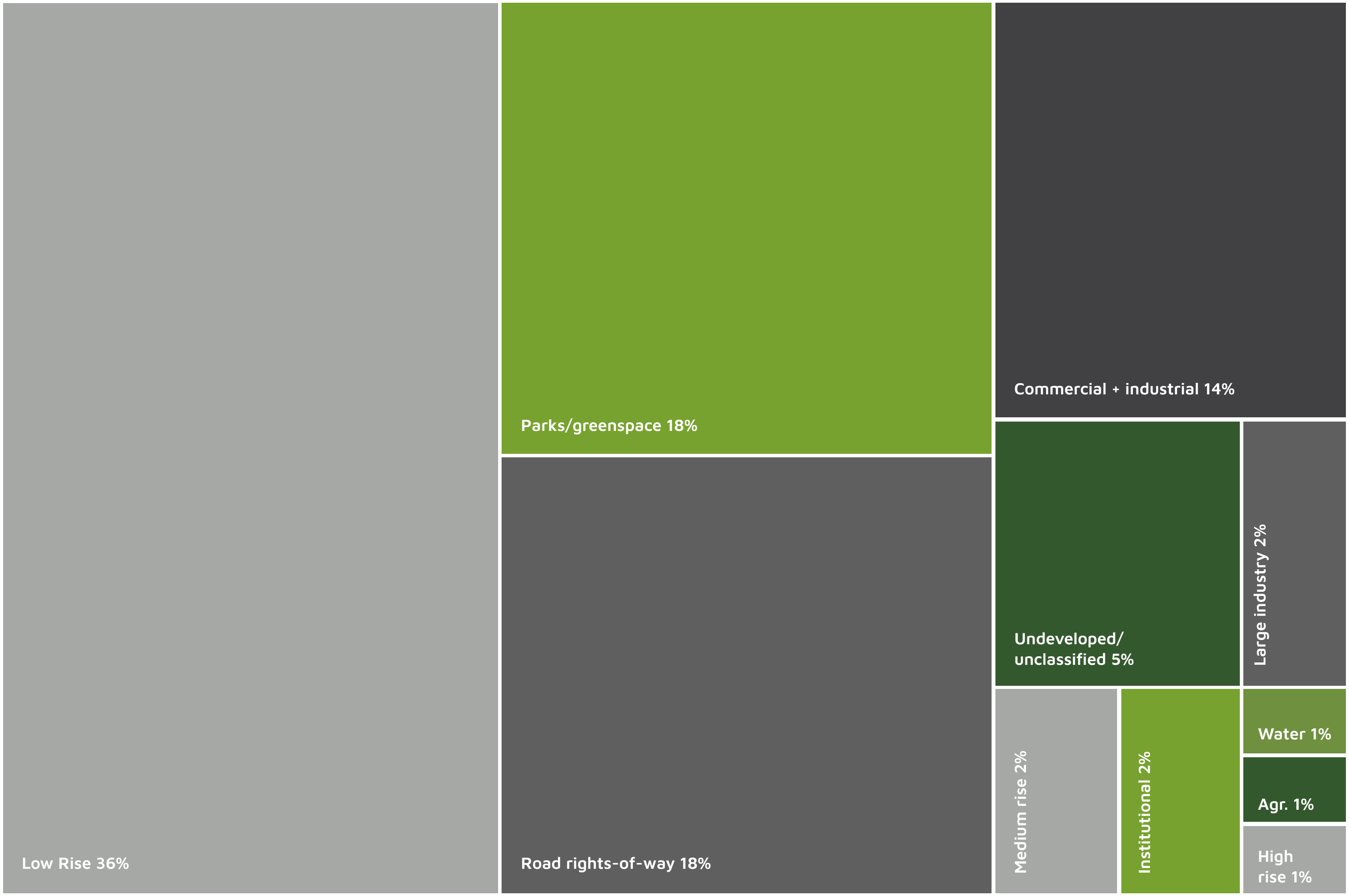


Figure 2. Approximate land uses contribution to Metro Vancouver's Urban Containment Boundary land base.

BC SMALL-SCALE, MULTI-UNIT HOUSING PROVINCIAL POLICY

In 2023, the BC provincial government introduced changes to the *Local Government Act* and *Vancouver Charter*. It published a Policy Manual to guide the implementation of changes to single-detached dwelling or duplexes zones to allow Small-Scale, Multi-Unit Housing (SSMUH). The Transit-Oriented Development Areas legislation will also concentrate development in areas within 800 m of rapid transit nodes. The regulatory changes will replace single-detached and duplex zones across the region's Urban Containment Boundary to allow a minimum number of residential units ranging from a minimum of three to six units based on the lot size and their proximity to a frequent transit stop.

This section of the Toolkit uses icons to highlight the anticipated impacts and implications of the provincial regulatory changes on relevant bylaw components.

Where is most of the tree canopy in our region?

Metro Vancouver's 2024 Regional Tree Canopy Cover and Impervious Surfaces report (Metro Vancouver, 2024) found that in 2020 31% of the UCB was covered with tree canopy. Previous reporting concluded that low-density housing land uses had historically had the highest tree canopy (≈35%), but since the 1970s, that canopy has been declining (Metro Vancouver, 2019). Meanwhile, high-rise housing had it highest canopy cover in the 1980s (≈30%) and has been declining since. Today, low-density housing land uses have 1.5 times the canopy coverage found across higher-density housing areas. Commercial, industrial, and office land uses supported the least canopy cover of any land uses. Parks in the region contain approximately 60% canopy cover, while road rights-of-way supported approximately 20% canopy cover.

AVERAGE CANOPY COVER IN 2020

Low-rise housing	**Medium-rise housing**	**High-rise housing**	**Commercial, industrial, office**	**Public realm streets and parks**
Single detached to small-scale multi-unit housing (up to 3 storeys)	Mid-rise residential or mixed-use (up to 6 storeys)	High-rise residential or mixed-use (higher than 6 storeys)	Non-residential commercial, industrial, and office uses	Local government-owned property

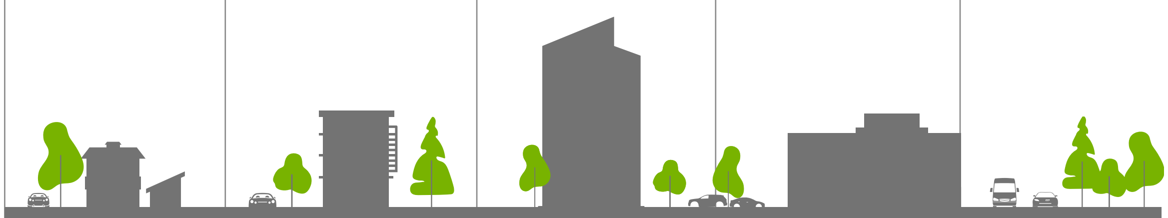
≈30% (lowest for multi-attached)	**≈20%** (lowest in mixed use apartments)	**≈20%** (lowest in mixed use apartments)	**≈5-10%** (lowest for retail and other commercial)	**Parks ≈ 60%** **Road ≈ 20%**

Where is most of the impervious cover in our region?

According to the Regional Tree Canopy Cover and Impervious Surface report (Metro Vancouver, 2024), in 2020 54% of land in the UCB was impervious, meaning it was covered by buildings or pavement. Commercial, industrial, and office land uses had the highest impervious surface of all land uses, reaching up to 94%. Housing land uses have seen comparable levels of impervious surface since the 1970s, with medium and high densities averaging around 75% impervious surface, because of larger site coverage and smaller lot sizes in lower density areas. In comparison, low density residential areas generally had lower impervious surface ranges from the 1970s to 2020 – 50% on average across the UCB. Recently adopted provincial government legislative changes promoting the transition in single-detached residential areas to small-scale, multi-unit housing are expected to increase site coverage and impervious surface further. Parks have the lowest impervious cover in the region at approximately 15%, while road rights-of-way have approximately 80% impervious cover.

AVERAGE IMPERVIOUS COVER IN 2020

Low-rise housing	**Medium-rise housing**	**High-rise housing**	**Commercial, industrial, office**	**Public realm streets and parks**
Single detached to small-scale multi-unit housing (up to 3 storeys)	Mid-rise residential or mixed-use (up to 6 storeys)	High-rise residential or mixed-use (higher than 6 storeys)	Non-residential commercial, industrial, and office uses	Local goverment-owned property
≈50-75% (highest for multi-attached)	**≈65-90%** (highest in mixed use apartments)	**≈70-90%** (highest in mixed use apartments)	**≈85-95%** (highest for retail and other commercial)	**Parks ≈ 15%** **Road ≈ 80%**



IMPORTANT IMPERVIOUS COVER THRESHOLD FOR TREE CANOPY

Research and practitioner comments suggest a strong relationship exists between the proportion of tree canopy cover on a site and the extent of impervious cover (i.e., paved surfaces). Metro Vancouver's land cover data (2014) shows that once a city block reaches 60% impermeable cover, it becomes unlikely to reach more than 30% canopy cover.

Given the close relationship between impervious and canopy cover, local governments seeking to preserve or grow canopy cover need to ensure that their regulations result in adequate pervious surface and soil to grow trees in the land uses where the community wants to see tree canopy. **Local governments need to retain soil to grow trees close to where people live.**

5.1.1 Setting a Tree Canopy Cover Target

To reach the regional 40% canopy cover target within the UCB, local governments must implement practical solutions that minimize the loss of canopy and pervious area, and maximize opportunities to enhance landscapes and retain and plant trees in each land use. Parks and conservation areas, crucial for providing canopy cover and space for nature, should not be the sole source of tree canopy. Research underscores the importance of providing nearby tree canopy for public health, exemplified by the '3-30-300 rule', which advocates for the visibility of 3 trees from homes, schools, or workplaces, at least 30% canopy cover in each neighbourhood (a minimum suggested to ensure residents receive health and wellbeing benefits), and access to greenspace within 300 metres of residences (Konijnendijk, 2022). The BC Coroner Service's report on the 2021 heat dome event also highlighted the provision of tree canopy and pervious surfaces as one of four core strategies to combat extreme heat and mitigate future public health risk (British Columbia Coroners Service, 2022). While not all land uses will be able to accommodate the same canopy coverage, it is essential to continue making space for trees and greenspace close to where people live across the region. Setting up a local government canopy cover target is an important tool to direct efforts towards achieving adequate tree canopy and distribute those important benefits across communities and the region.

Metro Vancouver's tree canopy cover reporting has highlighted a concerning trend of declining space for trees across various land uses. This trend threatens the regional target to grow canopy cover to 40% within the UCB. Setting canopy cover targets at the local level by land use will help practitioners focus on aligning their land use bylaws with those goals. A review of land use regulations and rights-of-way standards will allow for a better understanding of what can be achieved on a parcel or city block level. Those parcel-level targets can be scaled to the land use and local government-wide scale to better understand how the local government will contribute to regional targets.

When choosing a suitable target for a specific land use, practitioners should consider its contribution to a local government-wide target, the regional UCB target (as required in *Metro 2050* Action 3.2.7a), and to the provision of canopy close to where people live. Achieving 40% canopy cover across all land uses may not be feasible or appropriate.

To meet a canopy cover target, the number of trees and the necessary space required for planting must be allocated within each land use category. Table 1 presents the approximate tree density per hectare required to achieve various canopy cover targets. To achieve the targeted canopy cover with the tree density stated, the species planted should on average have a medium-size crown at maturity (mature crown spread 5 – 10 metres). The table also identifies that a certain percentage of each land parcel should be dedicated as a consolidated planting area (see inset) to accommodate tree growth. This percentage varies from around 5% to 30%, depending on the canopy cover target and parcel size. Ideally, each tree should have approximately 35 m^2 of pervious area; however, this can be reduced to 30 m^2 if shared with other trees (see Table 2 in section 5.3.2 for more details). If providing pervious area is not feasible, practitioners can employ engineered solutions such as soil cells or structural soil under impervious surfaces to achieve the desired outcome.

Table 1. Approximate tree density and percent of parcel area required to meet specific canopy cover targets at the parcel level

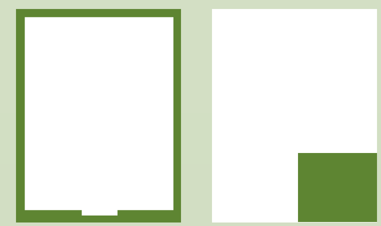
PERCENT CANOPY TARGET	TREE DENSITY PER HECTARE[1]	EXAMPLES OF PERCENT OF PARCEL REQUIRED FOR CONSOLIDATED PLANTING AREAS*[2]	
		2,000 SQUARE FEET PARCEL	9,000 SQUARE FEET PARCEL
60%	92	32% (space for 2 trees)	29% (space for 8 trees)
55%	85	32%	25%
50%	77	16%	22%
45%	69	16%	22%
40%	**62**	**16%**	**18% (space for 5 trees)**
35%	54	16%	18%
30%	46	16%	14%
25%	38	16%	11%
20%	31	16%	11%
15%	23	Less than 1 tree/lot needed	7%
10%	15	Less than 1 tree/lot needed	4%
5%	8	Less than 1 tree/lot needed	4%

[1] This tree density is based on the City of Vancouver's average canopy cover per tree of 65 m^2; Vancouver's tree population averages 35 cm diameter at breast height and young trees are most abundant. However, trees 30 cm and larger provide most of Vancouver's canopy area.

[2] To support a tree providing approximately 65 m^2 of canopy (8 m spread per tree), a minimum of 30 m^2 of consolidated pervious area should be provided. The examples of the percent of parcel required to provide the minimum planting area are based on parcel sizes of 2,000 and 9,000 sq. ft. (186 m^2 and 836 m^2).

WHAT IS A CONSOLIDATED PLANTING AREA?

Unlike pervious area cover, a consolidated planting area requires contiguous soil volume in an arrangement that would support the growth of a large-size tree.



Example of the same lot's pervious cover arranged in green slivers around a large grey impervious area (left) or in a consolidated form (right, preferred for tree planting)

For more details on implementing a consolidated planting area requirement in your land use bylaws, see section 5.3.2 on tree planting.

5.2 LAND USE BYLAWS AND DEVELOPMENT PERMIT AREAS

This subsection focuses on landscaping and site coverage guidelines, as well as regulations that create space to grow trees on private land. Practitioners may use various regulations to implement some of the components listed in this subsection based on local context and preferences. The regulatory tools are:

- **Zoning bylaws**, which set land use, density, building height and site coverage, and parking requirements
- **Form and character development permit areas**, which can regulate building design and landscaping
- **Climate change and energy conservation development permit areas**, which can promote landscaping solutions to reduce energy consumption
- **Screening and landscaping bylaws**, which can be used to preserve, protect, restore, and enhance the natural environment, screen or buffer land uses, and prevent hazardous conditions (e.g., require certain types of plants in wildfire hazard areas)
- **Development procedures bylaw**, which can define procedures to apply for variances to land use regulations, including application requirements and delegated minor variances

To supplement this section of the Toolkit, practitioners can refer to Appendix 4 for a worksheet that helps local governments assess their regulatory tools.

5.2.1 Landscaping Standards

Practitioners can use landscaping requirements or guidelines to meet canopy cover targets. These requirements can be used to encourage tree retention (given that retained trees help to achieve the landscaping requirements), but these requirements are primarily used for ensuring that a consistent landscape standard is achieved post-development. The core component of the landscaping requirements that influences canopy cover growth is the tree planting requirements.

RECOMMENDED COMPONENT
Tree planting and retention requirements

PURPOSE | Landscaping and screening requirements can set tree planting or retention minimums and specify adequate planting standards in all or specific zones.

In practice, it might include the following components:
1. Number of trees:

- **Tree density requirement*** to consistently distribute canopy cover across a land use. A tree density requirement may be based on:

  ◊ In residential land uses, the parcel or landscape area size

  ◊ In commercial or industrial land uses, the number of parking stalls
- **Screening buffer** to use trees as a buffer between different land uses. The buffer should be at least 3 metres wide to allow the planting of larger tree species.

*Note on tree density: Practitioners can align tree density targets in landscaping requirements with a tree bylaw's tree density target requirement (see the tree bylaw subsection 6.3.6.2 Replacement Requirements – Achieving canopy growth). For example, the tree bylaw may use the tree density to cap replacement requirements while zoning uses the same density as a minimum landscaping standard. Over time, the combined use of those tools would equalize the distribution of tree canopy, with heavily forested properties reducing canopy, and sparsely forested properties increasing it after development.

2. Planting standards:

- **Size at maturity** is an importance factor. To achieve the desired tree canopy target with the equivalent tree density requirement, trees must be mostly medium or large size at maturity, meaning that the species planted will reach a medium to large crown size. To achieve the targeted canopy cover with the tree density, local governments could require no more than 25% small trees at maturity, and no less than 50% large trees and medium trees at maturity to make up the difference.
- **Soil volume** minimums per tree are important to provide trees with sufficient growing space. They can be supplied with adequate pervious surface where trees are planted in the ground (see section 5.3.2 about planting area requirements) or with soil cells or structural soil if growing on structure or below impervious cover (see section 5.5.1 for recommended minimum soil volumes).
- **Installation and maintenance** requirements should reference the Canadian Landscape Standards, which provide industry best practices.
- **Tree species selection** should be guided by a list of climate-adapted and non-invasive species, as well as diversity guidelines. If it is not feasible to maintain a species list, practitioners should, at a minimum, require approval of the proposed species.

Examples of where this approach is used:

- Tree density requirements in zoning:
  ◊ Coquitlam zoning landscaping requirements for development
  ◊ Kelowna zoning landscaping standards (table 7.2; see inset)
  ◊ Portland city code (11.50.050 On-Site tree density standards)
- Trees per parking stall requirements
  ◊ Township of Langley parking lot landscaping (section 111.4)

TREE DENSITY REQUIREMENT FOR LANDSCAPING

The City of Kelowna's Zoning Bylaw includes landscaping requirements specific to four different types of land uses. The requirements include a minimum number of trees per hectare as well as a minimum growing medium area and soil volume.

Kelowna Zoning Bylaw – Section 7 Site Layout

ADDITIONAL OPTION | The recommended landscaping standards can be supported by development permit area (DPA) guidelines and other mechanisms to improve tree retention and planting:

Green standard/factor score or sustainability checklist: Local governments can use reporting standards that require applicants to report on their sustainability and greening efforts. Such tools can suggest a list of measures and their associated score, allowing applicants to select the tree retention or planting solutions that work best for their site. Sustainability report cards or green scores can be included in reports to Council and Committees for rezoning or development permit applications to demonstrate how well an application aligns with local government's sustainability values. While they are sometimes used as a voluntary standard, sustainability scores can also be used as a requirement for amenity density bonusing, as described in section 5.2.3.

- Examples of where this approach is used:
    - ◊ Toronto green standard (see inset)
    - ◊ Port Moody sustainability report card

Form and character landscaping guidelines: Form and character DPAs are a common tool for local governments to implement requirements related to greenspace, planting, and character for new development. Form and character DPA guidelines can support landscaping requirements by encouraging retention of existing mature trees or forest stands, tree planting (including sufficient spacing and soil volume), and achievement of specific goals such as shading, place making, native plantings, stormwater management, or energy efficiency.

- Examples of where this approach is used:
    - ◊ Landscaping guidelines in Surrey's Form and Character DPA provide details on the type of tree retention, landscaping, and planting conditions required in different land uses to maximize benefits from trees and provide adequate conditions to support tree growth.

Climate change and energy conservation Development Permit Area: Under energy conservation, water conservation and greenhouse gas emissions reduction DPAs, some guidelines can contribute to preserving trees and growing tree canopy while increasing carbon storage and meeting goals for climate action. These components include landscaping strategies such as planting trees for passive solar gain and cooling to reduce energy consumption (British Columbia Ministry of Community, Sport and Cultural Development, 2011). Trees should be located to serve as a windbreak, and shade trees to cool buildings and impervious surfaces where possible. Tree species that require less watering should be selected to minimize irrigation needs.

TORONTO'S GREEN STANDARD

The Toronto Green Standard is the City of Toronto's sustainable design requirements for new private and City-owned developments. The Standard was introduced in 2006 as a voluntary standard for new development and has since been structured into a tiered program that offers a mix of mandatory and voluntary elements. Projects that demonstrate higher levels of performance may be eligible for a refund on development charges paid to the City. Design guidelines in the Toronto Green Standard address urban forestry, including:

- Soil volume required on the site and in the adjacent public boulevard
- Minimum soil volumes for each tree planting area (permeable area consolidation)
- Placement and spacing of trees
- Required watering and maintenance of trees after installation
- References to relevant bylaws and policies governing trees on public and private property

The Toronto Green Standard requires all new developments to increase tree canopy, soil volumes, and tree watering, while promoting the use of native species and exclusion of invasive species from landscaping. Additional tree planting or ecological restoration is voluntary and can be used to qualify for a development charge refund. The Toronto Green Standard is updated every four years to provide certainty and regularity to private landowners and the development industry. The urban forest is a crucial performance area for the Toronto Green Standard, which is a major implementation tool for the City's Climate Action Plan.

Other example of a similar approach:

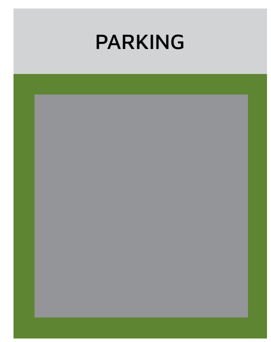
Seattle's Green Factor is another score-based approach to implementing greening requirement within the City's Municipal Code:

- Applicants must achieve a minimum number of credits
- Greening methods that earn credits: tree planting (highest for large species at maturity planted in adequate soil volume), pervious areas (highest for vegetated areas and greater depth of infiltration)

5.2.2 Planting Area Requirements

After establishing landscaping requirements aligned with their canopy cover targets, practitioners must ensure that site requirements provide adequate planting areas to sustain the desired canopy cover.

The additive impact of the regulatory components discussed in this section is shown on an example parcel where space to support trees on private property is initially insufficient:



RECOMMENDED COMPONENT

Planting area requirement

PURPOSE | The amount of pervious area provided on a parcel needs to be sufficient to support the landscaping requirements for tree retention and planting.

In practice, it might include the following bylaw components:

- **Minimum pervious area requirements (or maximum impervious area)** can support the provision of planting areas. Still, it may not be sufficient to achieve a consolidated tree planting area (e.g., narrow strips of grass surrounding a building).
- **Minimum consolidated planting (pervious) area** of at least 35 m^2 per tree (or 30 m^2 if the multiple trees share the soil volume) with minimum dimensions to create a shape large enough to support tree(s).
- **Engineered solutions** to achieve soil volume under impervious surfaces.

A consolidated pervious area requirement will create an area large enough to support a tree:

The table below summarizes the minimum surface area required to support a tree (assuming a 1 m soil depth).

Table 2. Surface area of soil per tree assuming 1 m depth

TREE SIZE	APPROXIMATE SURFACE AREA (M^2) OF SOIL REQUIRED PER TREE (ASSUMING 1 M SOIL DEPTH)		
	On ground	**Under hardscape – soil cells+**	**Under hardscape – structural soil++**
Small tree canopy spread is up to 6 m	8	x1.1	x5
Medium tree canopy spread is up to 10 m	20	x1.1	x5
Large tree canopy spread is greater than 10 m	35	x1.1	x5

+Soil cells are 92% soil, ++Structural soil is 20% soil.

Examples of where this approach is used: Victoria missing middle zoning; Ottawa missing middle; Portland City Code – Chapter 11.50 Trees in Development Situations

CONSOLIDATED PLANTING AREA

The City of Victoria recently adopted missing middle zoning that allows houseplexes (buildings with at least 3 and no more than 6 dwelling units), corner townhouses and heritage-conserving infill housing in areas previously limited to traditional residential zoning. Schedule P of the Zoning Bylaw lists new requirements for the missing middle zone, including requirements for open site space that the City developed to provide a minimum connected surface area of a size and shape that will enable tree planting:

Site coverage, open site requirement:

- Open site space (minimum): 45%
- A single space the greater of $35m^2$ or 6.5% of the lot area:
    - ◊ That is landscaped and not paved,
    - ◊ That does not have above or below ground structures, and
    - ◊ **All sides of which are at least 4.5 m long**

City of Victoria Zoning Bylaw Schedule P – Missing Middle Regulations

5.2.2.1 Making space for the planting area

To make space for the planting areas, practitioners need to consider site layout components that are competing for space on the parcels.

RECOMMENDED COMPONENT
Building setbacks to accommodate trees

PURPOSE | Trees require space from buildings and paved surfaces to grow to maturity without conflict with adjacent infrastructure. As such, local governments should be aware that setbacks will become limiting or altogether exclude tree planting once they get below the widths described below.

In practice, it might include the following bylaw components:

- **Front and rear setbacks:** at least 3 metres from foundations in the front or rear to allow tree planting more than 2 metres away from the building for medium-sized trees or 3 metres for large trees. Prioritize keeping the front setback larger to enable tree planting and cooling benefits, except where an existing forested area exists towards the rear of properties that could be preserved with a larger rear setback. Trees should be planted at least 1 metre from the property line.
- **Underground structures setbacks:** Setbacks often do not explicitly apply to underground structures in all zoning bylaws. Practitioners should note that if underground structures are permitted to reach the property line, it will result in tree impacts on and adjacent to that property. For instance, underground parkades that reach the property line may result in the removal of adjacent street trees and make it more difficult to replace trees. Being explicit about where zero setbacks for underground structures will be permitted would help to manage expectations about tree retention, planting, and canopy cover potential in adjacent streetscapes and sites as redevelopment occurs.

RECOMMENDED COMPONENT

Building setbacks to accommodate trees

A larger front setback will provide sufficient space from the building and soil volume to support trees that will grow to a larger size at maturity:

Where a 3-metre building and underground structure setback is not possible in the front or rear of the property, practitioners must review their Development Servicing standards for the rights-of-way to ensure that the boulevard width and placement make up for the lost opportunity for tree canopy – see section 5.3.1. Figure 2 below illustrates the relationship between front setbacks and boulevards for the provision of tree canopy.

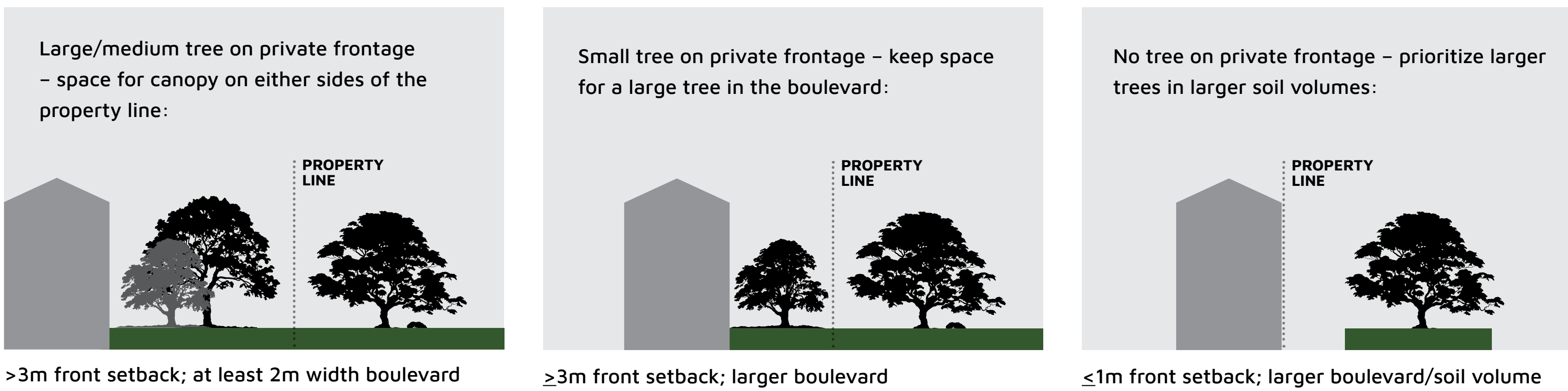


Figure 2. Relationship between front setbacks and boulevards for the provision of tree canopy.

The province's SSMUH Policy Manual recommends that local governments reduce building setbacks to improve the viability of more housing types. The Policy Manual recommends a range for front setbacks from 0-2m for lots with a minimum of 6 housing units to 5-6m for lots with a secondary suite or accessory dwelling. Recommended rear setbacks are as small as 1.5 m.

ADDITIONAL OPTION | Bylaw components to enable the provision of consolidated planting areas:

Site coverage: The maximum site coverage defines the proportion of a lot that can be occupied by structures. With the exception of landscaping grown on structure (discussed below), this represents an area that will not be available as pervious cover.

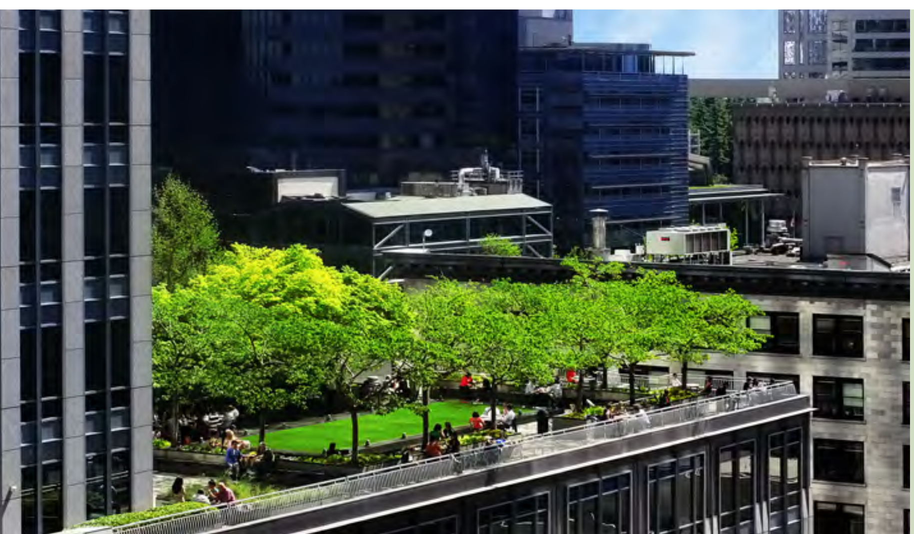
- ℹ The province's SSMUH Policy Manual recommends that local governments set a combination of maximum lot coverage with setbacks and maximum height requirements instead of floor area ratios. **Recommended maximum lot coverage** (i.e., proportion of the lot covered by a building footprint) ranges from approximately 30% for lots with only a secondary suite or accessory dwelling to 60% for lots with a minimum of 6 units.

- On mid- or higher-rise housing sites or other high-intensity land uses where full lot coverage cannot be avoided, tree planting will need to occur on structure. Tree planting on structure should still be supported by adequate minimum soil volumes (see section 5.5.1 for recommended minimum soil volumes).

Parking requirements: On site parking requirements increase impervious cover or the footprint of underground parkades. Numerous local governments have explored reducing or increasing the flexibility of parking requirements as a way to meet objectives for affordability or to reduce greenhouse gas emissions, and this flexibility would also increase the ability to retain or replace trees on a lot.

- ℹ The province's SSMUH Policy Manual recommends that local governments minimize or even remove parking requirements in some areas to retain space for buildable area and increase permeability.

Smaller site coverage and reduced parking requirements will further contribute to maintaining pervious coverage and space for trees:



GREEN ROOFS AND TREE PLANTING ON STRUCTURE

Green roofs may provide an opportunity to plant vegetation and small trees to offset canopy loss, and they can provide many benefits. However, trees growing on structure will provide less and shorter-lived canopy compared to trees planted in the ground because of the more limited soil volumes, and the need to remove trees periodically to repair membranes.

5.2.3 Negotiated Development

In addition to setting the parameters for landscaping standards and planting area requirements that will support achieving the selected canopy cover targets on as-of-right developments, local governments can use regulatory tools to improve tree canopy preservation and growth on negotiated developments.

OPTIONS | The following regulatory components can help improve tree retention and planting outcomes:

Amenity density bonusing: Local governments can use amenity density bonusing to preserve tree stands in exchange for additional density. For example, local governments may allow a higher floor space ratio (FSR) and a clustering of development away from the forested area. Conservation covenants in favour of the local government are often used to protect greenspace for the long term. Local governments may also acquire the area of interest as parkland beyond the 5% parkland dedication they can require at subdivision. Finally, local governments can use a green factor or report card scoring system that allows applicants to choose the most appropriate tree retention and planting actions for their site/project to gain additional density.

- Examples of where this approach is used:
    - ◊ Samamish (WA) uses a points system to allow applicants to select the tree retention or planting interventions best adapted to their project *(see inset).*
    - ◊ The Green Bylaws Toolkit (2021) provides several examples of local governments in BC that used amenity density bonusing to protect sensitive ecosystems.
    - ◊ In the US, municipalities like Portland, Oregon use density transfer mechanisms to achieve goals similar to what amenity density bonusing can provide in BC. For example, Portland's City Code includes Floor Area Ratio transfer aimed at preserving existing affordable housing and trees/greenspace to other parcels in exchange for affordability or tree protection restrictions.

Comprehensive development: Local governments can use comprehensive development zones to drive landscape-level planning for larger parcels of land. Communities may find it helpful to achieve forest stand preservation goals or to enable innovative treatments on sites with particular constraints.

SAMAMISH LOW IMPACT DEVELOPMENT INCENTIVES

The City of Samamish, Washington defines a set of techniques that can earn applicants 20% or 30% additional density on their development. The techniques listed in their Development Code include:

- Forest retention
- Restoration of vegetated areas
- Restoration of critical buffer areas
- Limited site disturbance, reforestation
- Reduced impervious surface
- Minimal foundation excavation

RECOMMENDED COMPONENT
Delegated minor variances for tree retention

PURPOSE | Local governments can use delegated minor variances to clarify how they expect permit applicants to modify their design to accommodate existing trees.

In practice, it might include the following bylaw components:

- **Significant trees** that are the target for retention. Most commonly, variances would be given for trees of high importance, such as heritage or significant trees (see tree bylaw section 6.3.1.1, additional options, for examples of typical categories of trees of high significance).
- **Delegated minor variances** that will be considered to enable tree retention. They commonly include variances to building setbacks, height, and parking.

The province's SSMUH Policy Manual recommends that local governments use delegated minor variances to expedite permitting where site conditions require variations to achieve the intended use, such as to retain trees or improve stormwater management outcomes.

Examples of where this approach is used:

- City of North Vancouver Development Procedures Bylaw section 2 – definition for minor development variance permit
- Seattle exceptional tree (*see the inset*)

5.2.4 Development Procedures

Practitioners can use their land use bylaws to provide flexibility for property owners and local governments to retain existing canopy with minor variances. Tree bylaws cannot prevent owners from achieving as-of-right development, meaning that tree removal will always be permitted where it is required to build a proposed development that conforms with the permitted use and zoning. Nonetheless, it is common for tree bylaws to require applicants to consider modifications to their proposed development to accommodate tree retention where possible (see tree bylaw section 6.3.4.2, conflict with buildings or structures).

5.2.4.1 Procedural Considerations

Land use bylaws should address the information required to support the application, such as a legal survey including trees, a tree inventory, and a site and landscaping plan that identifies retained and new trees. The bylaws should also define the appropriate professionals to undertake the inventories, design, and inspections (e.g., landscape architect, arborist, qualified environmental professional). Practitioners should seek out information about trees and environmentally sensitive areas on site at the pre-application or first application stage to consider options for retention at the early design stage.

SEATTLE'S EXCEPTIONAL TREE PROTECTION ZONING

The City of Seattle, Washington defines exceptional trees as species of a certain size growing individually or in groves. The City has a defined process to vary building setbacks and height to retain exceptional trees. The process and development requirements vary based on the zone:

- **Single-family zones:** Applicants must take advantage of front and rear yard setback departures to enable the retention of exceptional trees.

- **Lowrise zones:** Where an exceptional tree is threatened, applicants must either follow a Streamlined Design Review process to make adjustments to enable tree retention, or they must consider increases in the permitted height detailed in the Tree Protection Code to achieve the same purpose. Additional departures to increase FAR and height or reduce the number and standard of required parking spaces may also be explored with applicants to enable the retention of exceptional trees.

- **Midrise and commercial zones:** Applicants must explore options such as departures from the land use code (as approved by a Design Review) or changes to parking plans to retain exceptional trees.

Seattle Department of Construction & Inspections (2019) – Tree Protection Regulations in Seattle.

BOULEVARD LOCATION

The City of Coquitlam's streetscape standards require the installation of boulevards between the street curb and sidewalks to urbanize its streets. Since 2018, the Frontage Works Program has required development or building permit holders in southwest Coquitlam to either make the rights-of-way upgrades or to pay a fee for the City to make the improvements. The examples below show streets in the same neighbourhood that were built before and after the standards and Frontage Works Program required installation of a boulevard between the street curb and sidewalk:

Boulevards adjacent to private land:

Boulevards located between the curb and sidewalk:

5.3 DEVELOPMENT, SUBDIVISION AND SERVICING BYLAW

This subsection focuses on development, subdivision and servicing bylaws that set the standards and specifications for works and services for land development in local governments. In most cases, these bylaws define the standards for landscaping in road rights-of-way that make up a significant proportion of public lands across Metro Vancouver. Road rights-of-way often need to accommodate multiple functions and services within a limited footprint both above and below ground, which adds complexity to tree planting. However, roads are also an important location to grow tree canopy and to deliver the benefits of tree canopy close to where people live and work. The options presented in this section can improve outcomes by ensuring sufficient space and soil are provided in the road rights-of-way to support tree canopy.

To supplement this section of the Toolkit, practitioners can refer to Appendix 5 for a worksheet built to help local governments assess their regulatory tools.

5.3.1 Procedural Considerations

As part of the development, subdivision and servicing process, procedures should address the information required to support the application (e.g., legal survey including trees, tree inventory, site plan), securities that the local government will collect, documentation required for substantial completion, and the professionals (e.g., Landscape Architect) who will undertake the design, inspection, testing and record keeping of landscaping trail and street trees (unless installed by the local government).

5.3.2 Works and Services Standards for Trees in Boulevards

The first step to providing tree canopy in rights-of-way is for practitioners to ensure that the boulevard width and location are adequate to support the targeted tree canopy.

RECOMMENDED COMPONENT
Boulevard or median planting strip

PURPOSE | The boulevard designates the area between the private property line and the street curb that local governments generally use to plant trees and install street furniture like streetlamps or utilities. The boulevard excludes sidewalks, curbs, and driveways. The median is the strip of land between two lanes of opposing traffic. The works and services standards will generally define when a boulevard and landscaping are required by road classification and/or zone or land use. Local governments should require boulevard landscaping in their services standards/required service levels and provide the largest width possible for a boulevard or median tree planting strip.

In practice, it might include the following bylaw components:

- **Minimum boulevard width:** Where trees are planted in a median or a boulevard planting strip shared with utilities, a minimum width of 2 m is recommended. This width generally ensures enough space for trees to grow and allows for a setback from utilities or vehicles. However, if the utilities are not located in the boulevard area, trees can be planted in a space that is at least 1.5 m wide. Wider planting strips or access to additional soil volume either under the sidewalk or via root bridges to adjacent soil volume areas may be necessary to support medium- to large-sized trees.
- **Location of the boulevard:** Boulevard planting strips can either be located between the curb and the sidewalk or adjacent to the private frontage when there is a monolithic sidewalk (i.e., a sidewalk abutting a curb). While the planting strip adjacent to a private front yard can seem to provide a more continuous planting space, these locations are often perceived as an extension of private property where City tree planting may not be welcomed. Locating the boulevard between the curb and the sidewalk provides a clear distinction between public and private land, establishes a more continuous street tree canopy, and provides a more clearly dedicated space for trees in land uses with smaller front setbacks. Regardless of setbacks in the adjacent land use, locating boulevards between the street curb and the sidewalk should be prioritized where local governments seek to achieve more canopy closure above the street.

Examples of where this approach is used:

- The City of Coquitlam's streetscape standards and Frontage Works Program require boulevards located between the street curb and the sidewalk to achieve uniform tree planting (see inset).

5.3.3 Landscaping Design Criteria and Standard Specifications

After setting the location and width of the planting strips, practitioners should ensure that landscaping standards will support canopy growth.

RECOMMENDED COMPONENT

Landscaping criteria, standards, and specifications

PURPOSE | Landscaping standards are essential to ensure trees are planted in appropriate locations and are of a quality and size to survive and thrive. In most cases, local governments will use the Master Municipal Construction Documents (MMCD) as their base standard and then provide supplementary standards in a bylaw.

In practice, it might include the following bylaw components:

- **Plant spacing, location and type:** Design criteria should include minimum spacing to allow adequate space for trees of different sizes at maturity. Criteria should also guide location to avoid long-term conflicts. Local governments can incorporate species diversity guidance in the standards and provide a preferred species list to encourage planting climate-suitable and non-invasive species.
- **Stock size and quality:** Landscaping standards should refer to the Canadian Nursery Tree Stock Standard for stock size and quality.
- **Soil volume:** Soil volume minimums ensure that newly constructed streetscapes can accommodate trees (see Table 3 below). Soil volumes can be met either in ground where native soils have been retained or with a combination of topsoil and soil cells or structural soil. Continuous, connected soil trenches should be encouraged. When adequate soil volumes are not achievable via planting strips, use soil cells to increase soil volumes and connect root zones of planting under paving. The soil volume provided for local street trees is one of the most significant ways these bylaws affect urban tree canopy.
- **Soil depth:** Soil depth is an important metric for accommodating adequate soil volume. Most tree roots grow within the top 0.6 m of soil and as deep as 1 m if there is adequate air and water to survive. Establishing a soil depth of up to 1,000 mm enables boulevards to hold more soil in the planting strip. It may also provide options for integrating stormwater into the lower depths of the boulevard. The installation of soil to these depths must be done to the correct specification to minimize settling that could result in tripping hazards and the need to add more soil in the future.
- **Soil solutions, surface treatments and root barriers:** Design criteria should enable the use of structural soils or soil cells to meet soil volume requirements. Standards should establish the quality of soil and installation for topsoil, structural soil and soil cells. Root barriers should be used whenever trees are planted within 2 metres of hardscape.
- **Standards for the landscape plan and bonding:** Typically, a warranty period is attached to the landscaping requirement where developers are responsible for installing and planting boulevards. Bonds should be of an amount that covers the cost of stock, installation, maintenance, and inspections. Where surface treatments are required to prevent tripping hazards, tree grates should be used sparingly (due to cost), and alternatives such as bonded gravel or compacted sand should be enabled.

RECOMMENDED COMPONENT

Landscaping criteria, standards, and specifications

- **Irrigation and drainage:** Design criteria can specify when the local government requires irrigation for street trees. Standards can provide specifications for installing irrigation infrastructure or drainage in tree planting spaces. Irrigation and drainage requirements are particularly important for planting sites with more limited soil volume or extensive hardscape that limits infiltration.
- **Utility and infrastructure setbacks:** Utility and infrastructure setbacks can result in trees being excluded from a streetscape or private yard. It is necessary to balance the potential for infrastructure conflict with the flexibility to include trees in spaces shared with utilities. Setbacks should be firm when a hazard could be created (e.g., intersection visibility, gas main connections) but allow for reasonable flexibility in other situations. Where there is inadequate space to achieve utility setbacks and a dedicated trench for trees, consideration should be given to making up the difference by extending the right-of-way onto private land.

The table below provides the recommended soil volume minimums for street trees (Metro Vancouver, 2017).

Table 3. Minimum recommended soil volume per tree

TREE SIZE	Min soil volume (m^3)[4]	Shared or irrigated soil volume (m^3)
Small tree canopy spread is up to 6 m	8	6
Medium tree canopy - spread is up to 10.0 m	20	15
Large tree canopy - spread is greater than 10.0 m	35	30

Credit soil volume according to actual content of soil:

- Soil: Volume of soil (Length x Width x Depth)
- Soil cells: Volume of soil cell installation (Length x Width x Depth) x 0. 92
- Structural soil: Volume of structural soil (Length x Width x Depth) x 0.2

- **ADDITIONAL OPTION** | Components that can support the street boulevard standards described above to achieve more tree canopy:

Perforated curbs: Directing water from our streets into boulevards can be a way to reduce stormwater runoff while improving water access for street trees.

- **Examples of where this approach is used:**
    - ◊ The City of Coquitlam's streetscape standards make use of perforated curbs to direct stormwater from the roadway into boulevards.

Discrete solutions to expand tree planting space: Streetscape design standards define the standard location for streetscape components such as utilities, sidewalks, road lanes, bicycle lanes, boulevards, stormwater, trees and lighting in a streetscape. Standards should allow flexibility to adjust streetscape design when there are competing interests in the streetscape by establishing a hierarchy of preferred and alternative compliance methods for different streetscape components. They can also allow for discrete solutions that maximize tree planting space where space in the boulevard becomes limited, such as:

- **Curb bulges in the parking lane:** Curb bulges are commonly used to improve pedestrian safety at intersections but can also help stagger tree planting where space might be too limited in the boulevard.

- **Suspended slab sidewalks:** Suspended slabs can be used to achieve load-bearing requirements for sidewalks while retaining soil volume under sidewalks.

- **Permeable pavement:** Permeable sidewalks can allow for water infiltration through a sidewalk or bike lane.

- **Siting responsive to site condition:** Rights-of-way upgrades to improve action transportation can compromise tree retention or planting, yet tree canopy is also important to encourage those modes of transportation. Where healthy trees are already growing along a street, using atypical siting to install new bike lanes or sidewalks can help retain canopy.
    - ◊ **Examples of where this approach is used:** The 10th Avenue bike lane near the Vancouver General Hospital was designed to retain as many mature trees as possible along the corridor. The bike lane width and alignment vary along the corridor to respond to pre-existing site conditions.

Environmental development permit areas, covenants, and tree bylaws can be effective tools to regulate the protection, restoration, and replacement of trees. They should be supported by higher-level plans and land use regulations to effectively preserve trees and grow tree canopy.

6.0 Tools Primarily Regulating Trees

This Toolkit provides detailed information about regulatory tools focused on preserving trees and growing tree canopy, specifically:

- **Environmental development permit areas,** which identify locations that need special treatment for certain purposes such as the protection of the natural environment, its ecosystems and biological diversity and typically include:
    - Identification of the development permit area
    - Development permit area guidelines

- **Covenants**, which can require that an amenity be protected, preserved, conserved, maintained, enhanced, restored or kept in its natural or existing state

- **Tree Bylaws**, which regulate the protection and replacement of individual trees and typically include:
    - Bylaw definitions
    - Prohibitions
    - Permitted removal reasons
    - Permit application information requirements
    - Requirements and incentives for tree retention and replacement
    - Replacement tree planting standards
    - Actions on site
    - Securities
    - Penalties
    - Tree bylaw implementation

The following sections provide the detailed information for each key component of the two regulations, including:

- Purpose of the component
- Recommendations for each element, either as:
    - Must have – a recommended best practice or list of alternatives that should be chosen based on the community context, values, goals and impacts
    - Recommended or additional options – listed for every community's consideration, where they may help achieve specific goals or manage impacts
- Examples of where each option is found in existing regulations

6.1 ENVIRONMENTAL DEVELOPMENT PERMIT AREAS

The Local Government Act allows land to be designated under a development permit area (DPA) for the protection of the natural environment that may "require protection measures, including that vegetation or trees be planted or retained" (section 491(1) of the *Local Government Act*).

Regional and community planning processes will often identify natural values and hazards related to forest stands that overlap with but are not adequately addressed by tree bylaws. Using development permit areas (DPAs) can define land with a specific management intent to align it with strategic objectives for protection of the natural environment. For example, in British Columbia, DPAs can be used for the (LGA, 2015):

- *Protection of the natural environment, its ecosystems and biological diversity;*
- *Protection of development from hazardous conditions;*
- *Establishment of objectives to promote energy conservation;*
- *Establishment of objectives to promote water conservation; or*
- *Establishment of objectives to promote the reduction of greenhouse gas emissions.*

DPAs can complement tree bylaws by providing protection, restoration or enhancement guidelines to achieve a broader range of objectives in these areas when development occurs.

Practitioners surveyed emphasized the importance of environmentally sensitive areas, waterfront and riparian areas for protecting tree stands. Some communities have also found form and character DPAs and energy DPAs to be helpful in managing urban trees or tree stands.

Environmental DPAs are used to protect natural features from the impacts of construction or land alteration activities (Britton-Foster, Grant, & Curran, 2016). They are often used to protect environmentally sensitive areas including the marine foreshore, watercourses, wetlands and sensitive terrestrial ecosystems. Environmental DPAs can help protect trees from development activity by identifying significant forest stands and enforcing design guidelines to protect them. Environmental DPAs can be designed to require that identified forested areas be protected and, if degraded, restored or enhanced as a requirement of a development application. Environmental DPAs can be designed to work with, or independently of, a tree bylaw.

6.1.1 Identification of the Development Permit Area

PURPOSE | Identify the environmentally sensitive areas where the development permit applies and "describe the special conditions or objectives that justify the designation" (Local Government Act, 2015)

MUST HAVE: Mapping Environmentally Sensitive Areas

Environmentally sensitive areas must be defined in order to provide landowners with information on whether the development permit guidelines will apply to their development application.

EDPAs may use mapping of varying precision to designate areas where the development permit guidelines may apply. The designation of those areas is often done using external mapping data from regional or provincial sources. At a minimum, environmental DPAs should provide a principled basis for landowners to understand what falls within or does not fall within the approximate area boundary (Britton-Foster, Grant, & Curran, 2016).

Available technology and spatial information for mapping allows municipalities to provide relatively detailed locations of DPAs. The scale, precision and update frequency of mapping must be carefully considered, as environmental DPAs with precise but inaccurate mapping have been challenged.

ADDITIONAL OPTIONS | In addition to the mapping of environmentally sensitive areas, municipalities may wish to consider the mapping and protection of a network of ecosystems to preserve landscape level ecosystem connectivity. This network of ecosystems is called green infrastructure network mapping.

- **Green infrastructure network mapping**
  Green infrastructure networks seek to identify a network of interconnected natural areas that will conserve ecosystem values and functions as well as provide benefits to wildlife and people. A green infrastructure network consists of:
  - Core habitat areas that provide a home range for species
  - Natural corridors across urban areas that prevent the fragmentation of core habitat areas

  Once mapped, green infrastructure network areas can be included and protected within environmental DPAs. The mapping can also serve to inform Neighbourhood Plans and other landscape-level plans.

At the regional level, Metro Vancouver manages and updates the Sensitive Ecosystem Inventory. This inventory may be a good starting point for municipalities wishing to map environmentally sensitive areas. It would however need to be accompanied by a detailed assessment of environmentally sensitive areas to develop mapping at the municipal and neighbourhood scales.

PROTECTING TREES WITHIN DPAS

It is common for jurisdictions that have a tree bylaw and an environmental DPA to include trees within DPAs in the bylaw's definition of protected trees. The inclusion of trees within development permit areas in the tree bylaw strengthens their protection because of the enforcement mechanisms included in the tree bylaw. The tree bylaw can also ensure that, when the development permit is waived or not required, a suitable tree permitting and replacement process applies. If both an environmental development permit area and tree bylaw exist, consideration should be given to exempting applicants from a tree removal permit in cases where a development permit has been granted and ensuring that both policies are designed to have essentially the same requirements for tree protection, removal and replacement in DPAs.

In practice

The City of Surrey implements a sensitive ecosystems DPA that encompasses both a streamside protection DPA and green infrastructure network. It allows the City to protect habitat patches, to avoid the fragmentation of ecosystems, and to require habitat restoration with development.

6.1.2 Development Permit Area Guidelines

PURPOSE | Development guidelines inform landowners about what the requirements are for protecting DPAs when they develop adjacent lands.

OPTIONS

Many guidelines exist that can help preserve trees and grow tree canopy. The options highlighted in this Toolkit include tree protection within DPAs, the preservation and enhancement of forested ecosystems, restoration, and information requirements.

Tree protection within DPAs

Trees within EDPAs are usually protected unless deemed hazardous. Tree protection measures include:

- **Relocating** proposed buildings, structures, servicing or roads to prevent root impacts
- **Fencing** can be required during construction, or as a permanent fixture
- **Pruning** to carefully select branches for removal to reduce the wind load in trees (Stubbs et al., 2019)

Preservation or enhancement of forested ecosystems

Forested ecosystems can be preserved or enhanced with measures such as:

- **Tree species requirements** to maintain the composition and density of native species with replanting
- **Retention of wildlife** trees to provide habitat within forested stands
- **Preservation or enhancement of specific areas** to prevent fragmentation or maintain connectivity
- **Buffer zone planting** in the zone adjacent to the DPA. Natural landscaping may be required to provide a soft transition from the environmentally sensitive area to the development area

Restoration

Where existing ecosystems are degraded or damaged, environmental DPAs can require measures to return the environmentally sensitive area to its natural state:

- **Planting of native trees and plants** to restore the native plant community
- **Removal of invasive species** to prevent competition with native species and spread into adjacent natural areas

Information requirements

Environmental DPA guidelines can require applicants to provide reports from qualified professionals such as:

- **Site conditions and monitoring** from a qualified environmental professional (i.e., a person in good standing with a legislated self-regulating association in British Columbia who is acting within their area of expertise, such as a professional Biologist, Agrologist, Arborist, Forester, Geoscientist, Engineer, Architect, or Landscape Architect)
- **Riparian assessment to identify the Streamside Protection and Enhancement Area** per Provincial methods defined in the Riparian Areas Regulation
- **Stand prescriptions to reduce the likelihood of windthrow** along new exposed forest edges
- **The identification of hazardous trees** by an ISA Certified Arborist who holds the Tree Risk Assessment Qualification (TRAQ)

6.1.3 Other Types of Development Permit Areas

Tree retention is often regulated within hazardous condition DPAs such as steep slopes DPAs to be helpful for tree retention. However, wildfire DPAs may conflict with tree preservation or replacement goals where trees pose a wildfire risk to structures. Where wildfire DPAs apply, it is important to ensure that the wildfire DPA and the tree bylaw are aligned to enable consistency with wildland urban interface management objectives. Alignment could involve permitting removals for wildfire risk reduction in the bylaw and ensuring that replacement trees and landscapes conform with FireSmart guidelines.

6.2 COVENANTS

Covenants are a tool local governments use to regulate trees on individual land parcels, usually with rezoning, subdivision, or development permits. The Province of British Columbia's Land Title Act, section 219 allows covenants (sometimes also called conservation covenants) to be registered on title. This toolkit section offers a brief description of the use of covenants to preserve trees and grow tree canopy but is not a comprehensive discussion of the legal and technical requirements of covenants in British Columbia.

Covenants registered under section 219 of the Land Title Act are a voluntary agreement between a property owner and a designated organization (government body or land trust organization) registered on the property title. Section 219 covenants can be both positive (require actions) and negative (prohibit actions) in nature (WCEL, 2005; LTA of BC, 2014). They can be used to protect, conserve, maintain, enhance, restore or keep amenities such as natural, environmental, wildlife or plant value in its natural or existing state (LTA, s.219). Conservation covenants can 'run with the land', binding all future owners of the property for the full term of the agreement, which can be perpetual.

Section 219 covenants can protect trees or sensitive ecosystems on developing properties, impose maintenance or restoration requirements and restrict actions that could damage the protected features. For example, covenants can require documentation such as tree protection and replanting plans or risk assessments prior to undertaking the subdivision of land. Covenants usually include a baseline report documenting the state of the land at the time of registering the covenant (NATEP, 2018). The report can describe special features and serves as a benchmark for future monitoring. Covenants can help to provide clarity around what is protected on a site; both to the municipality as the site moves through the development process, and to future owners so that they know what is protected on their property. Covenants can be amended or discharged and do not have to be perpetual agreements.

Working landscape covenants can also be developed to allow sustainable activities such as organic farming or sustainable forestry on land under a conservation covenant (WCEL, 2005). This type of conservation covenant is more complex than ones that protect land in its natural state. Working landscape covenants should clarify the priority for the management of the covenant area and require a management approach to be established in accordance with those priorities and the objectives of the covenant.

Statutory rights of way created under Section 218 of the *Land Title Act* are sometimes used to secure access to a property, such as for a public trail, in addition to a Section 219 covenant that specifies the positive (e.g., maintenance requirement) and negative (e.g., restricting tree removals) obligations of the owner granting the covenant.

6.3 Section Table of Contents Tree Bylaws


CENTRAL CITY
WINNERS

6.3 TREE BYLAWS

The *Community Charter* enables Council to "regulate, prohibit or impose requirements in relation to [...] trees" (sections 8(3)(c), 50 and 52). Regional and local planning processes increasingly identify tree protection and replacement as important community values. While environmental DPAs often provide adequate protection for tree stands and ecosystems, tree bylaws serve to regulate the protection or replacement of individual trees or groups of trees found across the municipal landscape.

While there are established best practices for some bylaw components, others are less well-defined. The alternatives and options available should be selected after consideration of a municipality's urban forest governance context.

The following sections are organized in typical bylaw sections or themes. Each section describes the key components that should be considered when developing tree bylaws and highlights when a best practice recommendation or an alternative option would be relevant. Examples of communities that have used any of the approaches presented are not exhaustive but provide readers with further opportunities to explore and adapt the options that are most appropriate for their local context.

6.3.1 Bylaw Definitions

Bylaw definitions set a common understanding for terminology used throughout the bylaw. Many bylaw definitions refer to established technical standards and clarify how to interpret other sections of the bylaw.

6.3.1.1. Protected Tree

PURPOSE | To define what trees the bylaw applies to. Public or private trees (or both), tree size and species are common criteria discussed. The definition itself does not drive the protection or replacement outcomes; tree protection rather depends on the acceptable reasons for removal and the replacement requirements.

MUST HAVE: PROTECTED TREE SIZE

Tree bylaws need to identify the size of trees that the bylaw will apply to:
* Option 1: Small trees
* Option 2: Medium trees
* Option 3: Large trees

OPTION 1: SMALL TREES (for example ≥6 cm DBH)

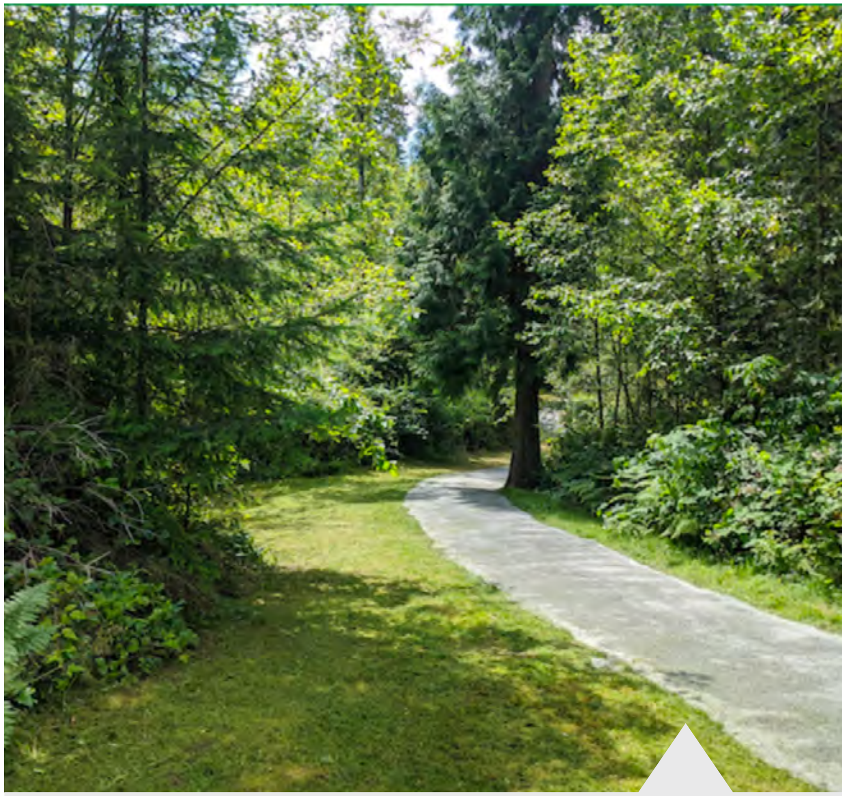
Communities may decide to regulate trees at a small size when the bylaw is less restrictive of tree removals and is using the permit system to track tree removals or is restrictive only under certain circumstances (e.g., limits removals in one year or when related to a subdivision). This could be used in conjunction with other categories of protected trees that have greater restrictions on their removal.

Context
This approach may be most relevant for municipalities interested in tracking tree removals and not placing too many restrictions on the removal of protected trees.
Found in Nanaimo, Anmore, Québec City (QC)

Pros
- Regulates most of the trees and canopy in a municipality
- Provides a good indication of the rate of tree removals
- Can identify and encourage retention of young trees that are more adaptable to development disturbances, with development

Cons
- Creates very high permit volume unless there are exemptions allowing removals in some circumstances (e.g., a certain number of trees being cut without a permit each year)
- May not be supported by the community without allowances to remove some trees
- Creates higher costs for development related applications to survey many trees and prepare management plans
- It is not usually practical to restrict removals or require replacements for small trees so often the bylaw functions more as a permit to track removals

This option may be best implemented with additional protected tree definition options, to restrict the removal of specific trees of importance.



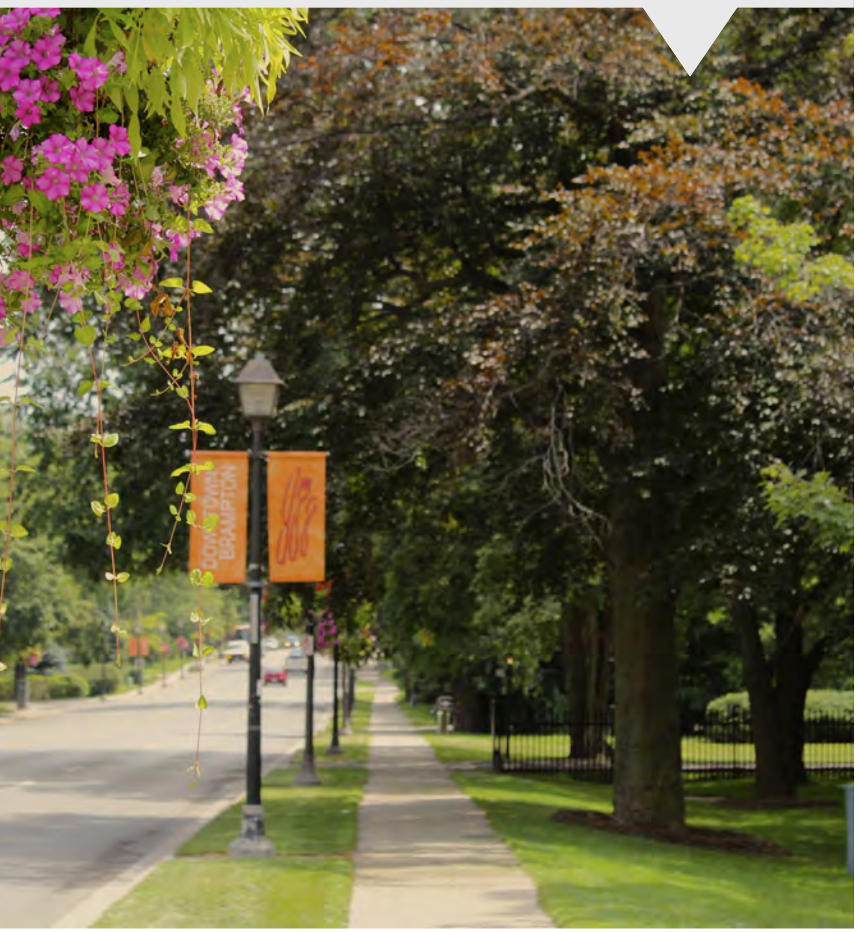
In practice

The Village of Anmore requires a tree cutting permit for all trees 10 cm or larger in DBH if the number removed is greater than annual allowable cut and not in direct hazard or conflict with infrastructure.

Hedges, alder and cottonwood are exempt from the definition.

In practice

Brampton does not require permits for trees with a DBH less than 30 cm.



OPTION 2: MEDIUM TREES (for example ≥20 cm DBH)

The tree bylaw applies to medium-sized trees, which enables municipalities to regulate reasons for removal and replacement requirements for those trees.

Context
Medium-size protected trees are the most common in Lower Mainland tree bylaws. This size class may be most appropriate for communities that are fairly urban and where most properties have few trees. Alternatively, it may be appropriate in communities that have many trees and where the bylaw is not restricting tree removal but is using the permit system to track removals.

Most commonly 20 cm DBH *found in Burnaby, Delta, Richmond, Port Coquitlam, Vancouver, New Westminster, Maple Ridge, Abbotsford, Courtenay, Squamish*
30 cm DBH *found in Surrey, White Rock, Victoria, Brampton (ON)*

Pros
- Typically regulates more than half of the trees and canopy in a municipality
- Seems to be a practical size for the number of trees brought into regulation based on the large number of municipalities using either 20 cm or 30 cm DBH
- Results in more tree replacement in the landscape than a larger protected tree size, if tied to a replacement requirement

Cons
- Creates relatively high permit volume unless there are exemptions allowing removals in some circumstances (e.g., a certain number of trees being cut without a permit each year)
- Increases regulation on private property. Tree replacement requirements also tend to be higher, which is a cost to applicants and may not receive broad community support.

For communities using this protected tree size to monitor removals, this would be best implemented with other categories of protected tree that have greater restrictions on their removal. Municipalities choosing this protected tree size should also consider defining hedges and whether they are protected under the bylaw.

OPTION 3: LARGE TREES (for example ≥50 cm DBH)

The tree bylaw applies to large-sized trees, which enables municipalities to regulate reasons for removal and replacement requirements only for mature specimens of larger species.

Context
This approach may be most appropriate for communities with limited resources and low development pressure that want to prioritize protecting the largest, oldest trees.
Found in the District of North Vancouver, West Vancouver

Pros

- Typically regulates the large canopy trees in a municipality
- Associated with a low volume of permits, generally easy for the community to support because few trees are regulated

Cons

- Most of the urban forest is unregulated and can be cut without a permit
- Only regulates large trees that are relatively rare on properties, so may be perceived as a disincentive for having a larger tree on a property

In addition to defining the protected tree size, municipalities that require replacement trees as a bylaw requirement should protect replacement trees regardless of their size.

In practice

The District of North Vancouver defines large-diameter trees as 75 cm or greater.

In practice

Courtenay protects 6 species 0.5 m and taller in size.

ADDITIONAL OPTIONS | In addition to defining protected trees with a diameter size, several municipalities adopt tree protection or replacement requirements for other types of individual trees or tree stands of interest. These options become particularly relevant when a tree bylaw is permissive of removals because they offer a more targeted way to protect trees of special interest. Common categories of trees included in protected tree definitions are municipal trees, species of interest, trees on sensitive land, heritage or significant trees and hedges.

Municipal trees: Municipal trees must be protected and many communities choose to protect trees on public land through their tree bylaw, although they can also be protected under different bylaws. Regulating the protection of municipal trees in a tree bylaw can offer consistency and ease of access for information about tree protection on public and private land. However, some communities protect them in other bylaws such as a street and traffic bylaw or a parks and boulevard bylaw supported by a municipal tree policy.

Places where this approach is found*: Surrey, White Rock, Saanich, Victoria, Courtenay and many others*

Species of interest: Communities that want to maintain habitat value with tree species important to the local ecology may decide to include smaller trees of specific species to their protected tree definition. In these cases, the potential impacts of climate change on these species should be considered so that regulations enable replacement with species suitable to the future climate when necessary.

Trees on sensitive land: Communities may choose to protect trees located on sensitive lands defined by a mapped boundary or descriptive criteria, such as lands that:

- Are susceptible to flooding or erosion, or have unstable slopes or poor drainage
- Have special significance for animal, bird or plant life, including wetlands, forests and nesting areas
- Have cultural or historical significance
- Foster connectivity and biodiversity for flora and fauna
- Are adjacent to waterways

Places where this approach is found*: Saanich, Courtenay, Squamish, Mississauga (ON)*

Heritage or Significant trees: A municipality might choose to protect a specific list of trees when:

- Heritage trees have been identified in the community and owners have allowed trees to be placed on a register
- Specific qualities have been defined for trees (e.g., size, health, age, heritage, endangered, uniqueness) that will require a higher standard to be met to remove the tree – a set of criteria, nomination process and community board would typically be required to assess whether trees are significant

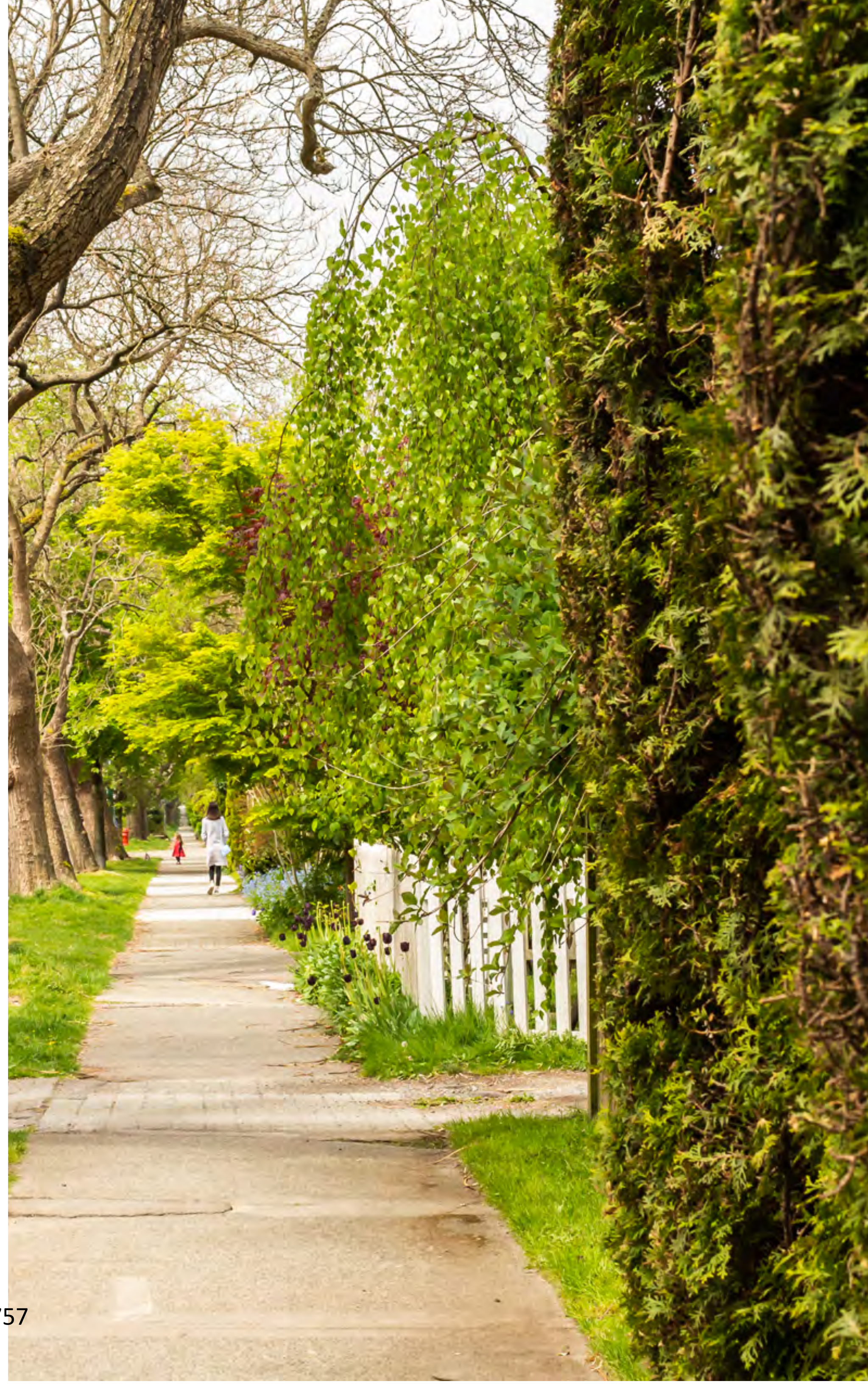
Places where this approach is found*: Maple Ridge, New Westminster, Surrey, Mississauga (ON)*

Hedges: Hedges can be challenging to regulate when they contain trees that meet the protected tree size definition because:

- All trees in a hedge grow up together and it may be appropriate to retain them or remove them as a group even if only one or some of the trees meet acceptable reasons for removal
- Hedges can contain many protected trees that, if approved for removal under a bylaw with a high replacement ratio, would have unreasonably high tree replacement requirements
- Hedges are often sheared and pruned in a way that would be considered damaging to a regular tree and so it can be necessary to distinguish regular maintenance of hedges from tree damaging activities that would be a violation of a bylaw

Once a hedge is defined, it can either be protected or exempted under the bylaw as a hedge, rather than as individual protected trees.

Places where this approach is found*: New Westminster*



6.3.1.2. Diameter at Breast Height

PURPOSE | A diameter at breast height (DBH) definition is typically used to indicate how to measure a tree and determine if it is a protected tree, to calculate the tree protection zone (see below) and sometimes to calculate replacement requirements.

MUST HAVE: Diameter at Breast Height Measurement

A measurable definition is a must have to consistently determine the DBH of a tree.

BEST PRACTICES FOR MEASURING DBH

The International Society of Arboriculture defines best practices for measuring DBH (Bond, 2013):

- For a 'typical' single trunk, DBH is found by measuring the diameter at 1.4 m above the ground[2]
- For a tree that branches out at or below 1.4 m, so that the diameter is smaller below 1.4 m, then the diameter is measured at the smallest point below the branching point
- For a multi-stemmed tree that branches between 1 and 1.5 metres, measure either:
  - The smallest point below the fork (Magarik, Roman, & Henning, 2020) or
  - Measure each stem 30 cm above the branching point and sum the result

Recent research recommends measuring multi-stemmed urban trees by taking the diameter measurement at 30 cm, or below the fork (Magarik, Roman, & Henning, 2020). The research found no significant differences between these and other multi-stemmed measurement methods, and that this approach was an improvement over other methods because of the ease of measurement, simplicity and repeatability.

[2] It is standard practice in forestry to measure DBH at 1.3 m (Husch, Beers, & Kershaw, 2003; Avery & Burkhart, 2002) and some bylaws use this height as the standard for measuring DBH.

6.3.1.3 Tree Protection Zone

PURPOSE | To define the area around a tree that must be protected to prevent damage to roots so that the tree can be successfully retained during construction, or to determine when a tree cannot be retained successfully.

MUST HAVE: Tree Protection Zone

A measurable definition is a must have to consistently determine the tree protection zone.

The International Society of Arboriculture's (ISA) best management practices for Managing Trees During Construction (Fite & Smiley, 2016) defines the tree protection zone as an arborist-defined area surrounding the trunk. It is intended to protect roots and soil within the critical root zone and beyond, to maximize future tree health and stability.

Typically, the tree protection zone is calculated using either a trunk diameter method or a dripline method. The ISA's best management practices and the American National Standards Institute A300 (Part 5) Standards refer to tree protection zone multiplication factors of between 6 x and 18 x DBH dependent on relative tree age and tolerance (based on Matheny and Clark, 1998, and the British Standards Institute) (Fite & Smiley, 2016). The American National Standards Institute A300 (Part 5) Standards state that the tree protection zone should not be less than 6 x DBH without mitigation measures. Australian and British Standards use a multiplier of 12 x DBH as standard. Best management practices for the Pacific
Northwest recommend using both 12 x DBH and dripline plus 1 m and selecting whichever is larger to define the tree protection zone (Oregon State University, 2009).

Based on the available best management practices guidance, it is recommended that municipalities consider defining the tree protection zone as:

- The area, on an approved plan prepared by an arborist, that shows the land surrounding the trunk of a protected tree expected to contain the bulk of the critical root zone of the tree, or
- In the absence of an approved plan, the area of land surrounding the trunk of a protected tree contained within a circle having a radius calculated by multiplying the diameter at breast height of the tree by 12 or dripline plus 1 m, whichever is larger

TREE PROTECTION ZONE VS. CRITICAL ROOT ZONE

The International Society of Arboriculture (ISA) defines the tree protection zone as an arborist-defined area intended to protect roots and soil within the critical root zone and beyond, whereas the critical root zone is the area immediately adjacent to the trunk where roots essential for tree health and stability are located.

The tree protection zone is used to inform the area around the tree that should be fenced during construction and should always be larger than the critical root zone; however, final fencing location is informed by professional judgment, species tolerances and site constraints that reflect where most of the roots are believed to be located on a site. For example, fencing would not block a sidewalk, or if a building existed within the tree protection zone, then the roots are less likely to be growing under the foundation and the fencing would be adjusted accordingly. If the tree protection zone is reduced on one or more sides, then increasing the tree protection zone on the opposite side may be appropriate (Fite & Smiley, 2016).

The ISA's best management practices for Managing Trees During Construction (Fite & Smiley, 2016) note that the critical root zone is subjective, they also note that regulations may choose to define it (e.g., the City of New Westminster defines the critical root zone as 6 x DBH). In the event that the tree protection zone needs to be temporarily reduced for a construction activity, the ISA best management practices note that the tree protection zone should not be reduced to an area smaller than the critical root zone.

While cutting roots within the critical root zone should always be avoided, there are instances when cuts may be required (e.g., sidewalk or utility repair). The ISA BMPs note that stability is compromised for some species when roots are cut at a distance of 3 x DBH (Fite & Smiley, 2016). However, an arborist must judge the proximity of cuts that can be tolerated and still allow the tree to remain stable.

6.3.1.4 Applicant or Application Type

PURPOSE | A definition of different types of applicants or applications is used when the requirements of the bylaw need to be differentiated.

RECOMMENDATION | Application types can be differentiated if a community wants to vary requirements such as the information required to assess the permit application (e.g., arborist report, tree survey, replacement plan, etc.), permit fees, replacement requirements, securities or cash-in-lieu according to the scale and complexity of the permit type.

DEVELOPMENT REQUIREMENTS IN LAND USE REGULATIONS AND DPAS

Requirements specific to development can instead be addressed separately in land use regulations or development permit area guidelines, in which case a tree bylaw would typically exempt tree cutting and removal approved under subdivision or development permits. It should be noted that regulating trees under multiple bylaws creates parallel processes that are usually administered by different departments; this approach requires careful coordination to ensure that the outcomes of each regulation are consistent with municipal objectives for the preservation of trees and growth of tree canopy.

6.3.1.5 Pruning

PURPOSE | To define acceptable pruning that can be carried out on a protected tree with or without a permit.

MUST HAVE: Acceptable Pruning

Describing acceptable pruning clarifies both enforcement and the public's understanding of what type of pruning is acceptable. The pruning definition should be in accordance with the most current version of the American National Standards Institute Publication "American National Standard for Tree Care Operations – Tree, Shrub, and Other Woody Plant Management – Standard Practices" and the companion "Best Management Practices" Series of the International Society of Arboriculture. Explicitly defining tree damaging activities, such as topping and excessive crown reduction, helps to clarify what is not acceptable pruning.

Bylaws do not always require a permit for acceptable pruning; however, if pruning is being regulated, then the pruning definition should define the size of limb requiring a tree permit, and only require that permit for protected trees.

PRUNING BEST MANAGEMENT PRACTICES

The ISA's Best Management Practices for Pruning (Lilley, Gillman, & Smiley, 2002) note that pruning dose is guided by the objectives of the pruning, and the tolerance of tree to loss of foliage. Objectives listed in the Best Management Practices include:

- Improving structure
- Risk mitigation
- Clearance
- Maintaining health
- Restoration
- Size management
- Improving a view
- Improving aesthetics
- Managing wildlife habitat
- Reduce density

Pruning systems described in the best management practices include natural, pollard, topiary, hedge, espalier, pleach and fruit (Lilley, Gillman, & Smiley, 2002).

6.3.1.6 Other Best Practices Definitions

Other definitions that may be useful to include are:

- **Arborist:** means a person holding a current certification of ISA Certified Arborist issued by the International Society of Arboriculture
- **Tree risk assessor:** means a person who holds the International Society of Arboriculture's Tree Risk Assessment Qualification (TRAQ)
- **Arboricultural best practices:** means practices in accordance with the most current version of the American National Standards Institute Publication, "American National Standard for Tree Care Operations - Tree, Shrub, and Other Woody Plant Management - Standard Practices" and the companion "Best Management Practices" Series of the International Society of Arboriculture
- **High or extreme risk tree:** means a tree that has, in the opinion of a Tree Risk Assessor, a high or extreme TRAQ risk rating
- **Qualified Environmental Professional:** means a person in good standing with a legislated self-regulating association in British Columbia who is acting within the individual's area of expertise and includes a professional Biologist, Agrologist, Arborist, Forester, Geoscientist, Engineer or Technologist

6.3.2 Exemptions

PURPOSE | Exemptions are used to enable certain groups or activities to proceed without a tree permit. Exemptions are needed when it would be impractical for a group to apply for tree permits given the frequency or volume of their work, or when other statutes give them the power to cut or remove trees. Exemption may include tree cutting or removal:

- For farming use
- Pursuant to the Hydro and Power Authority Act
- For Survey lines work pursuant to the Land Surveyors Act
- By the Government of Canada, the Province of British Columbia or Regional Government on their own properties
- By a public utility for the purpose of safety, maintenance or operation of the utility's service or infrastructure on their own properties
- By the municipality for works undertaken by the municipality on its own property

Some municipalities exempt their operations from the tree bylaw to enable a more efficient and adapted process to take place internally. Municipalities that exempt their operations from the bylaw should develop an internal policy that details the process to be followed by staff. This process should meet or exceed bylaw requirements. Research has shown that for local governments to be successful in preserving trees and growing canopy cover, they need to address those issues with good interdepartmental coordination (Ordonez & Livesley, 2020).

6.3.3 Prohibitions

PURPOSE | Prohibitions describe what is prohibited except when permitted in the bylaw and in accordance with the terms of a tree permit. Prohibitions typically include cutting, removal and damage, and often address requirements for compliance and accurate information.

RECOMMENDED: Damaging activities

Describing tree damaging activities provides clarity both for enforcement and for the public to understand what activities constitute damage. Just as with cutting or removal, there may be circumstances when tree damage is permitted in accordance with the bylaw and a tree permit. For example, cutting tree roots and altering the grade within a tree protection zone does damage the tree but may be required to accommodate a pathway. If the tree can tolerate the damage and still be safe to retain, then that damage could be allowed with a tree permit.

The definition of damage should be broad (e.g., any action that is likely to cause negative impacts to the health or structural integrity of a tree), but prohibitions, while not limiting that definition, can elaborate to include actions that could cause a tree to die or become hazardous such as:

- Pruning in a manner not in accordance with arboricultural best practice, including:
  - removal of more than 25% of the tree's total live foliage or bud bearing branches or limbs in any 12 month period
  - lift pruning where the lower branches of the live crown (green branches) of the tree are removed to reduce the live crown to less than 50 percent of the total tree height
  - topping, unless the tree in question has been previously topped and regenerative growth has a high likelihood of failure due to weak branch attachment, excessive branch elongation and end weight, or the formation of extensive decay or cavities that cannot be mitigated other than by re-topping the tree
- Poisoning or burning a tree
- Raising or lowering the grade within the tree protection zone
- Shearing, harming or undermining the roots of the tree growing within the tree protection zone
- Placing fill, building materials, asphalt, a building or structure or storing or stockpiling of material within a tree protection zone
- Operating, staging or parking trucks, backhoes, excavators, mini-excavators, hydro-excavators, mechanical trenchers or other heavy equipment within a tree protection zone
- Denting, gouging, drilling, harming or affixing anything to the branches or the trunk of a tree
- Removing bark from a tree
- Depositing concrete, washout or other liquid or chemical substances harmful to the health of a tree in a tree protection zone
- Removing soil from a tree protection zone
- Conducting blasting operations within a tree protection zone
- Conducting blasting or excavating operations outside of a protected root zone that would harm roots or disturb soil inside a tree protection zone

Describing tree damaging activities can improve enforcement by defining specific actions that would be considered a bylaw violation unless permitted in the terms of an approved tree permit.

6.3.4 Permitted Removal Reasons

PURPOSE | To define why a permit will or will not be issued to remove a tree. Describing the acceptable reasons for removal enables transparent and consistent decision-making by staff issuing tree permits. These reasons listed determine the strength of the bylaw in terms of protecting trees from removal.

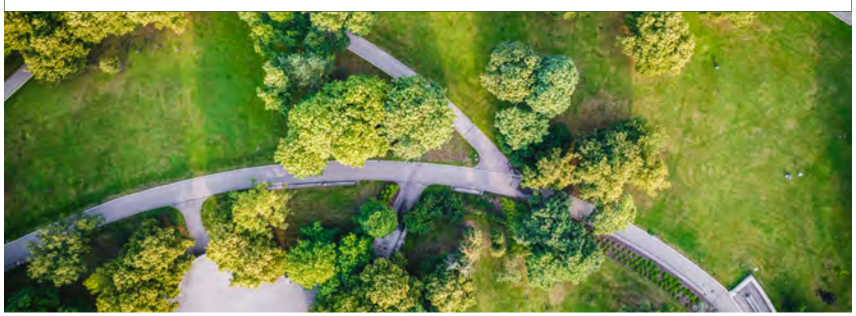
6.3.4.1. Risk, dead and dying trees

PURPOSE | To define why a permit will or will not be issued to remove a tree. Describing the acceptable reasons for removal enables transparent and consistent decision-making by staff issuing tree permits. These reasons listed determine the strength of the bylaw in terms of protecting trees from removal.

MUST HAVE: Dead, dying or high or extreme risk trees

The following reasons for removal must be enabled:

- Tree is high or extreme risk or has an imminent likelihood of failure and the risk or failure cannot be mitigated other than by cutting or removing the tree
- Tree is dead, or more than 50% of its crown is dead (or an alternative threshold that indicates when a tree would be accepted to be dying)



6.3.4.2. Conflict with Buildings or Structures

PURPOSE | To avoid conflicts that would sterilize development rights.

MUST HAVE:Conflict with principal or accessory buildings, off-street parking and utilities

A tree bylaw cannot sterilize development rights by preventing development to permitted use or density according to zoning. However, the extent to which applicants must modify designs or construction to retain trees can be controlled by reasons to permit removal. There are two ways in which communities choose to allow removals to enable permitted use.

- Option 1: **Tree can be removed to accommodate design**
- Option 2: **Design must be changed to accommodate trees if possible**

Option 1: Tree can be removed to accommodate design

Tree removal is permitted whenever protected trees are in conflict with buildings, parking or utilities proposed.

Context
This approach may be most suitable for municipalities with undeveloped/rural land within the Urban Containment Boundary where heavily treed lots are being subdivided in the wildland urban interface.

Pros
- Enables communities to focus on planting replacement trees in appropriate locations following development
- Reduces the potential impacts on development
- Is less resource intensive to implement than the alternative

Cons
- Will not often require trees to be retained during development

Option 2: Design must be changed to accommodate trees if possible

Tree removal is permitted only if it is not possible to retain the tree. Applicants may be required to make changes to their design to accommodate the retention of protected trees while still building to the current zoning.

Context
This approach may be most suitable for already developed and densifying municipalities and where the community places a high value on the preservation of protected trees. Communities using this approach should provide staff with additional guidance on what trees this would apply to and how to determine when it is not possible to retain the tree. This guidance may include criteria related to tree health and condition or safe useful life expectancy in the new site conditions.

Pros
- More often requires the retention of existing trees

Cons
- Results in greater impacts to development projects to accommodate tree retention
- Is more resource intensive for the municipality (longer applications review and interactions with applicants expected)

Note
Bylaws may distinguish between principal buildings and accessory buildings, off-street parking and utilities to require design changes only for some of those items.

TREE REMOVALS ON AGRICULTURAL LANDS

Municipalities in British Columbia cannot regulate tree removals that take place for farming use. However, some municipalities require affidavits from landowners to attest that the removals are for the purpose of farming. A tree bylaw can still apply to agricultural land when trees are being removed for non-farming uses, such as development.

Given the limitations for municipalities to regulate trees on agricultural land, communities with large proportions of agricultural land may instead consider implementing or promoting incentive and stewardship programs.

ADDITIONAL OPTIONS | Other common reasons to permit tree removals include wildfire risk, invasive species, yearly removal allowances, proximity to building foundations, infrastructure damage, construction access and trees on structures that require upgrades or replacement.

- **Wildfire:** Communities within the wildland-urban interface that manage wildfire risk through a Development Permit Area should ensure that the tree bylaw is consistent with FireSmart requirements, as detailed in their wildfire DPA. To ensure that wildfire risk management measures are appropriate, they should be guided by a Community Wildfire Protection Plan that defines high-risk areas, and a DPA that provides development guidelines for reducing risk in those areas. Measures to reduce risk may include conifer tree removal or pruning and FireSmart landscaping requirements.

- **Invasive species:** Communities may wish to enable the removal of invasive tree species that would otherwise be protected by their tree bylaw. Enabling the removal of invasive tree species may provide more consistency in municipalities that regulate or have policy related to invasive species. It should refer to specific lists or species from credible sources, such as the province of British Columbia or the Invasive Species Council.

- **Construction access:** Communities may consider allowing tree removals for trees located within the required construction access path, if the construction access cannot be modified to retain or avoid cutting the protected tree(s).

- **Proximity to building foundation:** Some communities choose to enable the removal of trees near building foundations. Enabling this can allow for poorly located trees to be removed and replaced by an appropriate species planted in a more suitable location. However, it could also lead to the removal of healthy trees that are not causing issues in some cases.

- **Infrastructure damage:** Some communities choose to enable the removal of trees that are causing or will imminently cause structure or infrastructure damage that cannot be mitigated other than by cutting or removing the protected tree. Implementing this option can allow for trees causing damage to be removed and replaced by an appropriate species planted in a more suitable location. However, staff will need additional guidance on determining when damage cannot be mitigated and the bylaw should enable the option to require a qualified environmental professional (e.g., professional engineer) or arborist provide an opinion on whether or not the damage can be mitigated other than by cutting or removing the tree.

- **Yearly removal allowance:** Communities sometimes elect to include an annual allowance of trees that can be removed for any reason. If considering such an allowance, it should be limited by factors such as tree density, tree size, zoning, lot size or a combination of them; those limits would prevent progressive clear cutting while providing flexibility to manage numerous trees on forested lots.

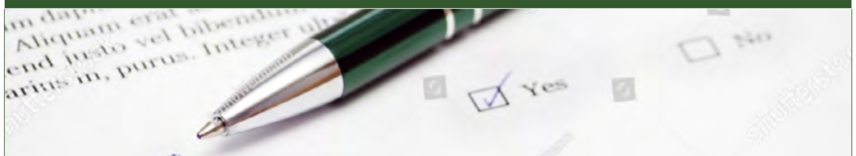
- **Trees on structures:** Communities that have trees planted on structures (i.e., above parkades or on roof-tops) may consider enabling the removal of trees for repairs to the structure.

6.3.5 Permit Application Information Requirements

PURPOSE | To enable staff to determine whether a permit application meets the bylaw requirements to issue a tree permit.

MUST HAVES | At a minimum, basic information should be required with every permit application.

BASIC PERMIT INFORMATION REQUIREMENTS



All permit applications must be accompanied by:

- The address and legal description of the lot/s
- Proof that the owner, or an authorized owner's agent, is submitting the application
- Written consent from the adjacent property owner that they support the application, where a tree shared between two properties is proposed for removal
- Reasons why the applicant is applying to cut or remove a protected tree
- A description and map/plan drawing of the protected trees included in the application

RECOMMENDED FOR DEVELOPMENT: Information requirements for all applications related to development*

Tree bylaws should provide clear information requirements, particularly for applications related to development. They should require sufficient and consistent information to enable staff to review permit applications efficiently.

Development-related applications are complex. Accurate information about trees is needed to understand which trees can be safely and effectively retained, and which trees need to be removed. Non-development-related permit applications can also sometimes require more information, for example, when a tree is proposed for removal because of risk and a tree risk assessor's opinion is needed. For these reasons, it is recommended that the bylaw enable staff to request when needed:

- A legal survey identifying the location of existing trees accurately.
- An arborist report and inventory detailing the location and condition of protected trees and trees proposed for removal.
- A risk assessment report from a tree risk assessor confirming that a tree is high risk if the application entails removal or cutting of a high risk tree.
- A tree management plan mapping the location of protected trees, their tree protection zones, recommended protection measures, location of tree protection fencing and trees proposed for removal.
- A replacement tree plan mapping the location and species of replacement trees to be planted. Build in the need to have these reflected in all landscape plans or at least cross referenced in the landscape plans.
- Additional information from qualified environmental professionals when sensitive lands are involved, for example, to assess impacts of removing trees in riparian areas or steep slope areas.
- A tree fencing confirmation letter from an arborist confirming that protective fencing has been installed per an approved tree management plan.
- A letter of assurance from an arborist, signed by the owner, to specify construction activities requiring arborist supervision to prevent and mitigate damage.

Terms of reference for these information requirements can be included in schedules or standard operating procedures.

***Tree bylaws should also enable staff to require or relax some of these additional requirements on an as needed basis.**

Municipalities can ask for a confirmation that a permit application is consistent with provincial and federal laws, for example require a Bird Nesting Survey for tree removals proposed during the nesting season.

6.3.6 Requirements and Incentives for Tree Retention and Replacement

Replacement requirements determine how protected trees are replaced when they are removed. There are numerous approaches to tree replacement. The appropriate choice should be tied to meeting the community's goals for tree preservation and growth.

6.3.6.1. Replacement Requirements – Achieving Successional Replacement

PURPOSE | To achieve successional replacement by defining the number of replacement trees required for every protected tree removed. Ratios are not generally effective for increasing the number of trees and growing tree canopy in low-canopy areas because they only require planting on properties that already have trees.

MUST HAVE: Replacement ratio

A replacement ratio can be consistently applied to require that each tree removed is replaced. This approach would require applicants to replace every protected tree removed with one or more replacement trees.

- Option 1: **1:1 or 2:1 replacement ratio**
- Option 2: **1:many replacement ratios based on diameter of tree removed**

Option 1: 1:1 replacement ratio with large trees (2:1 if small trees)

Context

A municipality might choose 1:1 or 2:1 replacement ratio when:

- Properties have limited space for additional trees and a higher replacement ratio would typically result in over-crowding
- The bylaw incorporates requirements to meet soil volume and spacing standards that will maximize the survival and growth of replacement trees
- The bylaw prioritizes replacement with a large tree species but provides flexibility to replace with smaller trees if the site is constrained
- It is coupled with other approaches to encourage or require canopy growth

***Found in**: Vancouver, Victoria*

Pros

- Encourages large tree species replacement and healthy growing environments
- Enables most properties to replace a tree in the space created by the tree removed
- Does not penalize properties that already have trees by requiring even more trees as replacements when a tree is removed

Cons

- Does not replace tree canopy removed as quickly as a higher replacement ratio.
- Does not increase the number of trees or grow tree canopy in low-canopy areas. It cannot be used to meet canopy cover targets.

Option 2: 1:many replacement ratios based on diameter of tree removed

This approach would require applicants to replace every protected tree removed with multiple replacement trees.

Context
The 1:many replacement ratio would be most appropriate for communities that have lots of space for more tree planting.

Found in: *White Rock (ranges from 2:1 to 6:1), Courtenay (3:1 if below density target), Saanich (2:1 or 3:1 removals for roads/services), Squamish (2:1 to 6:1 for significant trees, up to density target), Abbotsford (2:1 or 3:1), Oakville (1:1 to 1:12 based on size of tree removed)*

Pros
- Enables instant replacement of more of the tree canopy removed

Cons
- To properly compensate for the canopy removed, many more trees may be required than would be practical or reasonable to require as a replacement ratio (Nowak & Aevermann, 2019).
- Urban properties are often unable to fit multiple replacement trees without overcrowding and poor planting location choices, likely leading to more failures and removals in the future.
- Creates an incentive for people to plant small trees or hedges to try and fit replacements on their property, which is at odds with canopy cover goals.
- Penalizes properties that have more trees by requiring them to replace even more trees on their properties, while having few requirements for properties with few or no trees.
- Does not increase the number of trees and grow canopy in low-canopy areas. It cannot be used to meet canopy cover targets.

USING 1:MANY REPLACEMENT RATIOS TO ACHIEVE CANOPY GROWTH

While tree bylaws may attempt to achieve canopy growth through the implementation of higher replacement ratios, this practice is not recommended. When replacement ratios are high, either the trees are disadvantaged by being crowded into inadequate growing space and never reaching healthy maturity, or the applicant is disadvantaged by paying a large sum in cash-in-lieu. Another unintended consequence of high replacement ratios is that they penalize properties with more trees by requiring high replacement or cash-in-lieu and reward properties with few or no trees by imposing few requirements when they re-develop.

6.3.6.2 Replacement Requirements – Achieving Canopy Growth

PURPOSE | To require that every property meets a minimum tree or canopy cover target.

MUST HAVE: Minimum Target
A target can be measured and consistently applied to each property. There are two main approaches to growing tree canopy using tree bylaws in Canada and tree ordinances in the United States: • Option 1: **Tree density target** • Option 2: **Canopy cover target**
Option 1: Tree density target
The tree density target approach establishes a target number of trees per unit area that applicants are required to achieve after the tree removal takes place. **Context** A municipality might choose tree density target when: • The density of trees is targeted towards meeting a canopy cover goal that has been established for the community • The municipality wants to increase canopy in low canopy locations by requiring properties with few or no trees to meet the density target with development • The municipality is rural and is allowing some tree removals but wants to limit the extent of removals permitted per property (e.g., under an annual removal allowance) ***Found in****: Maple Ridge, Courtenay, Gatineau (QC)* **Pros** • Effectively increases the rate of tree planting across the community, even on properties that have few or no trees • Evens out the requirements across the community so that all properties have to contribute to meeting the target • Neutralizes the perception of a penalty for having trees on a property that occurs when tree bylaws only include replacement ratios for tree removed. • Can establish a relationship between tree density and canopy using tree canopy data **Cons** • Adds another replacement requirement to calculate on top of a ratio • Must be calculated, which is simple when an arborist report is required with development, but staff may otherwise have to assist applicants when non-development applications allow tree removals down to a minimum tree density **Best implemented with** differentiation for meeting the requirements during development versus non-development contexts. If an annual removal allowance is in place, it may be necessary to protect trees that are of particular importance to the community such as species of special interest, significant or specimen trees to prevent their removal under the allowance.

Option 2: Canopy cover target

The canopy cover approach establishes a canopy cover target that applicants must achieve on the lot after the tree removal takes place. The canopy area retained on site is measured and if the canopy target is not met then the shortfall is met by planting replacement trees. A replacement tree list defines a canopy area credit for small/medium/large tree species. Applicants plant the number of replacement trees that add up to the canopy area required to meet the target on site. The canopy cover target approach is used in Oak Bay and in several tree ordinances in the US to calculate replacement requirements.

Context

A municipality might choose a minimum tree canopy cover target when:

- The canopy cover target(s) set in the tree bylaw can work towards meeting a canopy cover goal that has been established for the community
- The municipality wants to increase canopy in low canopy locations by requiring properties with few or no trees to meet the canopy target with development
- The municipality is rural and is allowing some tree removals but wants to limit the extent of removals permitted per property (e.g., under an annual removal allowance)
- The community has many existing large canopy trees that overhang properties and wants provide incentives to protect and maintain offsite trees

Found in*: Oak Bay, Anmore, various US municipalities (e.g., Baltimore MD, Lake Forest Park WA, Fort Worth TX)*

Pros

- Effectively increases the rate of tree planting across the community, even on properties that have few or no trees
- Evens out the requirements across the community so that all properties have to contribute to meeting the target
- Neutralizes the perception of a penalty for having trees on a property that occurs when tree bylaws only include replacement ratios for tree removed.
- Relates directly to meeting canopy cover goals
- Reduces properties replacement requirements when canopy overhangs their property, which provides incentives to retain and protect offsite trees during development

Cons

- Adds another replacement requirement on top of a ratio
- Must be calculated and is more complex to calculate than tree density
- Must assume a relationship between species and typical canopy outcomes to simplify calculations for replacement requirements, so that replacement species can be credited for a certain amount of tree canopy at maturity

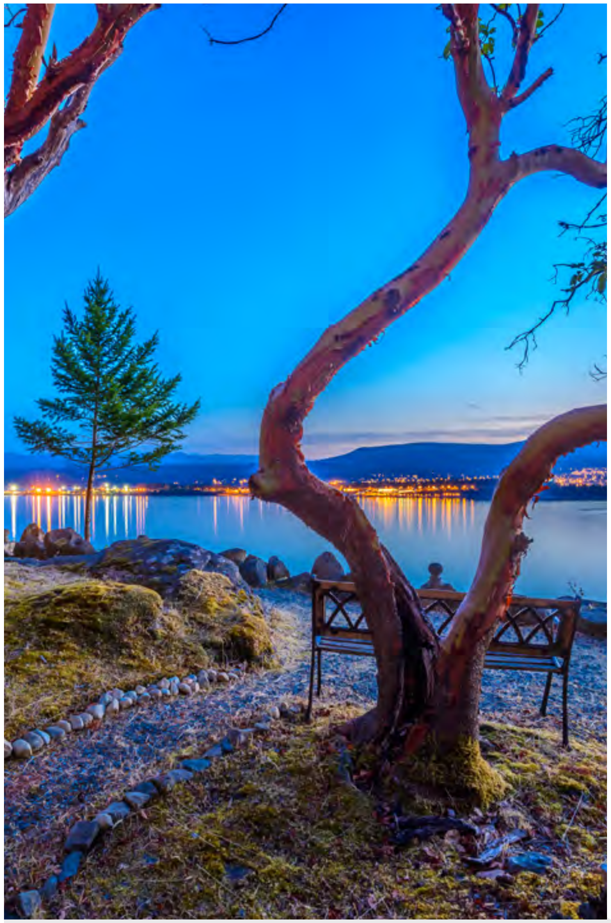
Best implemented with differentiation for meeting the requirements during development versus non-development contexts. If an annual removal allowance is in place, it may be necessary to protect trees that are of particular importance to the community such as species of special interest, significant specimen trees to prevent their removal under the allowance.

In practice

The City of Courtenay implements a tree density target of 50 trees per net developable hectare. This means most single-family properties require 3-4 trees.

In practice

The District of Oak Bay uses a canopy cover target approach when the owner of a parcel applies for a building permit. The canopy target varies by zone and ranges from 50% for Community Institutional Zoning to 20% for Multi Unit Residential.



In practice

In Nanaimo, cash-in-lieu is capped at a maximum per hectare value.

6.3.6.3 Cash-in-lieu

PURPOSE | To fund tree planting elsewhere on public or private property.

MUST HAVE: Cash-in-lieu

A dollar amount that applies consistently and is adequate to cover the cost of planting and establishing trees.

Cash-in-lieu enables municipalities to collect funding to plant replacement trees. To be effective, cash-in-lieu should cover the cost of replacing the trees.

Context

A municipality might choose to have a cash-in-lieu option when:

- Properties have limited space for replacement trees
- Infill development or higher site coverage development is limiting opportunities for tree planting on site post development
- If coupled with a minimum tree density or canopy target, it is used as a means of every property contributing to a canopy cover goal either by planting tree on site or by funding planting elsewhere

***Commonly Found in**: Bylaws that implement replacement requirements, for example in White Rock, Surrey, Vancouver, Township of Langley, Nanaimo, Oakville (ON)*

Pros

- Funds tree planting or enhancement towards growing canopy cover in the municipality
- Can fund stewardship efforts to encourage private land planting and tree maintenance

Cons

- Can become very costly if a 1:many replacement ratio is in place and effectively penalize properties with more existing trees
- If set too low, or enabled as a choice, then people may opt for cash-in-lieu instead of replacing trees

ADDITIONAL OPTIONS | Municipalities may wish to consider the additional options for managing replacement requirements that are species- or location-based, for dead or high or extreme risk trees, or credits to reduce the requirements.

Species based replacement*

A municipality might choose to add species-specific replacement requirements to:

- Require specific species of trees for the replacements of species of interest or native species in sensitive areas (e.g., like for like replacement)
- Reduce replacement requirements for fast growing species that tend to volunteer (e.g., alder or cottonwood) when a 1:Many ratio applies otherwise

*Future species suitability as a result of climate change should be considered when setting species-specific replacement requirements.

Location based replacement

A municipality might choose to define location based replacement requirements to:

- Require specific species of trees or replacement ratios for sensitive lands
- Require different replacement requirements for municipal trees

Exclusion of dead or high or extreme risk trees

- A municipality might choose to exclude dead or high or extreme risk trees to avoid discouraging owners from applying for a removal permit

Incentives for tree retention

A municipality might choose to reduce an applicant's replacement requirements if they retain certain trees on site (e.g., large, healthy trees). Credits can function as an incentive for tree retention when they meaningfully reduce the number of additional trees that must be planted on site. Some bylaws allow non-protected trees to be counted as replacement trees.

Other incentives such as a reduction in permit fees could help incentivize tree retention, or a reduction in securities could help incentivize redesign or implementing protection measures around retained trees.

In practice

The City of New Westminster reduces the retained tree securities by 50% for applicants that agree to modify a design to retain protected trees.

STEWARDSHIP AND INCENTIVES

In addition to or as an alternative to replacement tree planting for successional replacement or canopy growth, communities should consider stewardship and incentive programs to encourage tree planting and stewardship on private land.

- **Subsidised tree sales:** many municipalities in the region hold subsidised tree sales for their residents to encourage tree planting.
- **Adopt-a-tree programs:** some municipalities implement programs where residents are invited to water new street trees.
- **Citizen science programs:** such programs can support data collection for urban forest management. For example, the City of Melbourne's Citizen Forester Program recruits volunteer community members to help collect data on many urban forest components. The City has also led a genetic sampling program to learn about the genetic diversity of elm populations in the city, collect observations on pollinator species or carry out habitat planting.
- **Stormwater utility:** The City of Victoria charges a stormwater utility to property owners that offers incentives for properties that manage a stormwater more sustainably. The utility's rainwater rewards program credits on-site rainwater management installations that enable rainwater storage or infiltration.

6.3.7 Replacement Tree Planting Standards

Planting standards serve to guide applicants in the planting of replacement trees to maximize the establishment success of those trees.

6.3.7.1 Species list

PURPOSE | A species list can be used to encourage climate and site appropriate species choices.

RECOMMENDED: Species List

Species lists should:

- Be a list of approved species that is a schedule of the bylaw, or a list published online, but that allows flexibility for updates and for professionals to submit an alternative for approval
- Be large enough to support meeting diversity targets for urban tree species
- Include proven species (native and non-native) that are suitable for current and future climate

6.3.7.2 Spacing and soil volume

PURPOSE | Prescribing minimum spacing and soil volume requirements will ensure that trees have adequate space to grow.

RECOMMENDED: Spacing and soil volume

Requirements should include:

- Replacement trees should be planted at least 2 m away from a building foundation wall (or more for larger tree species), at least 1 m away from any property line of a lot, above and at least 1 m away from an underground utility, driveway or other paved surface, and in an approved location
- Minimum spacing from existing trees and other replacement trees should be set at 2 m for small trees, 4 m for medium trees and 6 m for large trees
- Soil volume required for replacement trees should be estimated based on canopy size at maturity

BEST PRACTICE TO CALCULATE SOIL VOLUME

TREE SIZE	Min soil volume (m^3)[4]	Shared or irrigated soil volume (m^3)
Small tree canopy spread is up to 6 m	8	6
Medium tree canopy - spread is up to 10.0 m	20	15
Large tree canopy - spread is greater than 10.0 m	35	30

Credit soil volume according to actual content of soil:

- Soil: Volume of soil (Length x Width x Depth)
- Soil cells: Volume of soil cell installation (Length x Width x Depth) x 0. 92
- Structural soil: Volume of structural soil (Length x Width x Depth) x 0.2

[4]0.3 m^3 minimum soil per 1 m^2 of crown projection based on Lindsey and Bassuk (1990).

6.3.7.3 Stock and planting standards

PURPOSE | Stock and planting standards are meant to maximize the chance of survival of replacement trees to maturity.

RECOMMENDED: Stock and planting standards

Requirements should include:

- Replacement trees must meet requirements set out in the latest edition the Canadian Nursery Trades Association "Canadian Standards for Nursery Stock"
- Define the size of planting stock that is acceptable (often 6 cm caliper for deciduous and 2 m height for conifer) but may be smaller for non-development tree permit applicants
- Define the acceptable timing of planting based on local planting season

6.3.8 Actions on Site

Actions on site are steps that applicants must take as a condition of a tree permit.

6.3.8.1 Tree protection measures

PURPOSE | To prevent damage when a tree permit is being issued with a development related permit where trees being retained.

RECOMMENDED: Fencing measures

Fencing requirements should include:

- A standard tree protecting fencing detail as a schedule in the bylaw.
- Signage indicating that the fencing is for tree protection. Signage could include contact information for the project arborist and a dollar value associated with the tree to indicate the cost of damage.
- Fencing should remain in place for the duration of the construction work.
- Removing fencing should be a violation of the bylaw except when part of an activity approved by the tree permit and under the supervision of an arborist.

RECOMMENDED: Supervision measures

If activities are occurring close to trees such that fencing needs to be removed or absent, then arborist supervision of the activities is an alternative method to prevent or minimize damage. Supervision requirements should include:

- A letter of assurance from the owner and arborist to define activities that will be supervised by an arborist, and supervision should be documented
- Documented supervision by the arborist of any planned works within the tree protection zone, pre-construction tree pruning, post-construction assessment or any other activities defined as requiring supervision

RECOMMENDED: Alternative measures

When tree protection fencing cannot be installed or maintained at the recommended distance, alternative tree protection measures (Fite and Smiley, 2016) may include:

- Mulching (15-30 cm)
- Laying minimum ¾ inch (2 cm) plywood, beams, commercial logging or road mats, on ground or over a 10 cm layer of mulch (on fabric to enable easier removal)
- Applying 10 – 15 cm of gravel over a taut, staked, geotextile fabric
- Protecting the trunk with wood planks on a closed-cell foam pad bound with straps or wire (no fasteners into the tree)
- Irrigation
- Any other measures defined to protect trees on site

6.3.8.2 Notification and marking

PURPOSE | Posting a notice of impending tree removals and marking trees to be removed lets the public know that an approved tree removal is taking place.

RECOMMENDED: Notification and marking

Requirements should include:

- A notice to post, similar other permits types (e.g., building permits), provided with the approved permit
- Trees to be removed be marked with flagging tape or survey paint

6.3.9 Securities

Securities are used as refundable deposits to guarantee that an applicant will follow through with actions required by a tree permit.

6.3.9.1 Securities for tree retention

PURPOSE | To guarantee that an applicant will follow through with tree protection measures that are conditions of the tree permit related to a development application.

RECOMMENDED: Tree retention securities

Securities must be determined using a method that can consistently calculate the security amount and be of a sufficient amount to deter bylaw infractions while still being affordable in the context of the project being undertaken.

It is recommended that securities:

- Be a set value for trees or categories of trees (e.g., value by diameter class)
- Be capped at a maximum value to avoid securities being unaffordable
- Incorporate flexibility to waive the security for on site trees that are not at risk of damage
- If applied to municipal trees, incorporate flexibility to be valued according to the Council of Tree and Landscape Appraisal Formula in addition to the cost of removal and planting
- Be returned upon final completion and confirmation by an arborist that the tree was protected as required in the permit, and supported by documentation of arborist supervision of any activities described in a letter of assurance
- Be transferred to a dedicated reserve fund for tree planting if forfeited, as opposed to general revenues

Context

Any community requiring tree protection measures may benefit from retention securities. However, municipalities will require sufficient staffing to manage securities.

Found in*: Surrey, New Westminster, White Rock, Courtenay (at Director's discretion)*

Pros

- Functions to guarantee the applicant and arborist follow through on protection and supervision measures for retained trees
- Requires evidence of compliance from the project arborist to reduce staff enforcement
- Provides another compliance tool in addition to penalties

Cons

- Increases the administration requirements of tree bylaws, with securities having to be calculated, held and then returned pending approval of documentation provided
- Requires applicants to provide cash or a letter of credit for the duration of the project

Variation

- **Amenity value-based** replacement securities, where trees are valued according to the Council of Tree and Landscape Appraisal Formula
- **Applicant/application type-based** tree retention securities typically require large sums to be held for larger development contexts in order to encourage compliance while avoiding burdening applicants for smaller works permits

Securities are best implemented with a requirement for arborist supervision and letters of assurance that can provide staff with evidence that work was carried out according to the requirements.

In practice

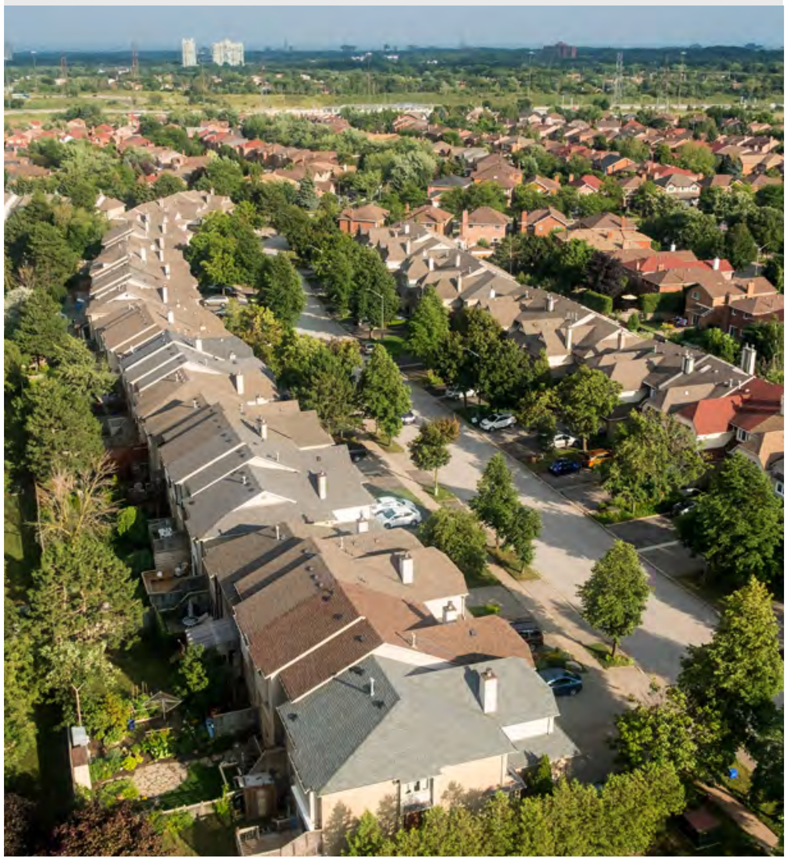
New Westminster's retained tree securities vary by size; the security for a protected tree is $2500 and greatly increases for a retained specimen tree, which is set at $10,000.

6.3.9.2 Securities for tree replacement

PURPOSE | To guarantee that an applicant plants and maintains replacement trees that are conditions of the tree permit.

In practice

In Mississauga, a tree replacement security deposit is determined on a case-by-case basis by the City.



RECOMMENDED: Replacement securities

Securities must be determined using a method that can consistently calculate the security amount and be of sufficient value to incentivize the planting of replacement trees.

It is recommended that securities:

- Be set at an amount that covers the cost of replacing a tree and maintaining it to establishment
- If cash-in-lieu is enabled, be set at an equivalent value for applications related to development
- Despite the previous points, if there is a 1:many replacement ratio or the cash-in-lieu amount is high, replacement securities can be modified to a type of applicant or application to avoid burdening non-development applicants
- Be returned once a tree has been planted and has survived for a set period of time

Context

Any community requiring tree protection measures may benefit from retention securities. However, municipalities will require sufficient staffing to administer securities.

***Found in**: Delta, Surrey, Vancouver, Abbotsford, Victoria, Mississauga (ON)*

Pros

- Incentivizes the applicant to follow through with planting and maintaining replacement trees
- Provides another compliance tool in addition to penalties

Cons

- Increases the administration requirements of tree bylaws, with money having to be calculated, held and then returned pending approval of documentation provided
- May require an additional inspection point at the end of the security period

Cash-in-lieu and replacement securities should be equivalent amounts to simplify enforcement by enabling the municipality to retain securities without having to fine applicants to recover the balance amount for cash-in-lieu.

COMPLIANCE WITH REPLACEMENT TREE PLANTING

A recent report from the University of Toronto (Conway, Khatib, Tetreault, & Almas, 2021) reviewed the level of compliance for replacement tree planting requirements in the City of Toronto. A survey sent to homeowners who received a tree removal permit found that 70% of respondents had complied with their permit's replacement tree planting requirement. The researchers conducted site visits and found a very high short-term survival rate for trees planted. The highest survival rate was for trees planted by professionals. The species planted where not all adequate for the local climate and were occasionally misreported to the City. Researchers concluded that an inspection would increase compliance and improve documentation on the replacement trees planted. They also suggested that species guidance and professional tree planting would improve the replacement planting outcomes. Authors also noted the importance of tracking and record keeping systems at the municipal level to enable adequate follow-up and the promotion of compliance.

ADDITIONAL OPTIONS | In order to ensure that replacement plantings take place, municipalities may wish to consider additional options to encourage tree replacement:

1. Enforcement is used as an alternative to securities in some municipalities such as Richmond in order to ensure that replacement planting is carried out as intended. To be as effective as securities, enforcement requires sufficient resources to carry out proactive inspections.

2. Stewardship measures can be used to encourage the planting of replacement trees, such as the municipality providing a free or low-cost replacement tree. Stewardship measures are usually perceived in a more positive light by the public and make replacement tree planting more accessible to applicants with lower incomes. However, such measures come at a cost to the municipality and should be supported by adequate budgets.

   Note: bylaw fees, cash-in-lieu or transferred securities collected in a reserve fund could be set up to support residents with tree care and planting on private land.

6.3.10 Penalties

PURPOSE | Penalties seek to deter bylaw infractions and require remedial measures.

MUST HAVES: Long form prosecution

Tree bylaws should enable municipalities to make use of the Offence Act and fines to penalize bylaw infractions.

Municipalities can enforce their tree bylaws with the long form information process under the provincial Offence Act. The Act provides municipalities with the ability to enforce penalties up to $50,000 if they do not have established penalties (as described under municipal ticketing) or for enforcing major bylaw contraventions.

MUST HAVES: Municipal ticketing

Municipalities can set up fines for tree bylaw infractions for specific minor to medium contraventions. **The Municipal Ticket Information system** enables municipalities to enforce and prosecute contraventions to tree bylaws through infractions listed in a Municipal Ticketing Bylaw. Penalties cannot exceed $1,000 but multiple fines can be issued for damaging a single tree if multiple infractions apply.. Tickets that are disputed go to provincial court.

The Bylaw Notice Adjudication System enables municipalities to establish an administrative system as an alternative to the provincial court for resolving minor local government bylaw contraventions. Local governments may join together to administer a bylaw notice system jointly to cover a broader geographic area more cost-effectively. Penalties cannot exceed $500.

ADDITIONAL OPTIONS | In addition to enabling the use of available enforcement mechanisms, municipalities may wish to consider additional measures to provide themselves with further options to enforce their tree bylaw, including stop work orders, securities transfer and replacement tree requirements.

Stop work orders

Municipalities can use stop work orders to interrupt work that is causing damage to retained trees until remediation measures are taken. This measure should only be used in situations where irremediable damage is being caused, where it may offer an effective solution to stop such damage when it is occurring.

Securities transfer

Municipalities could consider including provisions within their tree bylaws to automatically transfer unclaimed securities to their reserve funds after a set period of time. Including such a provision may offer more clarity and transparency to staff and applicants as to the expected process and timeline to comply to permit conditions before securities are transferred.

Requiring replacement trees

Some municipalities require people found to be in violation of the bylaw to plant replacement trees as a means of enforcement. This approach may be helpful in cases where applicants removed trees without knowledge or understanding of the tree bylaw requirements. It may however prove challenging to enforce in cases where applicants were purposefully tying to evade the bylaw and are not interested in planting trees on their properties. In such cases, fines may be a better way to recover funds to plant elsewhere in the municipality.

6.3.11 Tree Bylaw implementation

Practitioners surveyed for this project in the fall of 2020 highlighted the importance of the implementation process for creating an effective regulatory environment that balance canopy preservation and growth with competing priorities. Findings of the literature review further emphasize the importance of several factors beyond the bylaw content that will significantly impact urban forest outcomes.

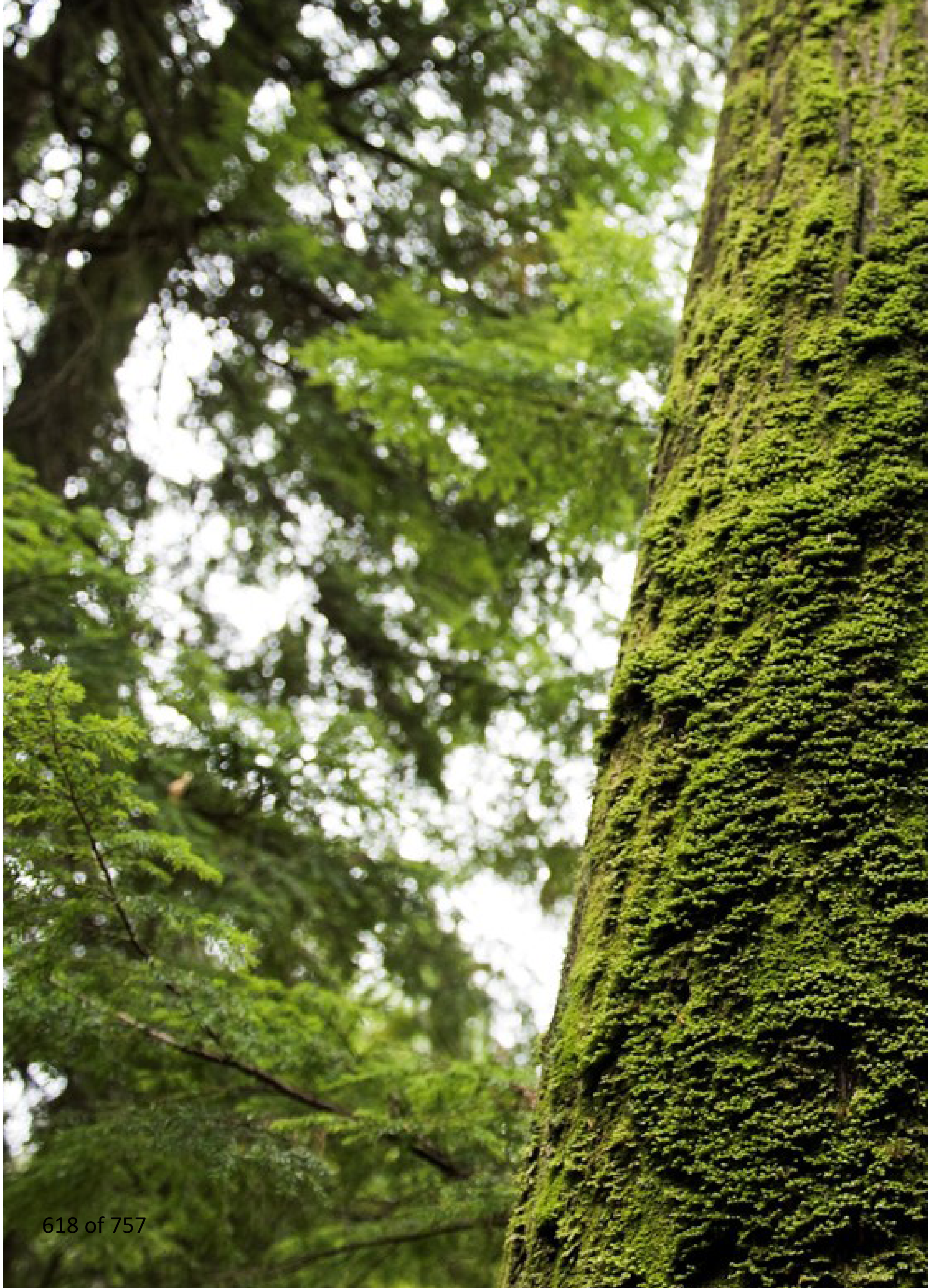
Bernhardt and Nichols propose seven implementation criteria for effective tree ordinances (Bernhardt & Swiecki, 2001; Nichols, 2007). These criteria are discussed in detail in the literature review and align closely to many of the comments compiled in the practitioner survey. The criteria include:

- **Clearly stated goals**: Describe the capacity of the bylaw to achieve certain goals with clear connection to any wider management strategies. Goals are essential to interpret the bylaw and evaluate its effectiveness.
- **Designated responsibility**: Assign authority of a single person responsible for bylaw implementation.
- **Basic performance standards**: Designate best management practices and standards to guide the bylaw whenever possible.
- **Flexibility**: Allow for site-specific decisions to be made by arborists and qualified environmental professionals on a case-by-case basis when appropriate. An appeal process is recommended to ensure decision-making is based on the technical merit of applications.
- **Enforcement**: Employ a variety of penalties consistently.
- **Comprehensive management strategy**: Develop a comprehensive management strategy alongside the bylaw to align goals and integrate them throughout community resources.
- **Developed with community support**: Align with community values and priorities that citizens are willing to comply with, and support.

7.0 Conclusion

The benefits of trees are widely recognised and valued by communities across Metro Vancouver and around the world, particularly in the context of climate change adaptation. Local governments are showing an increasing interest in developing or improving regulations to preserve trees and grow tree canopy. Yet, a limited number of resources exist to inform the design and implementation of regulatory tools for this purpose.

The *Metro Vancouver Tree Regulations Toolkit* provides readers with practical information about how they can develop comprehensive policy and regulations to preserve trees and grow tree canopy within British Columbia's current legislative framework. It is intended to offer information about the options available and important components to consider for each regulatory tool to allow readers to make decisions about the most appropriate options for their local context. This document will need to be periodically reviewed and updated as legislation and best practices in the region evolve.



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Appendix 1. Practitioner Survey Results (2020)

Detailed Results – Practitioners Surveys

Observations about municipalities in Metro Vancouver

Canopy loss: In Figure 1, staff indicated that:

- Most tree canopy loss in their community was due to:
  - Single-family/townhome subdivision development into greenfield (80% said moderate to high loss)
  - Higher density/commercial development into green field or already developed areas (40 to 50% said moderate to high loss)
  - Single-family/duplex/triplex infill into already developed urban areas (40% said moderate to high loss)
- Least tree canopy loss in their communities was due to:
  - Minor development (90% said low loss)
  - Municipal development and capital infrastructure upgrades (90% said low or not applicable)
  - Dying or high-risk trees needing to be removed (80% said low)
  - Industrial development (80% said low or not applicable)
  - Homeowners cutting trees for perceived nuisance (65% said low)

In addition to the causes for canopy loss listed in the survey, staff mentioned off-site infrastructure upgrades for development, climate change, wildfire and forest management, climate change impacts and tree management on other jurisdictions (e.g. School Districts) as causes of canopy loss.

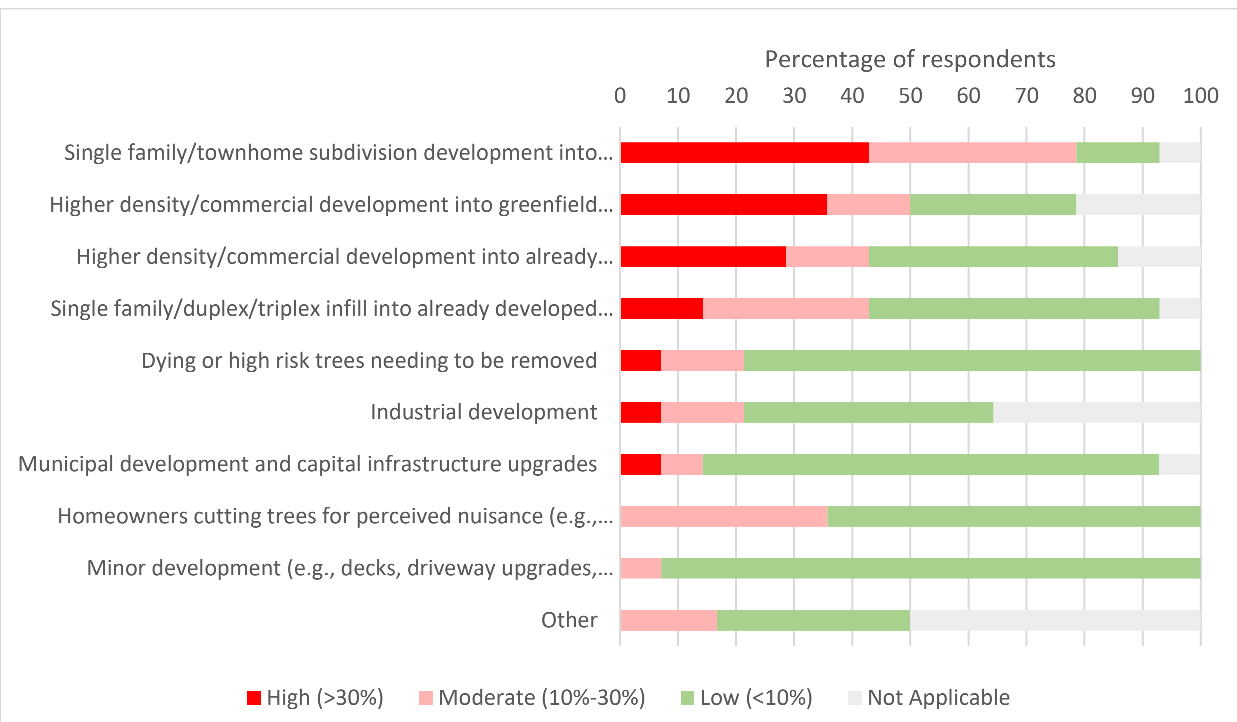

Figure 1. Municipal staff's perceived reasons for canopy loss in their jurisdiction (from survey responses).

Effectiveness of regulations: Municipal staff respondents identified Environmental Development Permit Areas (Environmental DPA), Public and Private tree bylaws as the most effective regulatory tools currently in their municipality (see Figure 2). Zoning and Subdivision and Servicing Bylaws were seen as least effective. Reasons cited included a lack of language to support urban forest objectives and landscaping and street tree requirements, and the inadequate regulation on the amount of impervious cover or building envelope size permitted. These reasons cited suggest that opportunities exist to improve those regulations for canopy preservation or growth. Staff also pointed to a lack of staffing and resourcing to implement regulations and ensure compliance and enforcement and fluctuating political will to implement regulations to their full extent.

In addition to the tools listed in the survey, staff highlighted the Watercourse Protection and Steep Slope Protection Development Permit Areas and guidelines as being effective for tree canopy regulation. Staff also commented on additional tools to sustain or grow canopy cover, including a donor tree program, carbon sequestration and biodiversity initiatives for public tree planting and Urban Forest Management Plans.

Figure 2. Current effectiveness of regulatory tools to preserve or grow canopy in municipal staff's jurisdictions (from survey responses).

Effectiveness of regulatory tools to achieve specific outcomes: Municipal staff and consulting arborists were asked to comment on the effectiveness of regulatory tools at achieving specific urban forest preservation and growth outcomes (see Figure 3 and Figure 4). Both municipal and consulting arborist survey respondents thought that the regulatory tools were effective for achieving tree protection during construction and retention of existing trees where reasonably possible. Both sets of respondents were also consistent in the finding that regulatory tools did not achieve protection and reuse of native soil, increased tree canopy in locations that previously had little canopy, or protection of permeable areas or future planting sites. Consulting arborists were more critical than municipal staff respondents on the effectiveness of those tools to achieve the selection of climate suitable species for the site and replacement planting of medium to large canopy trees. In general, the results indicated there was room for improvement in the region's regulations to achieve most of the outcomes listed.

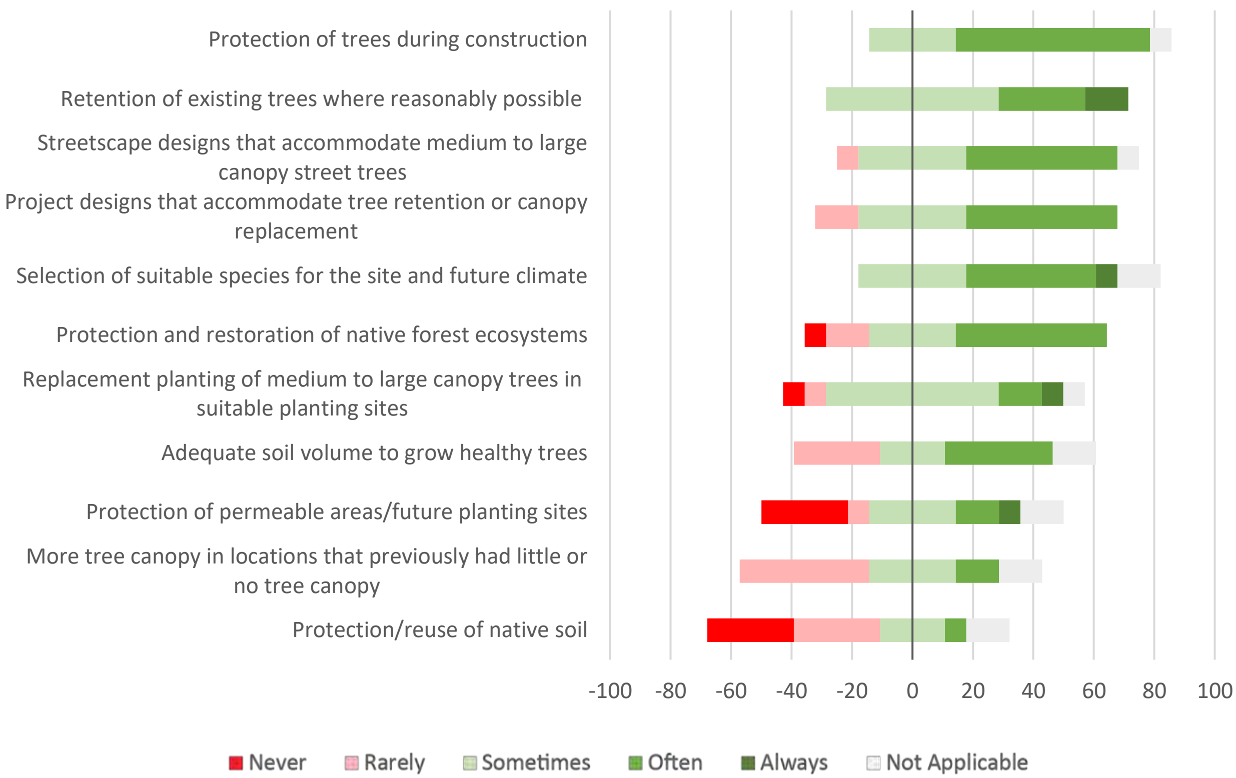

Figure 3. Effectiveness of regulatory tools to achieve specific outcomes according to **municipal staff** **(from survey responses)** (above).

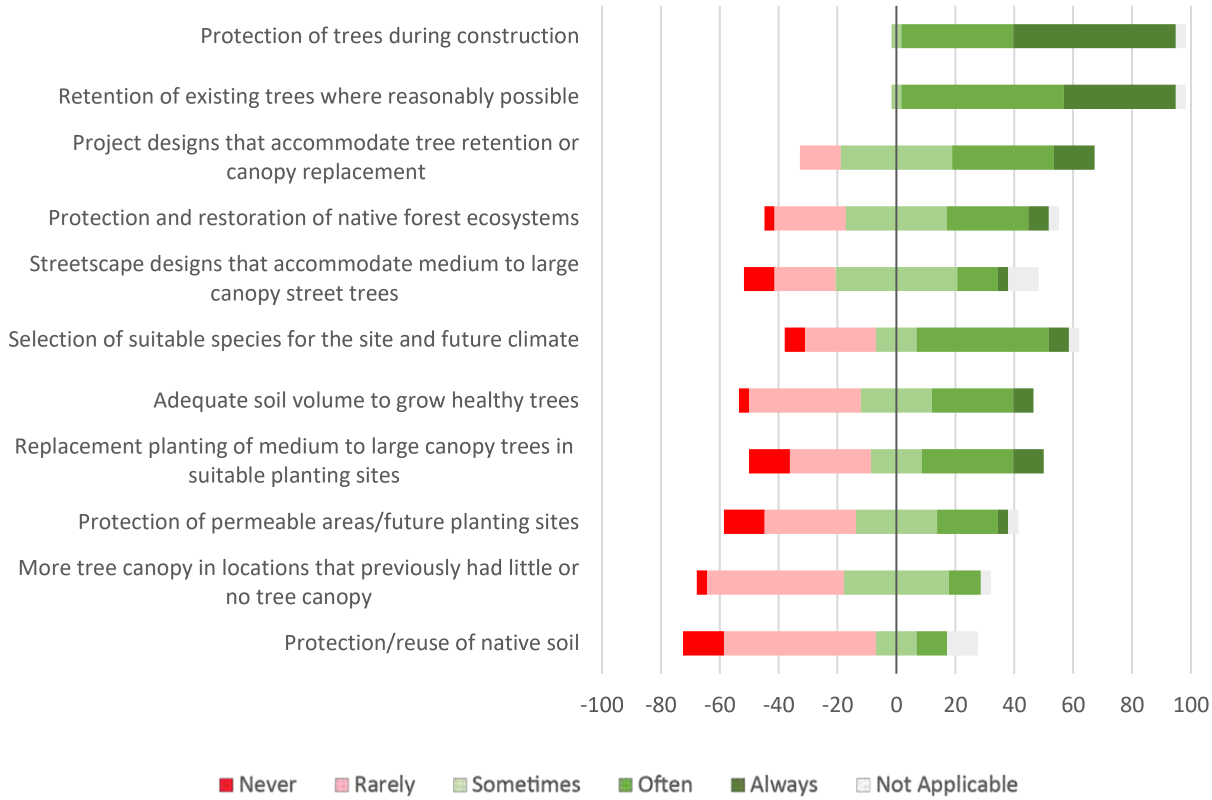

Figure 4. Effectiveness of regulatory tools to achieve specific outcomes according to consulting arborists (from survey responses) (above)

Most important objectives for introducing regulations: Municipal staff respondents clearly consider maximizing tree retention to be the most important objective guiding the introduction of regulations in their municipality, followed by increase new tree canopy in low canopy areas and maximizing canopy replacement (see Figure 5). The administrative metrics listed were not ranked as high. However, minimizing staffing required to administer the bylaw and costs to permit applicants were considered significant to a few municipalities, particularly those of a smaller size. It is worth noting that while increasing canopy cover in low canopy neighbourhoods ranked high in the priorities of municipal staff, many of them also noted that their current regulations rarely achieve that outcome currently.

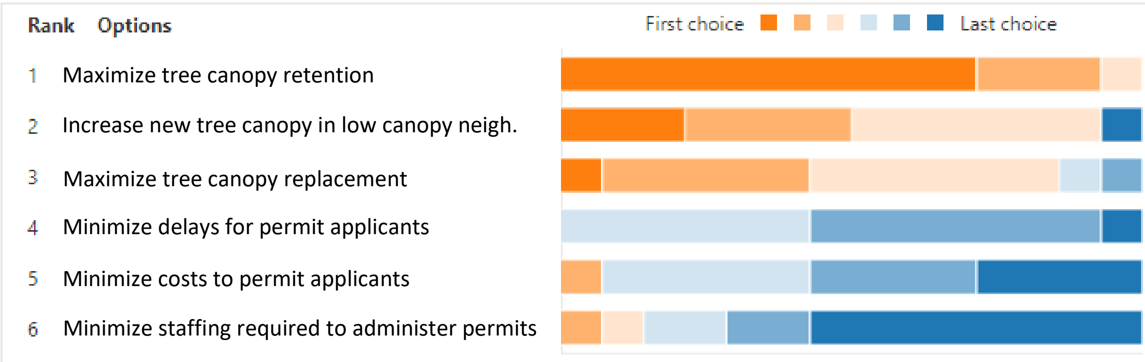

Figure 5. Objectives ranked from most to least important when introducing regulations in their jurisdiction, according to municipal staff (from survey responses).

Staff noted the following objectives as additional to the ones listed in the survey:

- Increase staffing for tree care on public land
- Protect available space for retention or replacement on urban infill lots (including rooftops/decks on high-rises) and off-site locations (neighbourhood shared spaces areas, community open spaces/facilities)
- Fiscal incentive for agricultural land tree planting + retention where land isn't used for farming
- Climate change resiliency targets (site, neighbourhood and municipal level)
- Access to green spaces (community health)
- Urban forest health & diversity (vs. simply coverage)
- Room to mature for replacement trees
- Wildfire management
- Public safety
- OCP/neighbourhood plans/parks plans

Finally, municipal staff highlighted the challenges of competing priorities (utilities, TOD, active transportation, parking), an interest in learning about tree retention and re-planting initiatives in the Pacific Northwest including carbon credit programs to support re-planting, and the fact that administrative procedure metrics are far less critical than sound canopy objectives and decision-making for canopy cover outcomes.

Perceptions on bylaw best practices

Zoning: Municipal staff highlighted maximum lot coverage and maximum impervious cover in the Zoning Bylaw as having the most potential to sustain or grow canopy cover (see Figure 6). Environmental setbacks and landscaping were also considered by staff from more urbanized municipalities to have a large impact, while smaller and more suburban communities found setbacks to be less impactful. This perception may partially be explained by there often being larger green spaces in the smaller communities that are found adjacent to Provincial land whereas in the denser and more developed communities, the environmental setbacks, outside of the major parks, are often the largest green spaces outside of major parks. Less urbanized municipalities that are seeing increased development pressures may need to consider the protection of large setbacks of a sufficient size to either preserve tree stands of value or future planting sites.

Additional zoning components of importance highlighted by respondents included buildings (accessory buildings and infill housing), utilities and stormwater management, other constructions (pools, patios, retaining walls) and re-grading. Respondents also mentioned the importance of tree canopy and vegetation cover treatment options, landscaping guidelines and greening guidelines on structure for higher density/larger footprint developments.

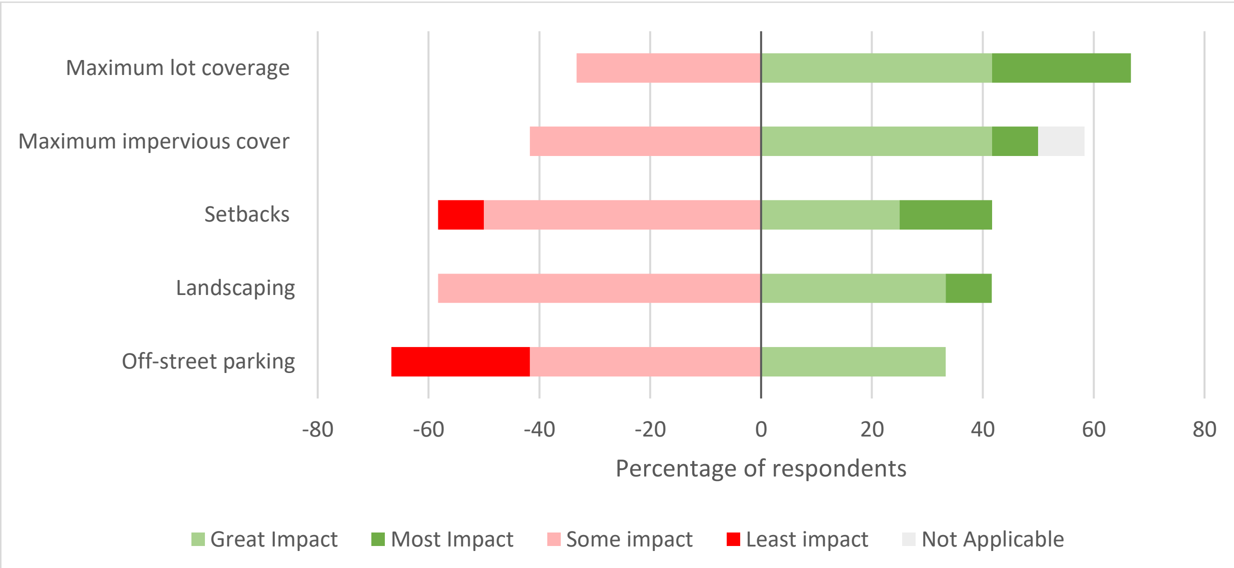

Figure 6. Impact of zoning bylaw components on canopy cover preservation or growth according to municipal staff (from survey responses).

Development Permit Areas: With regards to Development Permit Areas (DPAs), municipal respondents felt that the protection of the natural environment has an significant impact on sustaining and growing canopy, while most staff didn't find hazardous conditions DPAs to have a great impact. Other DPAs mentioned included Waterfront, Watercourses, Slopes, Form and Character and Energy.

Subdivision and Servicing Bylaw: Staff highlighted soil volume requirements as the most impactful component of this bylaw for sustaining and growing canopy. Boulevard width and tree spacing and setbacks were also found to have some or a great impact on canopy.

Respondents listed the following additional components as impactful for sustaining or growing canopy: servicing and trenching, private tree plantings (at the front and rear of buildings), street tree requirements and standards for planting and maintenance, and bio-filtration requirements that account for canopy cover. A few respondents pointed out implementation challenges with getting the requested soil volumes or the lack of involvement of urban forestry staff in the development process.

Tree bylaw: Replacement requirements and tree protection standards were found to be the components with the most impact to the greatest number of municipal staff respondents (see Figure 7). All respondents thought that securities had a great impact on sustaining and growing canopy cover. There was less agreement on the impact of components such as the permitted removal reasons and penalties.

Although information requirements were ranked as having less impact on sustaining or growing canopy, standardized arborist reports were noted as a component with a significant impact in the comments. Additional items related to securities and replacement requirements. Forest edge effects (trees blowing over) and wildfire management concerns were also highlighted in municipalities with large urban-wildland interfaces.

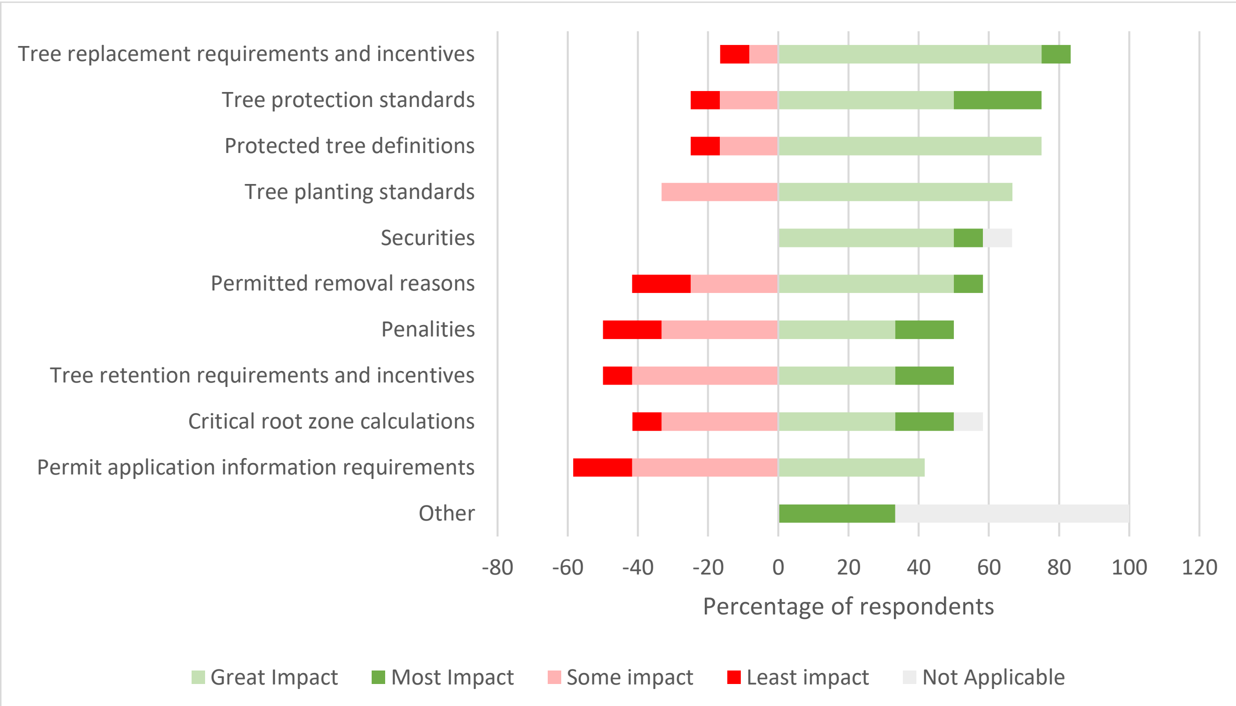

Figure 7. Impact of tree bylaw components on preserving or growing canopy cover according to municipal staff (from survey responses).

Appendix 2. Literature Review

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1.0 Introduction

Many jurisdictions in Canada and elsewhere use laws or policy, including comprehensive plans, zoning, tree bylaws/ordinances, and subdivision regulations, to influence urban tree canopy on private land. **Tree bylaws, ordinances or policies** are often used by municipalities to directly regulate or guide the protection, removal, and replacement of trees in urban and peri-urban forests. **Land use bylaws and planning overlays** (land use regulations) also influence urban tree canopy by controlling how and where land development can occur, what permeable space will remain to plant trees, specifying landscaping outcomes, and prioritizing the protection of or requiring restoration of environmentally sensitive or significant areas. Typically, **land use regulations**, and an owner's right to develop their property according to those regulations, **will override tree regulations**, therefore, **tree regulations and land use regulations need to be aligned to achieve a municipality's urban tree canopy goals**.

Approaches to regulating tree protection vary significantly between jurisdictions even within the same region. This literature review draws on scientific research and practitioner guides to explore best practices for regulating urban tree canopy and ultimately to inform a conceptual model for comprehensive canopy regulation that could be used in the context of British Columbia. Specifically, this literature review will explore:

- The role of urban forest governance
- Methods to incorporate tree canopy into land use regulations
- Guidance for effective tree regulation and the key elements that need to be in place, and pitfalls to avoid, to effectively regulate urban tree canopy
- Approaches to private tree protection in Canada and the United States
- The tools available to municipalities in British Columbia to regulate urban tree canopy
- A conceptual model for comprehensive canopy regulation in British Columbia

Tree and land use regulations are referred to using different terminology depending on the country. There are multiple words used throughout the literature review in reference to tree governance that are important to define. Generally, ***bylaw*** (also spelled by-law) is used in a Canadian context and ***ordinance*** is used in the United States. General definitions for key terms include:

- **Bylaw** – Laws passed by municipal councils and regional district boards to exercise their statutory authority. Bylaws may be used for a variety of different purposes, including establishing meeting procedures, regulating services, prohibiting an activity, or requiring certain actions (The Government of British Columbia, 2020).
- **Ordinance** – Law enacted by a municipal body, such as a city council or county commission. Ordinances govern matters not already covered by state or federal laws such as zoning, safety and building regulations (Lectric Law Library's Lexicon, 2020).
- **Policy** – Law, regulation, procedure, administrative action, incentive, or voluntary practice of governments and other institutions (Centers for Disease Control and Prevention, 2020).

- **Regulation** – An official rule. In the Government, certain administrative agencies have a narrow authority to control conduct, within their areas of responsibility. These agencies have been delegated legislative power to create and apply the rules, or "regulations" (Cornell Law School, 2020).
- **Standard –** Written limit, definition or rule that is approved and monitored by an agency as the minimum benchmark acceptable (Black's Law Dictionary Free Online Legal Dictionary 2nd Ed., 2020).

2.0 The Role of Urban Forest Governance

Urban forest governance refers to the processes, interactions, organizations, and decisions that lead to the establishment and maintenance of the urban forest. It is important to acknowledge, even though a local government may have the authority to regulate trees, that not every municipality may choose to exercise that power. In a study of urban forest governance in Australian cities, Ordonez (2019) found that central and inner urban centres face different challenges and prioritize issues differently than outer and regional centres. FitzGibbon and Summers (2002) state that tree regulations tend to be stronger in more populated areas in the US and Canada. In other words, tree regulations strengthen as communities become more urbanized. Ordonez et al. (2019) note that variation in urban forest governance may reflect differences among urban areas such as level of development, population density, and population growth. Hill et al. (2010) suggest that when a community is aware of the inhibitors to maintaining tree canopy cover – including insufficient budget, insufficient staff and equipment, competing priorities, lack of public support and political will, and lack of community recognition concerning the importance of tree management – it is an indication that the community is making efforts to acquire resources and protect trees to increase canopy cover. By contrast, if protecting or growing the urban forest is not a concern for the community, it will not identify any inhibitors and will not make efforts to maintain tree canopy (Hill et al. 2010).

Mincey et al. (2013a) observe that urban forest management is influenced across multiple scales by operational, policymaking, and constitutional rules that determine policy creation. The organization of urban forestry programs within governmental structures and communities is influenced by social systems and institutions. Lawrence et al. (2013) offer a comparative model of integrated urban forest governance which describes:

- **Context:** urban trees, forests, population size
- **Institutional frameworks:** policies, plans and regulations, ownership, and access
- **Actors and coalitions:** land managers, citizens and NGOs, partnerships, and power analysis
- **Resources:** funding, knowledge, delivery mechanisms
- **Processes:** discourses, participation, monitoring, and evaluation

This model is proposed as a method of mapping the whole picture of urban forest governance, that can help disentangle the complexity of the urban forest and enable comparison of urban forest governance between jurisdictions. Such a model may provide insight into the type of urban forest governance frameworks that support adequate funding, political will, public pressure, and municipal capacity to enact and enforce effective tree regulation.

Issues of environmental equity and justice in urban forest governance are also coming to the forefront but are not yet well represented in the literature on regulating urban tree canopy. The U.S. Environmental Protection Agency defines environmental justice as:

"the fair treatment of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws and policies and their meaningful involvement in the decision-making processes of the government."

Decisions made in urban forestry practice are not always equitable – for example, research found that resident associations involved in urban forest stewardship activities are more likely to be active in high income communities (Conway et al. 2011). Different stakeholders have varying levels of influence , with some urban forestry stakeholders such as municipal managers more connected to strategic planning and therefore more capable of influencing resource allocations (Campbell, 2016; Ordonez et al. 2020). Nesbitt et al. (2019) define urban green equity as equitable access to urban forests and governance. They present two practice-based models for urban green equity that practitioners can apply to recognize and overcome barriers to inequity in practice: recognitional equity and distributional equity. Recognitional equity describes the representation of stakeholders involved in urban forest decision making, stewardship, and representation in the profession (Nesbitt et al., 2019).

Distributional equity is focused on fair access to ecosystem services, which in urban forestry often relates to the proximity and extent of vegetation cover. The distribution of ecological attributes in cities, such as tree canopy, urban heat island, and environmental hazards are frequently driven by social inequity (Schell et al. 2020). Studies examining predictors of vegetation cover have proposed three social theories (Troy et al., 2007; Grove et al., 2006):

1. **Population density:** drives vegetation change through development.
2. **Social stratification:** predicts vegetation cover based on relative power, income and race differences among neighbourhoods, and the subsequent levels of public and private investment in greening.
3. **Lifestyle behaviour:** suggests increases in vegetation cover based on household patterns of consumption and expenditure motivated by social status resulting in a 'luxury effect', where groups with adequate discretional income outwardly express prestige and neighbourhood belonging through their landscaping.

Affluent residential neighbourhoods often have greater vegetation cover, canopy cover, and plant diversity (Schell et al. 2020). Housing age and race have also been associated with trends in canopy cover (Troy et al., 2007; Watkins & Gerrish, 2018). A study of potential plantable areas on private land found that potential planting areas were limited in locations with high lot cover and density, which also tended to be in neighbourhoods characterized by high population density with often lower incomes and higher proportions of minority households (Troy et al., 2007). This indicates that increasing canopy cover in underserved neighbourhoods may not be a matter of just increasing tree planting but increasing available plantable areas.

Studies find significant correlations between tree ordinance provisions and community urban forest characteristics related to wealth and education (Dickerson et al., 2001; Conway et al., 2011). Residents with a higher mean income and education level are more likely to live in areas that have ordinances with provisions biased toward protection and maintenance of existing community trees whereas residents with a lower education and income level are more likely to live in areas with ordinances focused on community aesthetics and safety (Dickerson et al., 2001). Understanding how current practices and policies contribute to environmental inequity and increasing diverse representation in decision making are important steps towards identifying policy outcomes that will improve environmental equity. When developing tree regulations, it is important to apply an environmental justice lens to ensure policies are not disproportionately impacting or penalizing minority or low-income populations.

3.0 Guidance for Effective Tree Regulation

Increasing or maintaining the number of trees and the extent of tree canopy cover in a city is an indication of effective tree regulation (Landry & Pu, 2010; Sung, 2012 in Clark et al., 2020). Tree regulations are commonly enacted by local governments to regulate tree removal, regulate the planting and maintenance of trees, and control landscaping and tree protection for new development sites (Yung, 2018). Beyond these direct control outcomes, tree bylaws serve broader urban forestry goals including watershed health, stormwater management, habitat, sustainability, canopy, aesthetics, and access to greenspace (Baur et al., 2016). Federal and provincial acts are often critical to provide local governments with the authority and guidelines to create bylaws. For example, BC's Community Charter delegates broad power to municipalities to regulate trees (on both public and private land), whereas Alberta's Municipal Government Act does not. Federal or provincial acts can also provide 'blanket' protection of the urban forest, such as for riparian areas or for species at risk, though this is not always the case (Fong, n.d.). The literature provides various insights into effective urban forest governance and implementation of tree bylaws and ordinances. This review focuses predominantly on private tree regulation because the majority of urban tree canopy loss occurs on private land, which is a more controversial space to regulate trees than on public land.

Given the complexity of urban forest governance, efforts to preserve trees must be trans-disciplinary and reach all the relevant actors. Much of the urban forest is owned and managed by private landowners (Clark et al., 1997). As a result, calibrating policy prescriptions (ordinances, standards) to community attitudes is important. There are significant differences between communities within and between regions which present challenges for recommending general best practices (Mincey et al., 2013a). Examples are common where bylaws not supported by a community fail to be adopted, are ignored, spark retaliatory actions, or detract from the community perception of the urban forest as a public good (Mincey et al., 2013a; Treiman & Gartner, 2005; Nesse, 2020). Copying generic bylaw templates prevents a city from meeting the specific needs of the community and misses an opportunity to work with property owners and developers in the process to strengthen connections (Schwab, 2009).

Bernhardt and Nichols propose seven criteria for effective tree bylaws (Bernhardt & Swiecki, 1991; Nichols, 2007). These criteria will be discussed in the following sections and include:

- **Clearly stated goals:** Essential for interpretation of the bylaw and evaluation of effectiveness. The goals should describe the capacity of the tool to achieve certain goals with clear connection to any wider management strategies.
- **Designated responsibility:** Assign authority of a single person responsible or when resources are limited, split between city staff and tree commissions as needed.
- **Basic performance standards:** Indicate best management practices and standards that address the overall urban forest.
- **Flexibility:** Allows for site-specific decisions in the variety of circumstances that may arise and supports staff to use their discretion in a fair, reasonable and transparent manner. An appeal process is recommended to ensure decision making based on technical merit.
- **Enforcement:** Adequate staffing to administer the bylaw and provide enforcement, and effective penalties to deter violations.
- **Comprehensive management strategy:** Development alongside a Comprehensive Management strategy ensures goals align and are integrated with other community policy.
- **Developed with community support:** Align with community values and priorities that citizens are willing to comply and support.

3.1 Defining Goals for Tree Regulation

Much of the literature highlights the establishment of clear goals and purpose as integral to developing a successful tree bylaw or ordinance (Bernhardt & Swiecki, 1991; Heaviland, 2007; Nichols, 2007; NC State University Cooperative Extension, n.d.). Ideally, these goals should be driven by a higher- level plan, such as an urban forest strategy with established community-supported urban forest goals. Having data about forest cover change and tree protection issues of the community is also important to inform tree regulations (Forest Conservation By-law & Lower Tier Advisory Group, 2013). The literature describes a wide range of goals that could be used to guide the development of bylaws and potentially evaluate their success including:

- **Goals that focus on preservation**
  - Preserve beneficial stands of multiple trees
  - Preserve trees in sensitive ecosystems or on steep slopes
  - Preserve significant trees
  - Preserve mature trees
  - Preserve trees along roadways and vegetation roadway buffers
  - Prevent loss of tree canopy

- **Goals that focus on growth or replacement**
  - Establish trees in non-forested areas
  - Preserve space and soil for new trees
  - Increase canopy cover equitably
- **Goals that focus on quality and character of retained or replaced trees**
  - Maintain trees in a healthy condition through good cultural practices
  - Maintain aesthetics associated with existing trees
  - Maintain habitat values
  - Maintain species diversity
  - Maintain age diversity
  - Conserve local genetic resources
- **Goals that focus on ecosystem services**
  - Maximize the environmental, economic and social benefits provided by trees
  - Reduce the urban heat island effect and building energy use
  - Improve air quality
  - Reduced water pollution
  - Beautify neighborhoods

No single, best practice set of goals was found in the literature. It is evident that goals will vary depending on the regional context and values of each community. Larson et al. (2020) reviewed 156 landscape related ordinances (not just tree ordinances) across six US cities to capture their goals for conservation and environmental management, aesthetics and nuisance avoidance, and health and wellbeing. They found variation in the goals of ordinances based on climate and contexts. For example, wetter climates tended to emphasize stormwater management and flood mitigation, while drier regions emphasized water conservation (Larson et al., 2020). Some regions prioritized environmental services such as biological conservation and water quality protection, while others prioritized aesthetic 'neatness and order' over naturalized landscapes (Larson et al., 2020). They also found contradicting regulatory goals were common within regions and ordinances tended to overlook contradictions or trade-offs between goals; for example, emphasizing water conservation in one place but requiring irrigation to maintain healthy vegetation in another. Overall, Larson et al. (2020) concluded that coordinated, multi-objective planning with key stakeholders is important to develop ordinances with cohesive objectives and explicitly defined trade-offs.

3.2 Designated responsibility

Assigning administrative responsibility for the bylaw or ordinance is critical. Communities may designate specific positions responsible, or a citizen tree advisory board to share responsibilities (NC Cooperative Extension Service, n.d.; Nichols, 2007). In British Columbia, Councils can delegate powers, duties, and functions to a council committee, an officer or employee or another body established by Council. Specifying responsibility is especially important for a successful permitting program where it is crucial to have staff that can approve criteria, supply a permit, and enforce any mechanisms. While context specific, an agency or official must have expertise and support for the bylaw goals, and should be available throughout the process (Nichols, 2007).

3.3 Performance standards

Performance standards specify standards to be met by permit applicants and are an important aspect of effective tree bylaws (Bernhardt, 2001). Performance standards often address acceptable practices for activities such as arborist inventories and reports, tree protection, pruning, tree compensation, replacement tree planting, and maintenance (NC Cooperative Extension Service, n.d.). Municipalities should have a strategic plan for tree planting to ensure there are suitable locations to plant trees funded by cash-in-lieu (i.e., money provided by applicants in lieu of planting a replacement tree), which is when the value of a tree replacement is collected and used for a more suitable site then the original replacement site. Bernhardt (2001) identifies performance standards not aligned to goals can be a limitation to ordinances. For example, ordinances may require tree planting but do not set standards for the eventual amount of canopy to be achieved or may have more permit requirements for removing native vegetation but do not ultimately limit the maximum amount of native tree canopy that can be removed (Bernhardt, 2001). Instead, establishing standards based on a percentage of existing tree density or canopy cover can provide objective standards for assessing whether projects comply with tree regulation and will meet defined goals (Bernhardt, 2001).

Performance standards are also important for ensuring appropriate professionals are engaged by applicants. Professional qualifications for arborists can be addressed through standards such as requiring tree assessments and specification of tree protection measures that can be factored into the design process. Arborists must work with planners, architects, engineers, and contractors to ensure grading, trenching, and pruning will be compatible with preserved trees (Matheny& Clark, 1998). To meet tree management goals, consistent, professionally qualified follow-through is found throughout the literature to be a key success factor (Matheny & Clark, 1998; Nesse, 2020; Oregon State University Extension, 2009; APWA n.d.).

Most jurisdictions have standards documents that guide performance standards for tree regulations and complement professional experience. In the US and Canada, the American National Standard for Tree Care Operations (A300 standards) and the accompanying ISA best practices documents provide various standards for tree work, including for tree protection during construction (Accredited Standards Committee, 2007). Washington's Department of Natural Resources has published a best management practices guidebook for tree protection on construction and development sites for the Pacific Northwest based on these standards (Oregon State University, 2009). Other references commonly used in Canadian tree regulations include in Canada include the Canadian Landscape Standard and the Council of Tree and Landscape Appraisers Guides to Plant Appraisals.

Despite the existence of these standards, they are often voluntary, and in practice there is substantial variability in the performance standards used in tree regulations. For example, many British Columbia bylaws use a multiplier with diameter at breast height to calculate root protection areas, which is a standard practice. However, one bylaw may define the radius of a root protection area for a 50 cm tree as being 6 times DBH, or 3 metres, while another defines it as 18 times DBH, or 9 metres. The ISA provides general guidelines for the critical root zone (CRZ) calculated in metres or centimetres as 6 to 18 x DBH, with a medium tolerance, mature trees having a 12 x DBH multiplication factor. Another common rule is dripline plus 1 m. The BMPs for the Pacific Northwest recommend using both 12 x DBH and dripline plus 1 m and selecting whichever is larger to define the root protection area (Oregon State University, 2009). Consistency in the application of performance standards at a regional scale could improve clarity for applicants and project arborists who work across multiple municipalities. While standards are helpful as a baseline, it is still important to build in flexibility to enable site/tree specific decision-making by professionals within the bounds of best practices guidance.

Several industry standards and best practices are relevant to consider when developing performance standards for Canadian tree bylaws, including:

Publisher	Standard	Detail
International Society of Arboriculture (ISA)	Best Management Practices	The ISA publishes best management practices on many subjects in tree care, maintenance, and urban forestry applications. Certified arborists are encouraged by the ISA to follow all applicable best management practices.
American National Standards Institute	Z133, A300	The American National Standards Institute releases and updates the accepted industry standards for safety in arboriculture operations (Z133) and tree care (A300). ANSI Z133 covers criteria in general safety, electrical hazard, use of vehicles and mobile equipment, power tools, hand tools, climbing, and other procedures for workers engaged in arboriculture. A300 contains ten parts addressing the major aspects of arboriculture planning and practice, including pruning, soil management, tree planting and establishment, protection during construction, tree risk assessment, and integrated pest management.
Council of Tree and Landscape Appraisers	The Guide for Plant Appraisal	The Guide, now in its 10th edition, presents a widely accepted protocol for tree appraisal. Winnipeg applies the Guide when requests to remove significant trees are made under the City's Tree Removal Guidelines.
Canadian Nursery Landscape Association	Canadian Landscape Standard, Canadian Nursery Stock Standard	The Association publishes standards in common use for landscape construction and nursery stock. Winnipeg incorporates the Canadian Nursery Stock Standard into its Tree Planting and Maintenance Specification.

3.4 Flexibility

Along with performance standards, flexibility is also important to cover the variety of circumstances that may arise and support staff to use their discretion in a fair, reasonable, and transparent manner. Flexibility is important for maintaining community support for tree regulation (Nichols, 2007; Nesse, 2020). Discretion is the ability to make a choice among one or more different possible courses of action that comply with applicable legislation (BC Ombudsperson, n.d.). To avoid inconsistent use of discretion, vague terms such as 'reasonably' and 'minimal' should be avoided when creating performance standards, and standards should not be undefined and left to the discretion of the delegated authority (NC Cooperative Extension Service, n.d.; Schwab, 2009). An example of a flexible ordinance policy is in Fulton County, Georgia which provides the permit-issuing arborist discretion to determine the location and species of replacement trees based on site-specific physical and biological factors (Nichols, 2007). Another aspect of maintaining flexibility is keeping the bylaw or ordinance as brief as possible and housing performance standards and specifications in a separate document or appendix that is also approved by council but is easier to change (Dickerson et al., 2001; NCC Cooperative Extension Service, n.d.).

3.5 Enforcement

Tree regulations need to be supported by enforcement in order to ensure compliance (Bernhardt, 2001; Yung, 2018; Schwab, 2009; NC Cooperative Extension Service, n.d.). Enforcement is authorized by the regulation but it also depends on adequate staff resources assigned to enforce the regulations (Bernhardt, 2001; Nichols, 2007; Schwab, 2009). Staff resources include the staff who administer the bylaw (e.g., landscape review, city arborists), staff who inspect site conditions (e.g., city arborists, building inspectors) and staff who are dedicated to bylaw enforcement. Broadening the range of staff who can assist with enforcement, for example swearing in urban forestry staff to issue tickets, is one way to overcome resourcing challenges (Nichols, 2007). Nichols provides a unique example to address challenges with resourcing tree enforcement from Chapel Hill, North Carolina where localities train a developer's employee to designate a person responsible for enforcement (Nichols, 2007).

Regulations can further support enforceability by including provisions that provide opportunities for oversight either by staff or qualified professionals. For example, the regulation may require staff or project arborists to provide items such as monitoring reports, inspections for tree barriers, and replacement trees (Nichols, 2007).

Penalties such as fines, forfeiture of securities, and stop work orders are often used as deterrents or punishments for violations (Bernhardt, 2001; Nichols, 2007). Penalties can also include requiring replacement trees or monetary charges for restoration. While rare and not recommended, some jurisdictions in the US allow for criminal penalties including jail terms (Nichols, 2007).

Private stewardship is also key when resources are lacking for enforcement. In the paper by Clark, Ordonez, and Livesley, the authors find private tree retention can be improved with tougher penalties alongside stronger enforcement – this can be supported by community education through stewardship engagement activities (Clark, Ordonez & Livesley, 2020). Nesse (2020) observed that laws alone cannot protect trees. The stakeholders such as developers, property owners, renters, politicians, and the public require awareness, understanding, and a willingness to participate in order to accomplish long term success.

3.6 Integration into a Comprehensive Strategy and Urban Forest Program

One common theme throughout the literature is the importance of implementing a tree bylaw alongside a comprehensive strategy such as an Urban Forest Strategy (UFS) or at minimum, alongside a community plan, such as an Official Community Plan (OCP) in British Columbia. Comprehensive plans often represent a long-term (10-20 year) vision and strategy for a community by providing a framework for implementation of land-use regulations including zoning and subdivision codes (Schwab, n.d.). These plans help provide strategic management direction to resource managers and serve to guide the intention of bylaws that are established. Fongar et al. (2019) found that municipalities in Norway with an adopted greenspace management strategy (including urban forest strategies) have significantly higher funding allocation to these resources than municipalities with no strategy.

Clark et al. (1997) describe a model for urban forest sustainability as a means of evaluating urban forest management in three elements:

1. **Vegetation resource:** dynamic systems providing continuity of services over time.
2. **Community framework:** public and private players and institutions to govern and steer urban forest management.
3. **Resource management:** plans, policies, funding, staffing, and implementation to realize established goals.

This model is helpful in identifying gaps and the strategic actions for a sustainable urban forest strategy. Nesse (2020) observe that the implementation of comprehensive strategies is dependent on key players or champions, especially in smaller municipalities. Management may hinge on the competency and initiative of individual staff members. In larger municipalities there is greater organizational separation from managers and decisionmakers. In either case, improving knowledge of the urban forest as a vegetation resource, building an understanding of urban forestry across the community, and integrating urban forests into resource management across the organization will help to shift urban forest policy and management towards more optimal sustainable urban forest management goals (Clark et al., 1997; Fongar, 2019; Nesse, 2020). Adaptive management can be used to integrate new opportunities for participation, science, and evolving community dynamics such as environmental justice movements into a responsive management system (Lawrence et al., 2013).

3.7 Community Support

In her approach to local ordinances, Sandra Nichols explains a successful ordinance must reflect the goals and needs of the community, therefore a variety of approaches to policy formation should be undertaken (Nichols, 2007). In recent years, the literature has addressed public response and attitudes to tree bylaws. One study, conducted across four neighborhoods of Mississauga (Ontario, Canada) by Tenley Conway, examined residential attitudes toward trees and level of support for various tree policies (Conway, n.d.). The study found that while nearly all residents appreciated trees, there were lower levels of support for municipal policies that encouraged planting and restricted the removal of trees (Conway, n.d.). People were more likely to support tree policies in areas where children were present, there was higher property-level tree density, people recently planted a tree, or where people had shorter residencies. Areas with older residents had lower support for tree policies because of the perceived maintenance required. Ordonez et al. (2019) found that strategies will fail if they focus solely on increasing tree numbers and urban tree-canopy, and do not address issues of interdepartmental coordination, risk aversion, and public engagement.

Weber et al. (2020) found that residents were willing to be active participants in tree preservation and management programs, but this engagement must be meaningful. Kangas et al. (2014) find that community participatory planning processes have been most successful when complex, 'wicked' problems affecting the urban forest, like climate change, are acknowledged up front and participants from different stakeholder groups are engaged in finding reasonable solutions such as through interdepartmental coordination. A participatory process in Finland (**Error! Reference source not found.**) r educed conflict between different stakeholder groups, and a pragmatic approach (that acknowledged differing values and perspectives) reduced miscommunications in discussions (Kangas et al. 2014).

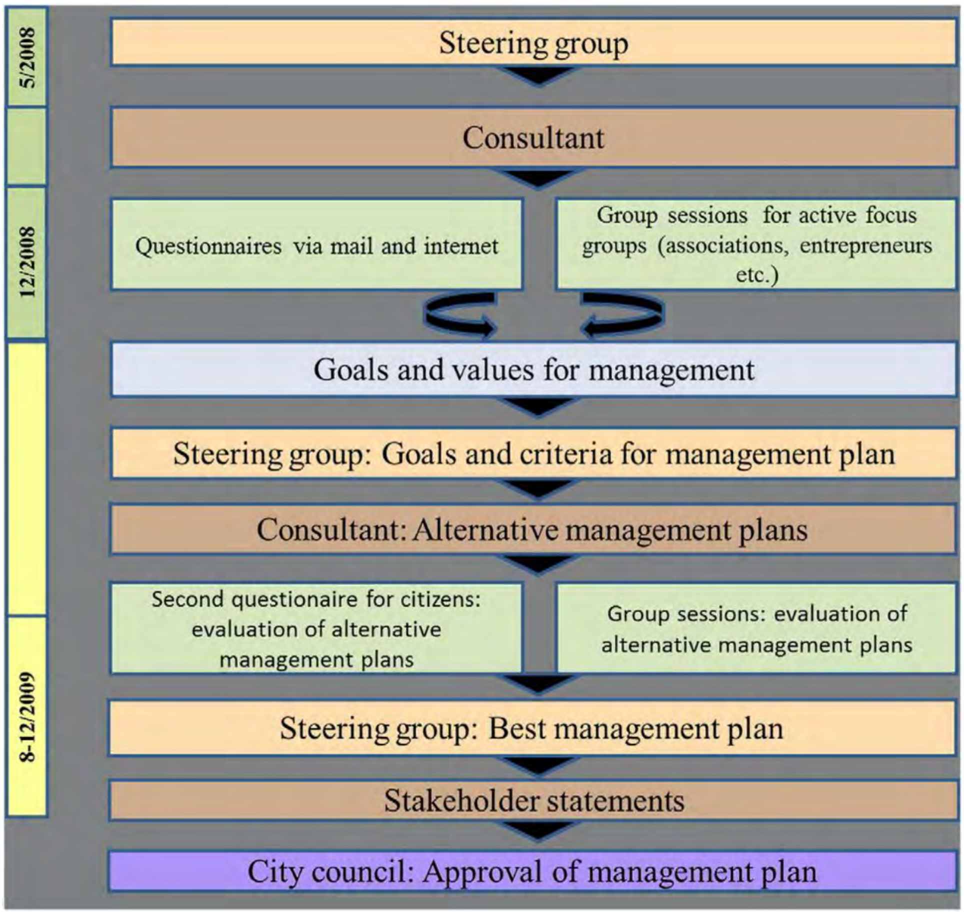


Figure 1. Participatory planning process from Kangas et al. 2014

In general, encouraging support for the urban forest may be possible using marketing, where planners and managers ''sell'' greener neighborhoods to different neighborhood-based consumer markets, building upon different groups' needs, sense of social status and group identity (Troy et al., 2007). Careful consideration must be taken to prevent community exclusion using this method, where canopy marketing could have the potential to favour affluent communities, therefore, canopy cover proportion must not be the predominant driver. It is proposed this method could involve using market segmentation to measure different lifestyle groups' preferences and motivations for various environmental behaviors, and then matching communication strategies to those preferences and motivations in a spatially explicit context (Troy et al., 2007).

3.8 Methods of Assessing Performance

Upon implementation of a tree bylaw, Bernhardt (2001) stresses the importance of evaluating Urban Forest bylaw performance by sampling populations, using photogrammetry/remote sensing, and ground surveys. Clark et al. (1997) also specify GIS and remote sensing, along with tree inventories and urban tree canopy assessments within their performance indicators for vegetation resources. Indicators may include canopy cover, age distribution, species composition, and specific biological characteristics affecting population sustainability (McPherson, 2013; Clark, 1997). Performance assessment and monitoring are ongoing measures for adaptively managing a sustainable urban forest.

A 2010 canopy cover study in Tampa, Florida, presented a method for assessing ordinance performance using an IKONOS imagery analysis. In the study, residential areas were assessed to quantify tree loss in areas lacking regulation. The study found greater tree canopy cover on parcels with homes built post tree protection than prior to (Landry & Pu, 2010). They concluded municipalities could implement scientific knowledge to guide future bylaw creation. Baur et al. (2016) found that residents tend to support science-based management.

Qualitative assessment can be used to assess public sentiment for policies (Lawrence et al., 2013; Baur et al., 2016) using surveys, town hall meetings, and committees. However, Fongar et al. (2019) found that related or partner organizations may tend to focus on their own interests, which may not be representative of the broader community. Considering recognitional equity by reducing barriers to participation ensures a diversity of voices are heard which is important from an environmental justice perspective.

4.0 Incorporating Urban Tree Canopy into Land Use Regulation

Tree bylaws and ordinances are typically considered the most direct way to regulate trees. However, land use regulations have a significant effect on influencing canopy cover outcomes in new developments (Mincey et al., 2013b; Troy et al., 2007; Wilson et al., 2003). Hill et al. (2010) evaluated the impact of land use policies on tree canopy cover and found that tree ordinance clauses, zoning ordinances, and sustainable development practices, when implemented together, were most effective for preserving canopy cover in a community. Where tree bylaws and ordinances tend to focus specifically on regulating trees, other forms of land use regulation tend to be focused on outcomes for biodiversity, connectivity, and managing natural hazards, which are often particularly important for peri-urban forests.

4.1 Regional and Community Plans

There are various policies and tools that regulate tree protection noted throughout the literature, dependent on location. In Canada, Regional Plans and Community Plans guide the vision for land use, which is then implemented through municipal zoning and planning overlays at the finer scale. In the United States, Comprehensive Plans guide land use, which is then implemented by zoning and other ordinances.

At the regional scale, addressing ecosystem concerns can help to protect larger shared resources such as water and air quality as well as set regional canopy goals that are compatible with local canopy goals (Schwab, 2009). In BC, a Regional Growth Strategy (RGS) is an agreement across member municipalities and regional districts that aims to develop priority actions for social, economic, and environmental goals. Section 428(1) of the *Local Government Act* defines the purpose of an RGS is "to promote human settlement that is socially, economically and environmentally healthy and that makes efficient use of public facilities and services, land and other resources" (Local Government Act, 2015). While the overall goal of a RGS is to guide growth and development, goals include protecting environmentally sensitive areas and preserving, creating, and linking urban and rural open spaces including parks and recreation areas (Stewardship Centre BC, 2016). Local governments are required to include a regional context statement within their Official Community Plan (OCP) to demonstrate consistency with the RGS. As defined in Section 471(1) under the *Local Government Act,* an OCP is "a statement of objectives and policies to guide decisions on planning and land use management, within the area covered by the plan, respecting the purposes of local government." Within the OCP, policy statement(s) can be included to further address components of the natural environment (Local Government Act, 2015). Below are examples of policy provisions that can be included in an OCP to support tree protection (Columbia Basin Trust, 2015):

- Integrate green infrastructure such as urban forests throughout the community to preserve existing ecological resources, support biodiversity and reduce climate risks
- Recognize and enhance ecosystem services provided by parks and open spaces and promote planning and design that enhances biodiversity, carbon sequestration and air and water quality

- Work with adjacent municipalities, regional, provincial and federal governments, First Nations and community groups to create a network of regional parks, trails, services, and facilities
- Include parks as secondary floor areas in stormwater management planning and flood plain mapping
- Ensure new park acquisitions maximize opportunities for biodiversity protection, stormwater management, flood control, and/or other functions that increase climate resilience
- Conserve water by improving efficiency of existing irrigation systems, improving park construction standards, designing for water conservation, using non-potable water, and converting park and civic building landscapes to reduce the amount of irrigated turf where appropriate

4.2 Zoning to Preserve and Grow Urban Tree Canopy

Zoning is the most common form of regulating land use and ultimately land cover. Zoning bylaws may indirectly influence urban tree canopy through land use rules, or directly by requiring maintenance of percentage canopy cover by zone (Mincey et al., 2013b). Different zones have rules for lot sizes, setbacks, building coverage, and how land can be used, which can in turn affect land cover and where tree canopy, and environmental benefits such as urban heat mitigation and stormwater interception are distributed (Wilson et al., 2003). Planners typically administer zoning bylaws and are often in the position of having to balance demands for growth while mitigating negative environmental impacts (Wilson et al., 2003). The conversion of land from a pervious, vegetated condition into urban materials such as concrete and asphalt has numerous environmental implications including increasing surface runoff, increased heat absorption and storage, biodiversity and biomass loss, and reduction in air and water quality, which in turn have negative effects on landscape aesthetics, energy efficiency, human health, and quality of life (Wilson et al., 2003).

Studies have found that canopy cover declines significantly when median building lot coverage or housing density increases (Hilbert et al., 2019; Landry & Pu, 2010; Troy et al., 2007). Wilson et al. (2003) used remote sensing to explore the relationship between zoning and density, radiant surface temperature and normalized difference vegetation index (NDVI – presence of live green vegetation). The study found that zoning characterized by low density development had the lowest impact on surface temperatures and vegetation cover. However, since urban sprawl is considered undesirable by many urban planners, Wilson et al. (2003) used the data to make the case against spawl and located examples of lower impact development in high density zones, such as multifamily housing. Multifamily housing included developments with retained tree cover near the parcel edges and parking incorporated into the building footprint so the only impermeable cover in addition to the building parcel were access roads (Wilson et al., 2003). Despite these studies, understanding of the relationship between urban tree canopy and zoning is still not well enough understood to inform fine scale land use planning (Mincey et al., 2013b).

Recent work by Metro Vancouver found that most of the tree canopy cover in the urban areas is in "Residential – single-family detached with no secondary unit" (Metro Vancouver, 2019). "Parking" and

“Retail and other commercial” areas have the least canopy cover at 5% and most impervious surface at more than 90% (Metro Vancouver, 2019). The study also found a relationship between tree canopy cover and age since development. High density housing stock actually showed gains in canopy cover from the 1940s to 1980s. Low density housing canopy cover was relatively steady until the 1970s and then shows a declining trend up to 2000. This decline indicated that fewer, or smaller, trees were being retained or planted during construction of low density housing over time as lot sizes shrunk and demand for bigger homes increased, resulting in increased lot coverage (Metro Vancouver, 2019). The high density canopy cover trend was attributed to the ‘skyscraper’ boom in 1960s, 1970s, and 1980s that was characterized by tall and slender buildings with low Floor to Area Ratio (FAR), and enough space between them to preserve view corridors (Metro Vancouver, 2019). Similar to the example of multifamily housing developments highlighted by Wilson et al. (2003), this “Vancouverism” architectural model featured residential buildings that used up little lot coverage and allowed abundant greenspace, street trees and other public space at ground level (Metro Vancouver 2019). However, average canopy cover has been declining in both high density and low density housing stock in Metro Vancouver between 1980 and 2000.

Zoning is an important tool for tree preservation because it determines development type by land cover, including the permeable space that will remain on a site post-development. Additionally, zoning can independently, or in combination with overlays such as development permit areas, regulate landscaping post-development, establish requirements and guidelines for the preservation of environmentally sensitive areas, encourage the clustering or transferring of density to preserve environmentally sensitive areas, and require setbacks or buffers form other land uses (Cullington et al., 2008). These tools often determine if a tree or stand of trees can be retained with development. While a tree bylaw can strengthen tree protection, it cannot prevent development to permitted use or density according to zoning. Landscaping regulations can also be incorporated directly into zoning, subdivision regulations, and site plan regulations and cover a variety of tree measures including tree planting, preservation of trees, plantable area, required tree canopy cover, maintenance, and enforcement.

In the United States, some cities instead choose to adopt overall landscaping ordinances that support a Comprehensive Plan which includes five provisioning components including site landscaping, buffering and screening, street trees, parking lot landscaping, and tree preservation. Under the landscaping ordinance, the urban canopy can be enhanced through the site landscaping provision which requires tree cover to fulfill a city-adopted canopy cover percentage or to meet an established number of trees per dwelling unit. Trees can also be planted under parking lot provisions, typically including multi-family residential, and non-residential use – for example in Des Plaines, Illinois one shade tree must be planted for every 100 square feet of landscaped area (Bowen, 2004). Similarly, in BC, municipalities can incorporate landscaping requirements into zoning and subdivision bylaws to regulate urban tree canopy during development without enacting a tree bylaw. However, this means that trees are not generally regulated and protected except during development.

4.3 Planning for values and hazards in urban and peri-urban forest stands

Regional and community planning processes will often identify natural values and hazards related to forest stands that overlap with, but are not adequately addressed by, urban forest strategies, tree bylaws and ordinances. In the US, zoning overlays identify areas where special provisions will apply; they can be used to protect natural resources or to preserve forestry integrity. Overlays incorporated into policies such as the OCP and other strategic plans can create policies that are more targeted to managing values and hazards in urban and peri-urban forest stands than tree bylaws.

Biodiversity, and the protection of environmentally sensitive areas, is a value of forests and other ecosystems that warrants dedicated strategies and policies in order to guide its preservation and enhancement. Regional conservation strategies can be used to inform the RGS, OCP, and other government processes on enhancement strategies and goals for protection and restoring diversity in ecological areas; they can also directly impact the urban forest by setting goals to map biodiversity, acquire forest, and protect green infrastructure (Stewardship Centre BC, 2016). One example from British Columbia of a Regional conservation strategy is the Comox Valley Land Trust Regional Conservation Strategy, which outlines priority ecological and recreation areas to provide recommendations applicable to all participating local governments (Fyfe, 2008). At the municipal level, biodiversity or green infrastructure strategies can achieve similar outcomes. An urban forest strategy helps to integrate the management and protection of tree resources into the municipal policy framework, biodiversity strategies integrate green infrastructure. These strategies set environmental targets that can be integrated into community plans, zoning, stormwater management plans, and other various bylaws and legal documents (Schwab, 2009).

Wildfire is a hazard of forest fuels. In British Columbia, and in other Canadian and US municipalities, many communities have developed or are developing community wildfire protection plans. Municipalities in BC and the US can have development permit areas or overlays that are specific to FireSmart or Firewise development in the wildland urban interface (WUI). With the increasing incidence of severe wildfire and its direct impact on lives, homes, and infrastructure, management of fire and fuels within the WUI is driving many policy decisions (Barrett, 2019). Fire resilience strategies such as Firewise USA and the Community Planning Assistance for Wildfire project focus on proactive strategies to reduce flammable materials including vegetation in proximity to structures (Mockrin, 2020). Within the WUI, correlation of population density within proximity to vegetation/forest type can be used to assess fire risk (Miranda, 2019). Canopy cover and tree preservation goals in this context may conflict with fire risk reduction goals, since contiguous fuels are a pathway for fire spread. In these instances, bylaws and ordinances need to enable consistency with WUI management, through permitting removals for that purpose and ensuring that replacement trees and landscapes conform with FireSmart guidance.

Layered on top of zoning, cities can adopt planning overlays to identify land with specific management intent to align with strategic objectives for protection of the natural environment (Ordonez & Livesley, 2020). For example, in BC development permit areas can be for the:

- Protection of the natural environment, its ecosystems and biological diversity
- Protection of development from hazardous conditions
- Establishment of objectives to promote energy conservation
- Establishment of objectives to promote water conservation
- Establishment of objectives to promote the reduction of greenhouse gas emissions

Such overlays can complement tree bylaws by providing guidelines to achieve specific objectives in these areas when development occurs. It is worth noting that, while land use zones, schedules, overlays, and local laws can equate to regulatory policy mechanisms toward private tree protection, effectiveness is still limited to the capacity and resourcing of the organization (Ordonez & Livesely, 2020).

5.0 Private Tree Protection in Canada and the US

In municipalities across North America, trends suggest the majority of tree canopy falls on private property (Clark et al., 2020). In Canada, the ability of local governments to regulate tree removal and replacement is controlled by provincial legislation. As regulating private trees becomes more commonplace, municipalities are increasing the restriction of residential tree removal, with initial evidence suggesting their effectiveness at increasing and protecting canopy cover (Conway, 2010). The degree of protections provided to trees on private property varies widely by jurisdiction and local bylaws which reflect community attitudes towards associated local bylaws. The following sections describe private tree protection approaches in Canada, the United States and Australia.

5.1 Private Tree Protection in Canada

Canada's urban tree canopy declined by 1.5% between 1991-2011 – however while the national average decreased, the prairies have seen an increase in tree canopy cover on land previously lacking trees (Webber et al., 2020). It is expected that communities in forested ecoregions see a net loss of trees as forests are cleared and fewer trees are replanted with development, while prairie ecoregions see a net gain of tree cover from developer plantings in what was previously grassland.

Across Canada, the literature revealed a variety of private tree bylaws in place at the municipal level in British Columbia, Ontario, Québec, and Prince Edward Island. Provincial legislation is the acting authority that regulates tree bylaws in Canada and only some provinces have legislation explicitly regulating trees on private land.

British Columbia

In British Columbia (BC), tree bylaws are variable in their approach to tree regulation, with many applying to specific species and diameter, some applying to only heritage trees, others applying to trees 10 cm or greater but not restricting their removal, and still others applying to only certain areas within a municipality (Cullington et al., 2008). The presence of tree bylaws in BC appears to be related to population size. A review by Diamond Head Consulting looked at BC municipalities with a population of 2,000 people or more and found that approximately half of the municipalities had some form of private tree bylaw, and municipalities over 25,000 people had a private tree bylaw almost 80% of the time. It is important to note that, despite a tree bylaw being in place, a tree is not protected if it would prevent a permitted use or development density enabled under a zoning bylaw. Limited literature exists on the effectiveness of BC's tree bylaws. Dunster (1994) examined several bylaws in BC relatively soon after provincial legislation enabled their enactment. At that time, Dunster highlighted several issues including:

- Public and political desire for strong tree protection and the potential for liability issues being created when forest trees retained were vulnerable to windthrow
- Inadequate protection during construction and maintenance after the development to ensure retention is successful
- Hazard assessments being performed by professions other than ISA Certified Arborists
- A need for post-development hazard assessments
- Lack of evidence to assess their effectiveness

Ontario

Ontario is unique in that is in the only province that explicitly identifies urban forestry in legislation through the Professional Foresters Act, Municipal Act, and Planning Act; while these policies succeed in acknowledging urban forests, they lack weight in placing significant authority onto municipalities (Barker & Kenney, 2012). Barker and Kenney in their 2012 study found that community residents are critical to elevate the quality of urban forestry programming in small communities and the public must be engaged. A study by Dr. John FitzGibbon and Sylvia Summers found that for over 50 years, the municipalities in Ontario have had authority to enact tree conservation bylaws, but penalties and enforcement of these bylaws is limited (FitzGibbon & Summers, 2002). Yung (2018) found bylaws in Ontario were fragmented across municipalities due to the scattering of urban forestry practice across public and private land. He noted several key problems, the most crucial being the variety of bylaws and non-legally binding policy, and the discretion of the municipalities to implementing a tree bylaw.

Quebec

In Quebec, the Act Respecting Land Use Planning and Development enables municipalities to regulate or restrict the planting or felling of trees in their zoning bylaw to ensure the “protection of the forest cover and promote the sustainable development of private forests” (*Loi sur l’aménagement et l’urbanisme*, chapter 19.1, section 79.1). Cities such as Quebec City regulate the removal of trees on a lot frontage or back and require the protection or replanting of trees for development projects. No literature was found that studied the effectiveness of Quebec’s tree bylaws.

Prince Edward Island

On Prince Edward Island (PEI), municipalities are enabled by the Municipal Government Act to pass bylaws for “tree preservation and protection” as well as the “development and implementation of maintenance standards for trees”. The municipality of Charlottetown updated its Tree Protection Bylaw in 2019, which focuses on the protection of public trees as well as private heritage trees (>100 cm DBH). No literature was found that studied the effectiveness of PEI's tree bylaws.

5.2 Private Tree Protection in the United States

The United States loses over 70,000 hectares of urban tree canopy per year (Koeser, 2020). Multiple forms of assessment have been undertaken to evaluate current standards of tree bylaws in the United States. The most comprehensive study was completed in 2014 by Richard Hauer which analyzed over 667 communities across the United States (Hauer, 2014). The results of the study showed over 90% of municipalities had some form of tree ordinance with the five most common ordinances as follows:

- 80% have defining authority
- 77% have regulated removal of dead and diseased trees
- 70% have an approved tree list for public tree planting
- 68% required tree planting in new developments
- 60% require tree planting around new parking lots

Hilbert et al. (2019) found that heritage tree ordinances, which protect large diameter trees, were a significant predictor of higher urban tree canopy and important for canopy retention.
Additionally, the study identified that 54% of municipalities surveyed require tree preservation during development. Only 25% restrict cutting on private property and 31% identify heritage/significant trees for preservation. These numbers illustrate the patchwork of protections for trees on private property. Communities that have established canopy goals may be in a better position to influence private tree canopy as a community resource (Haur, 2014).

Ordinances differ widely between communities. State and Federal laws generally do not impact local municipal urban forestry ordinances. Some exceptions include state level requirements for stormwater retention facilities (bioswales) and trees in new hardscape installations, invasive species regulations (eg. USDA Animal and Plant Health Inspection Service (APHIS)), and the Migratory Bird Act. Natural or undeveloped areas (especially on waterways) and the peri-urban forest fall more often under state and federal regulations. Tree removal or development in these areas may be prohibited under water quality permits (EPA), the Endangered Species Act (US Fish and Wildlife Service), or archaeological/cultural preservation laws (eg., Washington Forest Practices Act).

The United States administers urban forestry policy at the federal, state, and municipal level. The US Department of Agriculture administers the US Forest Service (USFS) which delivers the Urban and Community Forestry (UCF) program throughout the US in a multi-stakeholder framework through agencies – however this does not benefit all municipalities equally as the centralization of the urban forest program does not guarantee small municipalities will be equipped to meet challenges (Barker & Kenney, 2012). Federal UCF serves largely to support individual state programs, administered by various state agencies (Colorado State Forest Service, Oregon Department of Forestry, Washington Department of Natural Resources, Massachusetts Department of Conservation and Recreation). University Extension

Services and regional urban forestry councils (e.g., Texas) comprise another level of support for communities. Research partnerships between USFS and universities or extension services are found in nine geographic regions. Private research partners include the Arbor Day Foundation, Bartlett Tree Experts, and Davey Tree Experts.

In many cases, state efforts draw on the resources of the Arbor Day Foundation for outreach and incentives. The Tree City USA program is a common thread for communities engaged in UCF at any level. Four standards of the TCUSA program offer low barrier entry with minimal requirements including:

1. Tree Board or Department
2. Tree Care Ordinance
3. Community Forest program with annual budget of, at minimum, $2 per capita
4. Arbor Day observance and proclamation

State employees tasked with UCF typically work with communities who wish to attain or maintain TCUSA status and offer support in developing tree ordinances. No specific requirements are defined for what the ordinance shall include, however a brochure is available from the Arbor Day Foundation with a framework for content (Fazio, 2017).

In summary, tree ordinances at the local level have the most impact on a community's urban forest. A multitude of guidelines, Best Management Practices, and templates are available which policymakers and managers at the local level can tailor to meet community needs. Private tree protection in the US, as elsewhere, is a sensitive subject, fraught with pitfalls if not implemented with community support. In the policy context, canopy loss can be attributed to increased development, densification, lack of understanding of trees, and lack of integrated planning and development processes. To illustrate the variety of regulatory approaches across the United States, several jurisdictions are discussed in detail below:

Florida

A particular study by Andrew Koeser evaluated the impact of Florida's recent state statute which significantly limits local government oversight of trees on private property (Koeser, 2020). Florida leads in annual tree canopy loss in the United States and is second only to Texas in impervious surface area – this is in part because opponents of tree protection and regulation see unnecessary taxation as adversarial to economic growth. While Florida was an early leader in creating provisions to oversee private tree removals (twice as likely to regulate trees on private property compared to other cities prior to new law), it is now the first state to have local oversight removed. At the time of the study, very few cities had moved to comply with Florida's new state statute. As a result, the full impact to private tree regulation had not yet been observed (Koeser, 2020).

Massachusetts

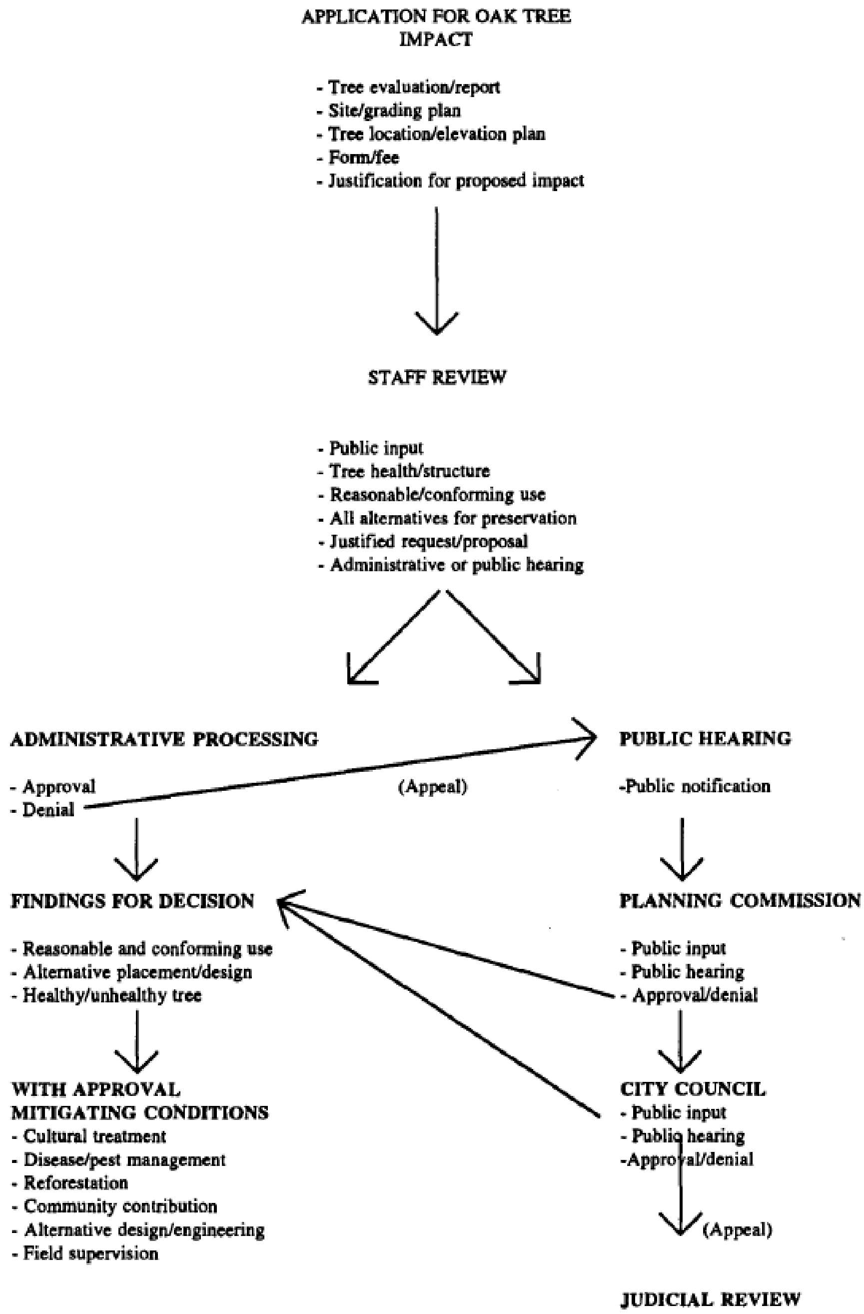
Massachusetts adopts a unique and historical approach to tree regulation through the implementation of Tree Wardens under state law (Steiner, 2010). Driven by early community support for trees, the Public Shade Tree Act was posed in 1899; the act places complete authority over maintenance, trimming, and tree removal at the hands of the wardens, requiring every municipality to have a position. The tree warden role (elected or appointed) has evolved over the years from a tree conservation focus to hazardous tree removal. The requirement of public hearings for tree alteration (except for six exemptions) has created issues and conflicts over tree damage and hazards. Adopted in 1973, the Scenic Roads Act overlaps responsibility and is implemented by the town planning board, however, this overlap can cause conflict between the controlling authorities (Steiner, 2010). Steiner recommends three advances to the Public Shade Tree Act to adapt to modern practice:

- Clarify authoritative control in the event of conflict between warden and planning board
- Clarify if trees may be removed to support efficiency of home energy systems
- Clarify appropriate level of training for wardens

California

Starting in 1972, the City of Thousand Oaks, California adopted the Oak Tree Ordinance as an Emergency City Council Proclamation – the toughest tree preservation ordinance enacted in California (Elmendorf, 1991). The ordinance was implemented following a public outcry when large valley oak trees were uprooted in an unapproved development. Citizens in Thousand Oaks demanded that oak trees were incorporated into new commercial construction and development designs. Having both staff and community on board with key objectives and a clear tree removal application system has enabled the City to protect trees. A key component to the success is the City's belief that private and public sector costs associated with enforcement and administration of the ordinance is insignificant compared to its benefits. Figure 2 below shows the method for evaluation of proposed Oak tree impact for the City of Thousand Oaks (Elmendorf, 1991).

Figure 2. Method of Evaluation of proposed oak tree impact, City of Thousand Oaks



6.0 Tools Available to Municipalities in British Columbia

There are a variety of tools available to municipalities in British Columbia for regulating urban tree canopy. The list below summarizes key tools that support tree regulation available for practitioners in British Columbia:

6.1 Acts

Local Government Act - Previously the Municipal Act, the Local Government Act recognizes the importance of all local governments including municipalities and regional districts and enables the creation of the Community Charter (BC Ministry of Municipal Affairs, n.d.).

Community Charter - Responsible for enabling municipalities to establish the below tools, the Community Charter enables Council to "regulate, prohibit or impose requirements in relation to […] trees" (sections 8(3)(c), 50 and 52). The Community Charter provides municipalities with the rights to provide services and develop bylaws including the development of Tree Bylaws and Official Community Plans, however, it does not include the City of Vancouver which has its own legislation *Vancouver Charter* (Government of British Columbia, 2020).

6.2 Regional Level Tools

Regional Growth Strategies (RGS) – Regional Growth Strategies are an agreement across municipalities on the future region, population and employment projects, actions proposed, and targets, policies, and actions for the reduction of greenhouse gas emissions (Local Government Act, RSBC 2015, c 1, 2015). The RGS aims to protect environmentally sensitive areas by detailing the means of green infrastructure protection and as defined in Section 429 of the *Local Government Act*, must cover a period of at least 20 years. The RGS can also include regional visions, raise the profile of regional issues to initiate discussion, and provide mechanisms for coordinating regional action through mapping sensitive ecosystems, committing to acquiring sensitive ecosystems, and designating urban containment boundaries (Stewardship Centre BC, 2016).

Regional Conservation Strategies (RCS) - Governed by the Local Government Act, the Regional Conservation Strategy (RCS) aims to enhance biological diversity in a region and protect and/or restore ecologically significant areas through establishing mapping frameworks to identify goals for protection. The RCS can be part of the Regional Growth Strategy or Official Community Plan (Stewardship Centre BC, 2016).

6.3 Municipal Tools

Official Community Plans (OCP) - The Official Community Plan (OCP) is a comprehensive plan that can include environmental protection policies. They can also define settlement patterns to guide development and avoid sprawl, map key areas, and designate Development Permit Areas and guidelines for Development Permits responsible for tree protection and replacement (Stewardship Centre BC, 2016). OCPs can establish goals and indicators related to preserving and growing a community's urban forest and support the implementation of community-supported bylaws and policies for that purpose.

Neighbourhood Plan – Adopted as an amendment to the Official Community Plan, the Neighbourhood Plan is a helpful accompanying policy tool to set targets for canopy cover, policy objectives, and character elements of importance. This scale enables additional consideration to local land use and neighbourhood context. Neighbourhood Plans can further define Development Permit Areas for protection of sensitive ecosystems and identifies green corridors (Stewardship Centre BC, 2016).

Development Permit Areas (DPAs) – Development Permit Areas (DPAs) can define land with a specific management intent to align with strategic objectives for protection of the natural environment. They can also provide local governments with site control over layout and design with the intent of limiting development for protection of the natural environment. Land must not be subdivided, or construction started unless a development permit is obtained (Columbia Basin Trust, 2015). Environmental Development Permit Areas (EDPAs) are permit areas specifically to protect sensitive ecosystems and prohibit disturbance activities to trees during development (Stewardship Centre BC, 2016).

Tax Exemptions and Conservation Funds – Supported through the Tax Exemption and Conservation Funds Community Charters, the funds can encourage landowners to protect and maintain natural areas (Stewardship Centre BC, 2016).

Security and Covenants – To prevent developers from damaging Environmentally Sensitive Areas (ESAs), a security deposit can be held and used to restore trees and damaged landscaping. Security and covenants are often managed through the Community Charter, under the Local Government Act, and Land Title Act (Stewardship Centre BC, 2016).

6.4 Bylaws

Zoning Bylaws –Allow for development to be directed away from sensitive ecosystems to help maintain green infrastructure by setting lot sizes and requiring buffers between new development; they can also allow a developer to seek a density bonus in return for protection of green infrastructure (Stewardship Centre BC, 2016). Zoning bylaws also enable the removal of trees to allow for permitted use and drive the extent of impervious cover.

Landscaping Bylaw- Regulates larger scale activities across different scales to specify planting and native species requirements. Tree and watercourse protection are often included in standalone bylaws and in Environmental Development Permit Area (EDPA) guidelines (Stewardship Centre BC, 2016).

Tree Bylaw – Sets standards for homeowners and developers for tree protection and replacement with a general goal to regenerate and enhance the urban forest. Can be a pathway to public education and is the most direct way to administer tree protection (Stewardship Centre BC, 2016). The Community Charter (Division 7 - Authority in Relation to Trees) places certain restrictions in relation to the authority to regulate trees. Notably, a tree bylaw would not typically apply to a parcel (or part of it) if it would prevent permitted uses or development density under the applicable zoning bylaw.

Watercourse Protection Bylaw – Regulates specific activities and development in riparian setback areas directly related to water quality and can provide protection of these trees to manage infiltration requirements (Stewardship Centre BC, 2016).

Rainwater Management Bylaw – Can support the planting of trees and bioswales as an infiltration strategy that can require developers to minimize changes to water flow during construction, often through the protection of vegetation (Stewardship Centre BC, 2016).

Screening and landscape Bylaw – Can require the use of screening or landscaping to preserve, protect, restore, and enhance the natural environment. They can also prevent hazardous conditions for example, requiring specific plant types in a wildfire hazard area.

Soil Removal and Deposit Bylaw - Often called sediment and erosion bylaws, these bylaws regulate grading, soil removal and deposition, soil storage, and erosion control guidelines during development which can impact trees (Stewardship Centre BC, 2016).

Pesticide Use Bylaw - Controls pollution from pesticides into sensitive ecosystems (Stewardship Centre BC, 2016).

Invasive Species Bylaw – Maintains sensitive ecosystems and controls noxious plans that may impact urban forest stands and plantings (Stewardship Centre BC, 2016).

6.5 Urban Forestry Specific Tools

Urban Forest Management Plans (UFMP) - A UFMP is a defining document that outlines the vision, criteria, and actions for the management of the urban forest. They can address themes such as tree maintenance, planting, climate change, social and educational opportunities, policy and administration, economics, and temporal-spatial time frames (Ordonez, 2013).

Stewardship Programs – Stewardship programs are an educational outreach tool that can include initiatives and groups dedicated to care of the urban forest. Stewardship groups can focus on aspects of tree maintenance, planting, and community education (Schwab, n.d.).

7.0 Conceptual Model for Comprehensive Canopy Regulation for Municipalities in British Columbia

The graphic on the following pages describes how the regulatory tools enabled by BC's institutional frameworks that can be used to protect or grow different types of urban forest canopy.

	PRIVATE FOREST	MUNICIPAL FOREST
REGIONAL GROWTH STRATEGIES (OCP* must be consistent with RGS*)	Encourage development patterns that avoid urban sprawl, minimize risks from natural hazards, protect environmentally sensitive areas (ESAs) and water quality.	Encourage preserving, creating and linking urban and rural open spaces including parks and recreation areas.
OFFICIAL COMMUNITY PLANS & NEIGHBOURHOOD PLANS (Other bylaws must be consistent with OCP*)	Direct development away from ESAs* and environmental hazards. Policies supporting preservation, protection, and enhancement of tree stands and wildlife trees, clustering and density bonusing in exchange for conservation covenants.	Policies supporting the preservation, protection and enhancement of tree stands and wildlife trees. Policies that support clustering and density bonusing in exchange for parkland.
ZONING BYLAWS (Or contained in related land use bylaws for runoff control, parking, landscaping etc.)	Require setbacks from riparian areas and ESAs*, enable clustering and density bonusing, set out standards for preserving, protecting, enhancing and restoring ESAs	At rezoning, parkland acquisitions can be negotiated through density bonusing.
SUBDIVISION SERVICING BYLAWS	Sets standards for drainage and onsite stormwater management that can be made low impact.	Sets standards for drainage and onsite stormwater management that can be made low impact.
DEVELOPMENT PERMIT AREAS	Establish riparian setbacks, ESA* soil and vegetation protection and restoration guidelines, environmental assessment requirements.	DPAs on private land can enhance connectivity, restoration and enhancement of natural areas adjacent to municipal forest.
COVENANTS	Protect natural areas and sensitive ecosystems on title and place maintenance or restoration requirements and restrict actions that could damage the protected features.	
TREE BYLAWS	Regulate all trees in ESAs*, on slopes and significant trees. Specify assessment, protection, replacement standards.	Regulate all municipal trees. Specify assessment, protection, compensation standards.

***Short forms:** ESA – Environmentally Sensitive Area | OCP – Official Community Plan | RGS – Regional Growth Strategy

Tree types: Forest stands and naturalized areas | Urban trees

Jurisdiction: Public | Private

Figure 3. Key regulatory tools in BC that can be used to protect or grow urban forest canopy types (con't on the next page).

MUNICIPAL STREET & PARK TREES	PRIVATE YARD TREES	PRIVATE TREE IN A DEVELOPMENT
Develop settlement patterns that minimize the use of automobiles and encourage walking, cycling and the efficient use of public transit.		
Policies and targets supporting parkland amenity contributions, new parkland, expansion of the urban forest, treed character of streets and areas, integration with goals such as stormwater management, biodiversity, energy conservation and walkability.	Policies supporting the treed character of new landscaping in land uses and neighbourhoods.	Policies and targets supporting tree and canopy retention, protection and enhancement.
At rezoning, negotiate amenity contributions for new parkland. Require setbacks of above and below ground structures, signage and weather protection favourable for street trees.	Require lot sizes, trees per lot, impermeable/ permeable cover, off-street parking, screening | and landscaping, favourable to yard trees.	IMPORTANT: The tree bylaw may not apply to the extent necessary to allow a permitted use or density.
Set standards for boulevard trees, spacing, soil volume, planting standards, access, utilities favourable for street trees.	Set standards for access and utilities placement favourable to yard trees.	Set standards for access and utilities placement favourable to retaining private trees.
	Promote energy conservation, water conservation and reduction of greenhouse gas emissions using trees.	
		Protect trees or tree groups on developing properties, place maintenance requirements and restrict actions that could damage the protected features.
Regulate all municipal trees. Specify assessment, protection, compensation standards.	Regulate certain trees and require a minimum number of trees/canopy per lot. Specify assessment and replacement standards.	Regulate certain trees and require a minimum number of trees/canopy per lot. Specify assessment, protection, replacement standards.

Tree types: Forest stands and naturalized areas | Urban trees

Jurisdiction: Public | Private

For a municipality considering the appropriate regulatory tool/s to select, the Lawrence et al. (2013) model of integrated urban forest governance provides a helpful framework for identifying factors that are important to the decision:

1. **Context:**
    - What are the urban forest canopy types (see Figure 3 on previous page) that are the target of canopy preservation or growth?
    - What level of administration and enforcement effort can be supported by the population size?
    - What level of regulation would align with community values?
2. **Institutional frameworks:**
    - What types of policies, plans and regulations are already in place and how could they be enhanced or complemented with updates or new regulation?
    - Are new policies or plans required to support new regulation?
    - What urban forest canopy or tree targets exist in policies and plans, and can the new regulation be used to achieve them?
3. **Actors and coalitions:**
    - Who are the key stakeholders who need to be consulted?
    - Who needs to support the decision and who will make the final decision?
4. **Resources:**
    - Will funding and staffing need to increase to support the new regulation?
    - What new technical information need to be provided to internal and external stakeholders?
    - Can other policies, programs or staff be able to support implementation of the changes?
5. **Processes:**
    - What are the narratives, conflicts and framing that justify the changes being made?
    - What are the specific ways that actors and stakeholders will be consulted, engaged, involved and empowered in decisions and implementation?
    - How will success be measured and reported in relation to targets?

8.0 Conclusion

A review of the available literature has provided insight into the variety of tree protection methods and their successes and limitations. The literature provides guidance for creating effective tree regulations, including the importance of supporting bylaws with adequate resources for compliance and enforcement, as well as implementing tree bylaws alongside comprehensive plans and strategies, and other regulatory tools and stewardship programs. While there is no one size fits all approach, there are best practices that could improve performance standards. Community engagement is key both to support tree protection efforts, and to develop a bylaw that meets the needs of each local community.

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Appendix 3. Worksheet to Review Higher-Level Plans

Higher Level Planning Tools: Official Community Plan (may also include neighbourhood plans and urban design guidelines)

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
A clearly defined vision that, at the highest level, supports the importance of trees and forests to the community						
The connection between human health and well-being and forests and trees						
Aligning urban forest strategies with transportation, park, and climate plans						
Supporting development and implementation of urban forest and biodiversity conservation strategies						
Natural Environment						
Strategies that support urban forest goals and operational targets including tree canopy extent, planting targets, condition, and distribution, ecosystem services and urban forest system vulnerabilities						
Best management practices for the planting, establishment, maintenance, protection, risk management, and removal of trees						
Protection of significant trees or stands of trees						
Maintaining or enhancing the ecological viability of the urban forest, including supporting a diversity of forest types and a minimum widths/size of retention areas						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Maximizing the retention of existing vegetation and soils through development and infrastructure projects						
Design of new developments to prioritize protection of environmentally sensitive areas identified in a Natural Environment Development Permit area						
Maximizing the retention of existing native vegetation and restoring native vegetation wherever possible during site development in environmentally sensitive areas identified in a Natural Environment Development Permit area						
Provincial or regional conservation planning and priority-setting efforts to conserve biological diversity and protect threatened and endangered species and ecosystems						
An ecosystem-level approach to ecological planning and management to ensure the ongoing function of environmentally sensitive areas, establishment and/ or retention of ecosystem connectivity corridors and the preservation of species at risk						
Strategies to manage and protect rivers, streams, lakes, wetlands, other water bodies, and riparian areas, and to manage stormwater						
Strategies to maintain and improve biodiversity through the establishment and preservation of ecosystem connectivity corridors						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Integrated management options where appropriate, such as prescribed fire, rotational grazing, and natural regeneration to increase forest health and vitality						
Strategies to restore critical habitat and culturally significant vegetation						
Incentives for voluntary environmentally sensitive area protection including allowing increased height and density on the balance of the subject property, transferring density to another property, trading land, purchasing land, offering grants-in-aid, or granting tax exemptions						
Requiring land use and development projects to have "no net loss" of natural ecosystems and their functions as determined through environmental assessment for properties identified in a Natural Environment Development Permit Area, and pursuing net gain overall						
Mitigation sequencing of management actions that could harm trees or habitats by first trying to avoid impacts through siting and design, mitigate impacts where possible, or compensating if the loss is unavoidable						
Compensation requirements for unavoidable losses or trees or habitat						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Stewardship of environmentally sensitive areas on private property through conservation tools such as conservation covenants, land trusts and eco-gifting						
Tools to protect environmentally sensitive areas including dedicating land, returning to Crown Land, covenants, density bonusing, cluster housing, amenity contributions and adequate setbacks						
Initiatives, policies, outreach, or public assistance strategies that encourage private landowners to replace trees that have died or been removed						
Equity						
Equity in planning decisions and resource allocation in the community to ensure that forests and trees are preserved and protected in all neighbourhoods regardless of social, ethnic, or economic demographics						
Strategies to ensure equitable distribution, access and utilization of urban forests, parks and greenspaces						
A commitment to recognize and respect the rights of Indigenous Peoples, including use of available resources and information to identify the Indigenous Peoples whose rights may be affected by the organization's urban forest management activities,						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
recognition of the established framework of legal, customary, and traditional rights such as the Calls to Action from the Truth and Reconciliation Commission and the United Nations Declaration on the Rights of Indigenous Peoples						
Inclusive community engagement, diverse partnerships, equitable protocols, and targeted programming to ensure that forests and trees are planted, preserved, and protected in all neighbourhoods regardless of social, ethnic, or economic demographics						
Land Acquisition						
The acquisition of new parks and protected areas						
Connectivity between parks and public spaces						
Partnerships to acquire and deliver parks and public spaces						
Climate Resilience						
Designing the community to be more resilient to a changing climate including protecting natural areas and habitats, increasing park space and tree canopy cover, and reducing energy consumption by building energy-efficient neighbourhoods						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Green infrastructure strategies to mitigate the effects of urban heat islands, ecological disruption, and social/economic disruption due to climate change						
Encouraging collaboration with Indigenous Peoples to incorporate Indigenous knowledge into climate action						
Encouraging the community to take action to mitigate and adapt to climate change						
Investing in trees and green infrastructure to mitigate and adapt to a changing climate on public land, in urban centres, and in new development						
Encouraging the use of adaptive management strategies in municipal operations to cope with uncertain climate conditions						
Reducing the risk of invasive species and diseases in sensitive ecosystems and where they threaten public health, the economy and the environment						
Urban Design						
Land use-specific guidance protecting and integrating nature and greening, including tree planting in both the public and private realm						
Form and character development permit areas that provide guidelines for incorporating high-quality landscape, and streetscape design to support livability, sustainability, and a sense of place						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Form and character development permit areas that provide guidelines for the design of streets and open spaces, create visual interest, comfort, and safety for pedestrians, and positively contribute to urban ecology and stormwater management (see Toolkit section 5.2.1 for more details on the use of form and character landscaping guidelines)						
Form and character development permit areas that provide guidelines to ensure the provision of adequate servicing, vehicle access, and parking while minimizing adverse impacts on the comfort, safety and attractiveness of the public realm						
Neighbourhood or area plans that guide future development in an area, including the locations of parks and public spaces and development standards to provide a link between the high-level planning found in an Official Community Plan and the regulatory detail of a zoning bylaw						
Public realm design guidelines that describe outcomes expected for urban centres, including public realm typologies, streetscape components, and expectations for the standard of trees, soils and materials installed in the public realm						

Appendix 4. Worksheet to Review Land Use Bylaws and Development Permit Areas

Planning Tools: Zoning bylaw, landscape and screening bylaw, form and character development permit areas, climate change and energy conservation development permit areas, and development procedures bylaw

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Landscaping Standards[1] (Toolkit section 5.2.1)						
RECOMMENDED COMPONENTS – Number of trees:						
Tree density requirement by zone or development type, aligned with selected canopy cover targets						
In surface parking lots associated with commercial, industrial, or office uses, a planting requirement of 1 tree per number of parking spaces (e.g., one tree for every 5-6 parking stalls)						
Between land uses, landscape and screening buffers 3 m or larger to accommodate larger tree species						
RECOMMENDED COMPONENTS – Planting standards:						
Tree size requirements establishing no more than 25% small trees at maturity, no less than 50% large trees and medium trees at maturity to make up the difference						

1 These outcomes could be required in zoning or included as guidelines in a development permit area.

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
A minimum soil volume per tree that is adequate to support it growing to a healthy, mature size, modified for single tree soil volume versus shared tree soil volume						
Reference to meeting or exceeding the Canadian Landscape Standard for installation and maintenance						
Trees species selection from an approved list, and/or reviewed and approved by the local government						
ADDITIONAL OPTIONS:						
Green standard/factor score or sustainability checklist that promotes tree retention (particularly trees of high value to the community or growing in sensitive ecosystems) or planting						
Form and character development permit area landscaping guidelines that support mature trees and forest stand retention and tree planting to achieve community goals (e.g., native plantings, placemaking, shade, energy efficiency, stormwater management) and grow healthy trees						
Guidelines for tree planting for passive solar gain and cooling to reduce energy consumption						
Pervious Surface and Lot Layout Requirements (required in zoning; Toolkit section 5.2.2)						
RECOMMENDED COMPONENTS – Planting area requirement:						
Consolidated pervious areas required by zone or development type aligned with selected canopy cover targets						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Or, in low-rise housing zones, a minimum pervious area requirement of a size sufficient to provide 35 m^2 per tree as aligned with the selected canopy cover targets						
In zones or land uses with high surface coverage, engineered solutions (i.e., soil cells, structural soil) to achieve soil volume under impervious surfaces or above a structure						
RECOMMENDED COMPONENTS – Building setback for trees:						
At least one setback larger than 3 metres, (preferably larger) in the front or rear to make space for tree planting in the ground, except where smaller setbacks are the preferred design outcome, and the public realm frontage will accommodate large trees (see Toolkit section 5.3.2)						
In zones other than low-rise housing, consider applying setbacks to underground structures, except if boulevard width and location compensate for smaller setbacks (see Toolkit section 5.3.2)						
ADDITIONAL OPTIONS:						
The maximum site coverage retains sufficient pervious surface to support the target tree density						
Parking requirements minimized to allow sufficient pervious surface or parking is built with pervious materials to allow soil volume under the surface						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Negotiated Development (Toolkit section 5.2.3)						
Use of amenity density bonusing to protect environmentally sensitive areas, supported by a sustainability checklist or green factor incentive that provides credits based on desirable tree retention or planting in exchange for additional development floor area or density (see section 5.2.1 for examples of green factor scoring systems)						
Comprehensive development zones integrate the relevant requirements to maximize the retention of existing environmental assets, such as setbacks, site coverage, and clustering						
Development Procedures (Toolkit section 5.2.4)						
RECOMMENDED COMPONENTS – Delegated minor variances						
Delegated minor variances are enabled and define the setback, height, and parking variances that applicants must consider retaining significant trees						
PROCEDURAL CONSIDERATIONS						
A requirement for a survey by a BC Land Surveyor that includes the location of existing trees, protected areas, or natural areas, water bodies and water courses as part of an initial application						

Appendix 5. Worksheet to Review Development, Subdivision, and Servicing Bylaws

Planning Tools: Development, subdivision and servicing bylaw

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Procedural Considerations (Toolkit section 5.3.1)						
A requirement for a survey by a BC Land Surveyor that includes the location of existing trees, protected areas, or natural areas, water bodies and water courses as part of an initial application						
Security or bonding for works and services including landscaping, with return subject to local government verification of total performance of works and services						
Option for the applicant to provide a cash payment alternative for the local government to perform the works and services including boulevard construction and tree planting as part of a broader frontage works construction program						
Requirement of a Landscape Architect to undertake the design, inspection, testing and record keeping of landscaping requirements						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Procedural Considerations (Toolkit section 5.3.1)						
RECOMMENDED COMPONENT – Minimum boulevard width for trees:						
Works and service level requirements, and supporting schedules, that require boulevards of sufficient width to support tree planting (>1.5 m without utilities in boulevard, >2.0 m with utilities sharing boulevard), landscaping and trees as standard for most road classifications						
Boulevard located between the curb and sidewalk if seeking canopy closure above the street						
Landscaping Criteria, Standards, and Specifications (Toolkit section 5.3.3)						
RECOMMENDED COMPONENT – Landscaping:						
Requiring a minimum number of street trees based on species size and spacing per linear frontage, encouraging preferred tree size/canopy cover target outcomes by road classification						
Selection and siting of urban trees in pavement to eliminate long term above-ground and below ground conflicts with utilities, buildings and structures, and pedestrian and vehicular traffic						
Tree planting setback distances from intersections, streetlights, utilities, etc. do not prohibit tree planting in most streetscapes						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Requiring a minimum soil volume per tree that is adequate to support its growth to a healthy, mature size						
Specifying the basic sod boulevard and median treatments and defining where treatments will be varied based on location (e.g., adjacent to commercial properties, urban centre development permit areas, streetscape improvement plan areas) to provide hard surface materials, soil cells to extend soil volume under hard surfaces, or other landscaping						
Trees and plant species selection from an approved list, and/or reviewed and approved by the local government						
Continuous tree planting trenches encouraged						
Root barriers used when tree pit or boulevard opening width is less than 2 metres						
Irrigation installed where needed and when boulevards are covered with hard surface materials that are not permeable						
Alternatives to tree grates are provided (e.g., bonded gravel, compacted sand)						

Does your plan contain policy direction that addresses the following?	Yes	No	Partially	N/A	Priority to Update?	Notes for update:
Construction standards require at least 1 year maintenance post-planting and a landscape completion certificate prior to acceptance by the municipality						
Supplemental standards to MMCD detail growing medium composition and depth (minimum 0.6 m to preferred 1 m), options for reuse of native topsoil, compost, structural soil, soil cells, planting standards for landscape trees, riparian and restoration planting, stock quality and irrigation systems						
Encourages underground utilities to be aligned and buried to provide a continuous 1 m deep utility-free trench beneath tree planting locations. When the distance from the property line to utilities is insufficient to accommodate a utility-free trench, the difference should be provided as a statutory right-of-way on the adjacent property						
ADDITIONAL OPTIONS:						
Provides standards to enable solutions to maximize retention potential, planting space and quality for tree health, such as perforated curbs curb bulges, suspended slab sidewalk or bike lanes, permeable pavement, siting responsive to site conditions						

metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

E5

To: Regional Planning Committee

From: Stefanie Ekeli, Regional Planner, Regional Planning and Housing Services

Date: March, 15, 2024 Meeting Date: April 5, 2024

Subject: **2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver**

RECOMMENDATION

That the MVRD Board:

a) receive for information the report dated March 15, 2024, titled, "2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver"; and
b) forward the "2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver" and its attachment to member jurisdictions for information with an offer for Council presentations upon request.

EXECUTIVE SUMMARY

The 2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver found that there has been a substantial increase in child care spaces in the region, from 18.6 spaces per 100 children under 12 in 2019 to 25.1 in 2023. This is a 35 percent increase. The positive results are likely directly related to the significant increase in funding provided from the Provincial and Federal Governments under the ChildCareBC strategy, the notable increase of stand-alone child care strategies in local governments across the region, and other regulatory tools such as zoning and financial incentives. Metro Vancouver updates the Survey every four years. The 2023 update of the Survey reflects the current inventory of the total number of child care spaces in the region. In addition, the municipal mail-out survey that is undertaken in support of the update was expanded to capture a more robust view and a better understanding of the challenges of current child care planning in the region.

PURPOSE

To share the results of the 2023 Survey of Licensed Child Care Spaces in Metro Vancouver with the Regional Planning Committee and MVRD Board to support local government planning for child care.

BACKGROUND

The Survey of Licensed Child Care Spaces and Policies in Metro Vancouver is updated every four years. The first two iterations of the Survey were published by Metro Vancouver in 2011 and subsequently updated and released in 2015 and 2019 (References 1,2, and 3). The 2023 Survey update expands on the 2019 iteration by establishing a Peer Review Group to help inform and guide the project, and to ensure data accuracy and comprehensiveness in capturing a more robust view and a better understanding of the challenges of current child care planning in the region (Attachment 1). The 2023 Survey expands analysis to include an assessment on the number of child care spaces per 100 children for the three Group Child Care licence types.

Child Care Planning in British Columbia

In British Columbia, child care planning is a shared responsibility among the BC Government, health authorities, local governments, First Nations, the not-for-profit sector, and the private sector. The role of the BC government has become increasingly important since 2018 with the launch of the ChildCareBC strategy. With this strategy, the Province and the Federal Government have boosted funding for local governments, Indigenous communities, not-for-profit organizations, families, and child care workers to support child care space creation, to make child care more affordable for families, and to increase the recruitment and retention, and enhance wages, of Early Childhood Educators.

Data contained in the 2023 Survey is intended to help support child care planning work, including applications for funding through ChildCareBC, in Metro Vancouver municipalities.

KEY FINDINGS OF THE 2023 SURVEY

The 2023 Survey provides a more robust discussion on the findings of the estimated and projected number of children aged 12 and under, and the number of child care spaces in Metro Vancouver. The following are the key findings:

- The number of children under the age of 12 is expected to continue to grow slightly in the near term by 1.1 percent (from an estimated 323,796 in 2023 to 327,397 in 2028);
- The number of child care spaces in Metro Vancouver grew by 35 percent between 2019 and 2023 (up from 60,970 to 81,264);
- As of 2023, Metro Vancouver has on average 25.1 spaces per 100 children 12 and under, which is an increase of 6.5 spaces per 100 children aged 12 and under from 2019 (35 percent increase, but remains slightly below the 2021 national average of 29 spaces but above the BC average of 21 spaces);
- As of 2023, Metro Vancouver has an average of 13.9 spaces per 100 children aged 0-3 (Group Child Care under 36 months), 38.7 spaces per 100 children aged 3-5 (Group Child Care 30 months to School Age), and 9 spaces per 100 children 5-12 (Group Child Care School Age);
- The survey results show that the major challenges in the provision of child care are mainly:
    - Lack of funding to cover capital operating and maintenance costs and operator lease / rent challenges;
    - Staffing shortages / low wages for child care workers;
    - Insufficient provincial funding to build new spaces; and
    - Persistent demand for new child care spaces;
- 16 respondents support child care through building space (e.g., rent-free, reduced lease, or market lease);
- 16 respondents have staff resources dedicated to child care work and 9 respondents have a dedicated staff person specifically for child care work; and
- 14 of 21 respondents have $10/day child care facilities within their communities offering affordable child care to families.

MUNICIPAL MAIL-OUT SURVEY RESULTS

Local governments play a key role in enabling an adequate supply of child care spaces. One way that local governments can support the creation of child care spaces could include developing a local child care plan, strategy or bylaw that outlines municipal policies for child care provision. According to the 2023 Municipal Mail-out Survey, 15 of 20 (75 percent) of survey respondents have a stand-alone child care strategy, which is substantially higher than reported in 2019 (8 of 21 respondents, or 38 percent). In addition: 14 of 19 respondents noted addressing child care in Official Community Plans; 7 of 16 respondents address child care in Social Plans; 15 of 21 respondents identify child care as a community amenity; and 4 of 20 survey respondents identified that their local government has a Child Care Bylaw.

Although child care licensing is regulated by the Health Authorities, local governments also play a role in regulating child care through zoning and business licensing. Of the survey respondents, the majority of local governments permit child care in residential, commercial and institutional zones, and approximately half permit child care in industrial zones. The survey results also indicate that local governments often use financial incentives to enhance child care space creation which include the use of municipal grants, property tax exemptions or tax dollars used to support operation and maintenance fees, developer incentives, and the use of municipal building space by child care providers. In some cases, local governments also own child care facilities and/or partner with child care providers for the operation of facilities. The survey results show that the majority of local governments own child care facilities, and roughly half partner with child care providers for their operation.

The results of the Municipal Mail-out Survey signify that local governments have placed a greater emphasis on increasing the number of child care spaces within their communities since the 2019 survey through use of available regulatory tools and financial resources and incentives. While the results from the 2023 Survey show a positive outlook for child care space creation in the region, local governments still face challenges to meet child care needs including lack of funding, staffing shortages / wages, and persistent demand.

ALTERNATIVES

1. That the MVRD Board:
   a) receive for information the report dated March 15, 2024, titled, “2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver”; and
   b) forward the “2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver” and its attachment to member jurisdictions for information with an offer for Council presentations upon request.

2. That the Regional Planning Committee receive for information the report dated March 15, 2024, titled “2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver”, and provide alternate direction to staff.

FINANCIAL IMPLICATIONS
There are no financial implications to this report. The report was completed as part of the Board approved Regional Planning 2023 work plan.

NEXT STEPS
It is recommended that copies of the 2023 Survey of Licensed Child Care Spaces in Metro Vancouver be forwarded to all member jurisdictions for information. The final report will also be posted on the Metro Vancouver website for download. Staff are available to present the report to Councils upon request.

CONCLUSION
Regional Planning has prepared the *2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver*. The report updates previous child care surveys prepared by Metro Vancouver in 2011, 2015, and 2019. The 2023 Survey found that there has been a substantial increase in child care spaces in the region, from 18.6 spaces per 100 children under 12 in 2019 to 25.1 in 2023, which is a 35 percent increase. This substantial increase can be correlated to the significant increase in funding provided from the Provincial and Federal Governments under the ChildCareBC strategy. The 2023 Survey also found that local governments are taking a range of approaches to facilitate child care provision and operation in their local context but are still facing various challenges associated with the provision of child care. This information is intended to support member jurisdictions and local governments in planning for complete communities and supporting the economy, thereby supporting the implementation of Goals 1 and 2 of *Metro 2050*.

ATTACHMENT
1. 2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver

REFERENCES
1. A Municipal Survey of Child Care Spaces and Policies in Metro Vancouver, 2011
2. A Municipal Survey of Child Care Spaces and Policies in Metro Vancouver, 2015
3. 2019 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver
4. ChildCareBC, Province of British Columbia

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2023 Survey of Licensed Child Care Spaces in Metro Vancouver

December 2023

Prepared by: Metro Vancouver Regional Planning

Indigenous Territorial Recognition

Metro Vancouver acknowledges that the region’s residents live, work, and learn on the shared territories of many Indigenous peoples, including 10 local First Nations: q̓ićəy̓ʼ(Katzie), q̓ʷɑ:n̓ƛ̓ən̓ (Kwantlen), kʷikʷəƛ̓əm (Kwikwetlem), máthxwi (Matsqui), xʷməθkʷəy̓əm (Musqueam), qiqéyt (Qayqayt), se’mya’me (Semiahmoo), Sḵwx̱wú7mesh Úxwumixw (Squamish), scəw̓aθən məsteyəxʷ (Tsawwassen) and səlilwətaɬ (Tsleil-Waututh).

Metro Vancouver respects the diverse and distinct histories, languages, and cultures of First Nations, Métis, and Inuit, which collectively enrich our lives and the region.

Thank you

Many thanks to the members of the Peer Review Group who helped guide and inform this study. We are grateful to the following individuals who participated in the Peer Review Group and shared their expertise and knowledge in support of the project:

- Chris Duggan, Acting Manager, Community and Social Development, City of Richmond
- Tiffany Mallen, Planner I, Child Care, Community and Social Development, City of Richmond
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- Marylyn Chiang, Senior Policy Analyst, Union of BC Municipalities
- Tracy Hoskins, Project Lead, Wellness Promotion, Fraser Health Authority
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- Sally McBride, Senior Policy Lead, Vancouver Coastal Health Authority
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Contents

Introductions and Key Findings

Introduction

Access to quality child care is vital to the well-being of working families and children, is a fundamental ingredient for regional economic prosperity, and is a critical component of complete and equitable communities. Access to convenient and affordable child care supports families in many ways, enabling parents to work or pursue education outside the home, and quality care in early childhood supports school readiness and healthy child development. Child care can often be a major household expense for families, and thus affordability of child care is of critical importance. Child care availability is also essential for economic development in the region – lack of appropriate, accessible, and affordable child care can negatively impact employee recruitment and retention which in turn stunts productivity as well as the financial wellbeing of families. For these reasons, child care supply, accessibility, quality, and affordability that keeps up with growth continues to be priority issues in Metro Vancouver.

Metro 2050, the Regional Growth Strategy, sets out the long-term regional vision for livability, sustainability and prosperity. It includes the following two strategies and two specific policies, which are new from *Metro 2040*, that require Metro Vancouver to support member jurisdictions to better plan for child care and adopt policies that advance the creation of child care spaces in compact, complete communities:

Strategy 1.2 Focus Growth in Urban Centres and Frequent Transit Development Areas:

Member Jurisdictions will:

1.2.24 Adopt Regional Context Statements that:

vi) consider support for the provision of child care spaces in Urban Centres and Frequent Transit Development Areas;

Strategy 1.3 Develop resilient, healthy, connected, and complete communities with a range of services and amenities

Metro Vancouver will:

1.3.1 Support member jurisdictions and work with First Nations and other agencies in developing resilient, healthy, connected, and complete communities through regional strategies, research, and best practices that:

a) promote greater local access to affordable community services and child care, healthy food, and public spaces (including regional parks and greenways);

Member Jurisdictions will:

1.3.7 Adopt Regional Context Statements that:

b) locate and support community, arts, cultural, recreational, institutional, medical/health, social service, education and child care facilities, and local serving retail uses in Urban Centres or areas with good access to transit.

The role of the Province in the development and provision of child care spaces has become increasingly important since 2018. The Province provides operating funds, child care subsidies and capital funding through the ChildCareBC strategy, which was launched in 2018. Under the ChildCareBC strategy, the Province, along with the Federal Government, have boosted funding for local governments, Indigenous communities, not-for-profit organizations, families, and child care workers to support child care space creation, to make child care more affordable for families, and to increase the recruitment and retention, and enhance wages, of Early Childhood Educators (ECE). The Province also licenses and regulates child care facilities through the Health Authorities, and liaises with local governments and child care providers. In 2022, the Province shifted the responsibility of child care into the Ministry of Education and Child Care, which signified important early learning opportunities and support for the future educational success of children.

Local governments also play a significant role in the provision of child care spaces. Local governments regulate land use and development, which affects the size, location, and operation of child care facilities much of which is not regulated by the Province through health and safety regulations or *BC Building Code* requirements. Local governments also aim to facilitate the provision of additional quality child care spaces in a number of ways, in the right locations to match their growing populations.

Community stakeholders including not-for-profit and private operators, developers, and parents also play important roles in the development and operation of child care facilities. The *2023 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver* (2023 Survey) is concerned primarily with the municipal role in child care, and it is prepared as a resource for municipal government planners and policy makers. Therefore, this report presents an up-to-date inventory of child care spaces in the region and the findings of a region-wide municipal survey of policies and regulations relating to the provision of child care spaces.

The 2023 Survey was completed with the guidance and support of a child care expert Peer Review Group, which comprised staff representatives from municipalities, Health Authorities, the Union of British Columbia Municipalities, and in cooperation with the members of the Regional Planning Advisory Committee Social Issues Subcommittee. The intent of the Peer Review Group was to help inform and guide the project, to ensure for data accuracy and to update the 2019 municipal survey to capture a more robust view of and to better understand the challenges of current child care planning in the region.

Specifically, the 2023 Survey highlights the number of children 0-12, the number of all child care spaces, the number of child care spaces for the three group child care licence types, and local government policies and resources that aim to facilitate and enhance the supply of child care spaces in the region. These include: planning policies, zoning regulations, business licence requirements and fiscal actions. Appendix A provides a detailed inventory of child care spaces, by community, using data from the Vancouver Coastal and Fraser Health Authorities collected in May 2023. Appendix B summarizes the relevant zoning, planning and regulatory policies and financial contributions. Appendix C shows the number of regulated spaces available per 100 children under 12 by province and territory, as reported by the *2021 Early Childhood Education and Care in Canada* report.

Key Findings of the 2023 Survey

- The number of children under the age of 12 is expected to continue to grow slightly in the near term by 1.1 percent (from an estimated 323,796 in 2023 to 327,397 in 2028).
- As of 2023, the number of child care spaces grew by 35 percent (up from 60,970 in 2019 to 81,264 in 2023) in Metro Vancouver.
- As of 2023, Metro Vancouver has on average 25.1 spaces per 100 children 12 and under, which is an increase of 6.5 spaces per 100 children 12 and under from 2019 (35 percent increase), but remains slightly below the 2021 national average of 29 spaces but above the BC average of 21 spaces.
- As of 2023, Metro Vancouver has an average of 13.9 spaces per 100 children 0-3 (Group Child Care under 36 months), 38.7 spaces per 100 children 3-5 (Group Child Care 30 months to School Age), and 9 spaces per 100 children 5-12 (Group Child Care School Age).
- The survey results show that major challenges in the provision of child care are mainly:
  - Lack of funding to cover capital operating and maintenance costs and operator lease/rent challenges;
  - Staffing shortages / low wages for child care workers;
  - Insufficient provincial funding to build new spaces;
  - Persistent demand for new child care spaces.
- 15 respondents have a standalone child care strategy and identify child care facilities as a community amenity in the development approvals process.
- 5 respondents have a standalone child care bylaw for the provision of child care.
- 16 respondents support child care through the provision of local governments building space (e.g., rent-free, reduced lease, or market lease).
- 16 respondents have staff resources dedicated to child care work and 9 respondents have a dedicated staff person specifically for child care work.
- 7 respondents offer grants for child care capital projects; 3 offer grants for child care operating costs; and 7 offer property tax exemptions for child care provision.
- 14 of 21 respondents have $10/child care facilities within their communities offering affordable child care to families.

Provincial Role in Child Care

Child Care Regulation in British Columbia

The Province of British Columbia regulates licensed child care facilities under the *Community Care and Assisted Living Act, Child Care Licensing Regulation*, and the standards of practice. There are four broad types of child care in British Columbia: Licensed, Registered Licence-Not-Required, Licence-Not-Required, and In-Child's-Own Home Care (Table 1). Only licensed child care spaces are inventoried in this report.

Under the *Community Care and Assisted Living Act and Child Care Licensing Regulation*, Health Authorities are legislated to issue child care licences, inspect facilities, suspend of cancel licences and investigate complaints. In British Columbia, there are ten different categories for licensed care, which are summarized in Appendix D. A change in the 2023 Survey from the 2019 report is the introduction of two new licensed child care categories in 2022: School Age Care on School Grounds and Recreational Care.

TABLE 1: TYPES OF CHILD CARE IN BRITISH COLUMBIA

CHILD CARE TYPE	REGULATORY REQUIREMENTS
Licensed	Monitored and regularly inspected by regional health authorities; they must meet specific requirements for health and safety, staffing qualifications, record keeping, space and equipment, child-to-staff ratios, and programming.
Registered Licence-Not-Required	Registered licence-not-required child care providers are unlicensed but have registered with a Child Care Resource and Referral Centre. To become a registered licence-not-required provider, operators must have completed a criminal records check, character references, a home safety assessment, first aid training, and child care training. Licence-not-required child care providers are allowed to care for up to two children (or a sibling group) who are not related to them.
Licence-Not-Required Child Care	Unlicensed child care providers can operate legally in BC and are allowed to care for up to two children (or a sibling group) who are not related to them; they may be operating illegally if they have more children in their care than permitted. There is no monitoring or inspection and no health or safety standards.
In-Child's-Own Home Care	This type of unlicensed care is when parents arrange for child care of their own child within their own home – like a nanny, family member, or a child-minder. There are no legal requirements for monitoring this type of care.

ChildCareBC Program

In response to the lack of availability and affordability of licensed child care for families in British Columbia, the Province launched the ChildCareBC program with the aim to create universal child care that is affordable and available for all families. Launched in 2018, the ChildCareBC program is the platform through which the investments and partnerships between the Government of Canada and the Province of British Columbia are implemented. Through the Early Learning and Child Care Agreement, a bi-lateral agreement between the Province of British Columbia and the Government of Canada, the Province has committed to invest $5.2 billion in child care from 2018-2025 and the Federal government has committed to investing a total of $3.2 billion from 2021-2026.[1]

ChildCareBC offers various funding programs to support families, local governments, Indigenous communities, not-for-profit organizations, and child care workers to enhance the quality, affordability, accessibility, and inclusivity of child care. Those programs include:

- New Spaces Fund Primary Stream and School Age Care on School Grounds Stream;
- $10/day ChildCareBC Centre Program;
- Child Care Operating Funding:
  - Child Care Fee Reduction Initiative;
  - ECE Wage Enhancement Program;
- Maintenance Fund; and,
- Aboriginal Supported Child Development and Supported Child Development programs.

To date, the ChildCareBC program has been highly successful for both creating new spaces and making child care affordable for families. Since 2018, the Metro Vancouver region has seen an increase of 68,640 child care spaces funded through the New Spaces Fund and the $10/day ChildCareBC Centre Program.[2] In addition, over 2000 Indigenous led child care spaces were created in British Columbia through ChildCareBC New Spaces Fund. In terms of affordability, the Province reached its goal to cut fees for child care by 50 percent, largely due part by the child care fee reduction initiative and expansion of the $10/day ChildCareBC Centre program. Lastly, to further advance the goal of universal child care, the responsibility of child care moved from the Ministry of Child and Family Development to the newly named Ministry of Education and Child Care in April 2022. This shift signalled the need to bring more certainty and reliability to child care and also the need to recognize child care as a core service of government and education.

1 Government of British Columbia. "B.C. Reaches Milestone in Newly Funding Child Care Spaces." May 2, 2022.

2 Government of British Columbia. B.C. Child Care Data and Reports. October 3, 2023.

Data Sources

Child Care Spaces: In British Columbia, health authorities are responsible for licensing child care. To support the 2023 Survey, Vancouver Coastal Health and Fraser Health Authorities provided the data for the Metro Vancouver region (current as of May 2023). The 2023 Survey uses data of licensed facilities, and does not include child care facilities located on First Nations reserve lands with the exception of Tsawwassen First Nation.

Child Care Policies: Local governments develop policies, land use plans, bylaws, and business licensing requirements for child care. In Metro Vancouver there are 20 municipalities, one Treaty First Nation (Tsawwassen First Nation), and one electoral area (Electoral Area A). Within Electoral Area A, University of British Columbia (UBC) Campus and Community Planning is the entity responsible for land use planning and licensing on campus while planning and licensing in the unincorporated University Endowment Lands (UEL) is conducted by a manager appointed by the Ministry of Municipal Affairs. The remaining areas of Electoral Area A are administered by Metro Vancouver. Child care policies are reported for UBC Campus and UEL separately.

Number of Children: Metro Vancouver's Regional Planning and Housing Services Department provided data on the estimated number of children by community for 2023 and projected for 2028.

Data for small communities including Tsawwassen First Nation, UBC Campus, UEL, and the Villages of Lions Bay, Anmore, and Belcarra was not available in previous child care inventories. In the 2019 and 2023 version of the Survey this data is provided, where available. Note: due to differences in the number of communities surveyed between 2011, 2015, 2019, and 2023, the data is not always directly comparable over time.

Demographic Profile of Metro Vancouver's Children

The estimated number of children under the age of 12 in Metro Vancouver is expected to grow slightly in the near term. In 2019, there was an estimated total of 325,142 children under the age of 12 living in the Vancouver Census Metropolitan Area (CMA), and in 2023 that number is estimated to be 323,796, which is a decrease of 1,346 children aged 0-12 (Table 2, and Table 3 for the 2023 estimated population of children by age group). By the year 2028, the projected number of children aged 0-12 is projected to grow by 3,601 to approximately 327,397, or 1.1 percent (Table 2). Nearly half of the projected growth of children under the age of 12 is expected to occur in Surrey, Vancouver, Burnaby, and Richmond, which is the same trend as seen in the 2019 Survey.

The reasons for a decrease in the estimated number of children under the age of 12 from 2019-2023 can be associated with various factors. Metro Vancouver projects population growth using an age cohort model to project the number of children aged 0-12, which was updated in 2023 to reflect data from the 2021 Census and historical data and trends. The Age Cohort Model establishes population by gender and single year of age for a given base year. Then for every subsequent year, the population for that single year of age is predicted by estimating the change in natural increase and migration trends. Demographic components of population growth are expected to generally follow historical trends over the projection period.[3]

By comparing the analysis of the 2016 and 2021 Census years to assess the accuracy of the 2023 projections and better understand the high-level trends, one can see that the results in Table 2 are in line with Statistics Canada's projections, which show a -0.3 percent decrease in children aged 0-5 and an overall increase of children aged 0-12 by 2 percent between 2016 and 2021 (Table 4).[4] Because the children in the 0-5 age cohort will be in the 5-10 age range in 2028, we can expect a slight decrease in the 0-5 age cohort by 2028. Another factor that may be a cause for the decline in number of children aged 0-12 may be a change in fertility rates and number of women of childbearing age given these factors determine the number of newborns in any given year. Between 2019 and 2022, there was a decrease in fertility rates at the regional and municipal levels. To estimate future births, the analysis applies historical data and assumes the change in these historical rates will continue till the year of 2051. This results in lower rates compared to previous projections, and possibly leading to fewer newborns being born over the near-term and therefore, a lower population growth in children aged 0-5.

3 Metro Vancouver Growth Projections – Methodology Report. June 2021.

4 Statistics Canada. Table 42-10-0012-01 Number of children in Canada

TABLE 2: CHANGE IN ESTIMATED NUMBER OF CHILDREN UNDER 12 IN METRO VANCOUVER (FROM 2019-2023) AND CHANGE IN PROJECTED NUMBER OF CHILDREN UNDER 12 IN METRO VANCOUVER (2023 TO 2028)

ESTIMATED NO. OF CHILDREN 12 AND UNDER						PROJECTED NO. OF CHILDREN 12 AND UNDER		
Geographic Area	2019 Est. No. of Children*		2023 Est. No. of Children*		Change in Est. No. of Children (2019-2023)	2028 Proj. No. of Children*		Change in No. of Children (2023-2028)
	No.	%	No.	%	No.	No.	%	No.
Anmore	249	0.1%	266	0.1%	17	237	0.1%	-29
Belcarra	45	0.0%	25	0.0%	-20	35	0.0%	10
Burnaby	29,319	9.0%	29,056	9.0%	-263	30,229	9.3%	1,173
Coquitlam	19,810	6.1%	19,118	5.9%	-692	19,257	5.9%	139
Delta	13,441	4.1%	13,573	4.2%	132	12,643	3.9%	-930
Langley City	3,735	1.1%	4,301	1.3%	566	4,564	1.4%	263
Langley Township	19,585	6.0%	21,108	6.5%	1,523	20,385	6.3%	-723
Lions Bay	157	0.0%	165	0.1%	8	170	0.1%	5
Maple Ridge	12,394	3.8%	13,954	4.3%	1,560	12,906	4.0%	-1,048
New Westminster	8,596	2.6%	9,206	2.8%	610	10,361	3.2%	1,155
North Vancouver City	6,921	2.1%	6,832	2.1%	-89	8,161	2.5%	1,329
North Vancouver District	12,141	3.7%	12,267	3.8%	126	10,572	3.3%	-1,695
Pitt Meadows	2,825	0.9%	2,858	0.9%	33	2,571	0.8%	-287
Port Coquitlam	8,473	2.6%	8,207	2.5%	-266	7,709	2.4%	-498
Port Moody	4,976	1.5%	4,519	1.4%	-457	4,147	1.3%	-372
Richmond	24,713	7.6%	24,507	7.6%	-206	24,280	7.5%	-227
Surrey	82,295	25.3%	81,034	25%	-1,261	81,586	25.1%	552
Tsawwassen First Nation	114	0.0%	334	0.1%	220	307	0.1%	-27
UBC	1,736	0.5%	1,951	0.6%	215	1,949	0.6%	-2
UEL	403	0.1%	394	0.1%	-9	356	0.1%	-38
Vancouver	67,003	20.6%	63,300	19.5%	-3,703	68,822	21.2%	5,522
West Vancouver	4,823	1.5%	5,114	1.6%	291	4,434	1.4%	-680
White Rock	1,390	0.4%	1,707	0.5%	317	1,716	0.5%	9
Vancouver CMA	325,142	100%	323,796	100%	-1,346	327,397	100%	3,601

* Source: Metro Vancouver

TABLE 3: ESTIMATED POPULATION OF CHILDREN AGE 12 AND UNDER, BY AGE GROUP, IN METRO VANCOUVER, 2023

GEOGRAPHIC AREA	2023 ESTIMATED NO. OF CHILDREN 12 AND UNDER*		2023 ESTIMATED POPULATION AGE 12 AND UNDER BY AGE GROUPS			
	No.	%	0 to 2 years	3 to 5 years	6 to 9 year	10 to 12 years
Anmore	266	0.1%	42	42	100	83
Belcarra	25	0.0%	8	5	12	0
Burnaby	29,056	9.0%	6,485	6,507	9,171	6,894
Coquitlam	19,118	5.9%	3,653	3,952	6,456	5,057
Delta	13,573	4.2%	2,367	2,793	4,619	3,795
Langley City	4,301	1.3%	1,062	1,034	1,283	922
Langley Township	21,108	6.5%	4,122	4,553	7,049	5,384
Lions Bay	165	0.1%	25	36	55	49
Maple Ridge	13,954	4.3%	2,644	3,070	4,797	3,442
New Westminster	9,206	2.8%	2,314	2,171	2,768	1,954
North Vancouver City	6,832	2.1%	1,845	1,508	1,934	1,545
North Vancouver District	12,267	3.8%	1,961	2,450	4,256	3,599
Pitt Meadows	2,858	0.9%	543	649	962	704
Port Coquitlam	8,207	2.5%	1,537	1,872	2,720	2,078
Port Moody	4,519	1.4%	857	1,000	1,467	1,195
Richmond	24,507	7.6%	4,573	5,368	8,393	6,174
Surrey	81,034	25.0%	16,479	17,448	26,074	21,032
Tsawwassen First Nation	334	0.1%	81	78	105	71
UBC	1,951	0.6%	313	423	687	528
UEL	394	0.1%	64	87	137	105
Vancouver	63,300	19.5%	15,820	14,828	18,694	13,958
West Vancouver	5,114	1.6%	654	843	1,884	1,734
White Rock	1,707	0.5%	344	349	548	465
Vancouver CMA	323,796	100%	67,793	71,066	104,171	80,768

* Source: Metro Vancouver

TABLE 4: POPULATION OF CHILDREN COMPARISON ANALYSIS BETWEEN 2016 AND 2021 CENSUS DATA

GEOGRAPHIC AREA	CHILDREN AGED 0-12*			CHILDREN AGED 0-5*		
	2016	2021	Change%	2016	2021	Change%
Anmore	310	280	-0.1	90	95	0.06
Belcarra	70	55	-0.21	20	20	0
Burnaby	27160	27965	0.03	12950	12725	-0.02
Coquitlam	19090	18935	-0.01	8325	7880	-0.05
Delta	13775	13790	0	5535	5530	0
Langley City	3445	3935	0.14	1650	1930	0.17
Langley Township	18610	20755	0.12	8085	9055	0.12
Lions Bay	180	160	-0.11	65	70	0.08
Maple Ridge	12445	13850	0.11	5535	6130	0.11
New Westminster	7770	8675	0.12	3860	4250	0.1
North Vancouver City	6235	6295	0.01	2935	2875	-0.02
North Vancouver District	12490	12620	0.01	4985	4895	-0.02
Pitt Meadows	2750	2845	0.03	1265	1270	0
Port Coquitlam	8380	8230	-0.02	3630	3610	-0.01
Port Moody	5195	4650	-0.1	2270	1935	-0.15
Richmond	23395	23955	0.02	10555	10525	0
Surrey	79835	80260	0.01	35210	34010	-0.03
Tsawwassen First Nation	80	290	2.63	30	150	4
Electorial Area A**	2045	2300	0.12	2045	2300	0.12
Vancouver	61550	61145	-0.01	29320	28555	-0.03
West Vancouver	5045	5260	0.04	1615	1755	0.09
White Rock	1515	1665	0.1	655	680	0.04
Vancouver CMA	311,370	317,915	2%	140,630	140,245	-0.30%

* Source: Metro Vancouver

**Includes UBC and UEL

Current Inventory of Child Care Spaces in Metro Vancouver

Significant investments and progress have been made since 2019 for creating child care spaces in the region, reducing fees for families, enhancing the wage grid for child care workers, and enhancing the quality of child care. It has been 5-years since the launch of ChildCareBC program and as the results in the following sections illustrate that the increase in child care spaces can be correlated with the investments the Province and Federal Governments have contributed since the 2019 Survey of Licensed Child Care Spaces and Policies in Metro Vancouver was completed.

2023 Inventory of Child Care Spaces of Children 12 and under

On average, there are 25.1 child care spaces per 100 children aged 12 and under in Metro Vancouver (Table 5). In 2019 there were 18.6 spaces per 100 children aged 12 and under on average, which is an increase of 35 percent over the previous four years. The 2023 average is also much higher than previous reports where on average there were 16 spaces per 100 children reported in 2011 and 18.5 spaces per 100 children reported in 2015 (Table 6).

The ratio of children to child care spaces varies across Metro Vancouver jurisdictions with the highest ratios seen in UBC (51.1 spaces per 100 children) and Tsawwassen First Nation (at 49.1 spaces per 100 children), and the lowest ratios seen in Belcarra (0 spaces per 100 children) and the UEL (12.2 spaces per 100 children). As shown in Table 5, all but two local governments in the region have increased the number of child care spaces. Both the Tsawwassen First Nation and Village of Lions Bay have fewer spaces per 100 children from 2019 to 2023, noting however, Tsawwassen First Nation still has the highest ratio of children to child care spaces.

TABLE 5: ESTIMATED NUMBER OF CHILDREN (0-12) AND CHILD CARE SPACES IN METRO VANCOUVER, 2023

GEOGRAPHIC AREA	2023 ESTIMATED NO. OF CHILDREN 12 AND UNDER*		ESTIMATED NO. OF CHILD CARE SPACES **		CHILD CARE SPACES PER 100 CHILDREN 12 AND UNDER
	No.	%	No.	%	
Anmore	266	0.1%	91	0.1%	34.2
Belcarra	25	0.0%	0	0.0%	0.0
Burnaby	29,056	9.0%	6,433	7.9%	22.1
Coquitlam	19,118	5.9%	5,299	6.5%	27.7
Delta	13,573	4.2%	3,041	3.7%	22.4
Langley City	4301	1.3%	1,280	1.6%	29.8
Langley Township	21,108	6.5%	5,303	6.5%	25.1
Lions Bay	165	0.1%	40	0.0%	24.2
Maple Ridge	13,954	4.3%	3,316	4.1%	23.8
New Westminster	9206	2.8%	3,164	3.9%	34.4
North Vancouver City	6,832	2.1%	1,930	2.4%	28.2
North Vancouver District	12,267	3.8%	4,156	5.1%	33.9
Pitt Meadows	2,858	0.9%	1,260	1.6%	44.1
Port Coquitlam	8207	2.5%	2,794	3.4%	34.0
Port Moody	4,519	1.4%	1,277	1.6%	28.3
Richmond	24,507	7.6%	8,521	10.5%	34.8
Surrey	81,034	25.0%	14,795	18.2%	18.3
Tsawwassen First Nation	334	0.1%	164	0.2%	49.1
UBC	1,951	0.6%	996	1.2%	51.1
UEL***	394	0.1%	32	0.0%	8.1
Vancouver	63,300	19.5%	15,203	18.7%	24.0
West Vancouver	5114	1.6%	1,732	2.1%	33.9
White Rock	1,707	0.5%	437	0.5%	25.6
Vancouver CMA	323,796	100.0%	81,264	100.0%	25.1

* Source: Metro Vancouver

** Source: Fraser Health and Vancouver Coastal Health (data as of May 2023)

*** Source: Licensed spaces received directly from Child Care Centres in UEL (data as of September 2023). UEL does not record data.

TABLE 6: COMPARISON FROM 2011-2023 OF ESTIMATED NUMBER OF CHILDREN AND CHILD CARE SPACES

	2011	2015	2019	2023
VANCOUVER CMA CHILD CARE SPACES PER 100 CHILDREN 12 AND UNDER	16	18.5	18.6	25.1

Metro Vancouver is below the 2021 national average of 29 spaces per 100 children but is ahead of the British Columbia 2021 average of 21 regulated spaces per 100 children. The ratio of regulated child care spaces to 100 children aged 12 and under varies significantly by province, with the highest rate found in Quebec (54 spaces per 100 children) and the lowest rate found in Saskatchewan (10 spaces per 100 children), which remains unchanged from the 2019 reporting.[5] Appendix C shows the national data by province.

In 2011 and 2015 data was not available for a number of the smaller communities in the region including the Villages of Anmore, Belcarra, and Lions Bay, and Tsawwassen First Nation. Additionally, in 2011 and 2015 child care spaces at UBC and on UEL were reported under Vancouver. Excluding the smaller communities listed above, the number of child care spaces region-wide has increase by 20,329 spaces between 2019 and 2023, and by 33,603 between 2011 and 2023 (from 47,547 to 81,060) (Table 7). Looking at the Vancouver Census Metropolitan Area (CMA), including the smaller municipalities, the number of child care spaces has increased by 20,644 spaces between 2019 and 2023 (Table 7).

The rate of increase in spaces was much higher between 2019 and 2023 compared to the years between 2011 and 2019. This is likely directly correlated with the implementation of the ChildCareBC program and the heightened amount of provincial and federal funding contributed to enhance child care space creation.

5 Early Childhood Education and Care in Canada 2021 (13th edition, April 2023), Childcare Resource and Research Unit.

TABLE 7: ESTIMATED CHANGE IN CHILD CARE SPACES (2011, 2015, 2019, 2023

GEOGRAPHIC AREA	2011 SPACES	2015 SPACES	2019 SPACES	2023 SPACES
Anmore*	Data not available	Data not available	83	91
Belcarra*	Data not available	Data not available	0	0
Burnaby	4,456	4,820	5,062	6,433
Coquitlam	3,369	3,719	4,095	5,299
Delta	2,097	2,260	2,162	3,041
Langley City	197	598	830	1,280
Langley Township	2,502	2,886	3,404	5303
Lions Bay*	Data not available	Data not available	40	40
Maple Ridge	2,205	2,053	2539	3,316
New Westminster	1,337	1,671	2,049	3,164
North Vancouver City	1,256	1,418	1,680	1,930
North Vancouver District	2,988	3,248	3611	4156
Pitt Meadows	500	648	964	1,260
Port Coquitlam	1,714	1,998	2,083	2,794
Port Moody	668	797	1005	1,277
Richmond	4,580	5,462	5,071	8,521
Surrey	6,452	9,675	10,489	14795
Tsawwassen First Nation*	Data not available	Data not available	116	164
UBC	Data not available	Data not available	735	996
UEL	Data not available	Data not available	104	32
Vancouver	Data not available	Data not available	12,758	15,203
Vancouver + UBC + UEL Subtotal**	11,708	14,539	13,597	16,231
West Vancouver	1,142	1,227	1,439	1,732
White Rock	286	348	301	437
Vancouver CMA (excluding smaller communities)*	47,457	57,367	60,464	81,060
Vancouver CMA	not available	not available	60,620	81,264

*In 2011 and 2015 smaller member jurisdictions of Tsawwassen First Nation, Anmore, Belcarra, and Lions Bay were not included.

**In 2011 and 2015 UBC and UEL were counted and reported as part of the City of Vancouver.

2023 Inventory of Child Care Spaces – Group Child Care Licence Types

New to the 2023 Survey is an assessment of the ratio of children to child care spaces for Group Child Care (under 36 months), Group Child Care (30 months to School Age), and Group Child Care (School Age). Access rates were only calculated for the three group child care licence types, because local governments in Metro Vancouver typically only report out on these categories in their child care needs assessment.

It is important to note that the population by age category per licence type is estimated and some ages are rounded up from half ages. For example, population for Group Child Care (30 months to school age) is estimated based on children aged 3-5, given that 30 months is 2.5 years old population estimates were rounded up to age 3 for the purpose of this analysis. For Group Child Care (school age) the age range selected was 5-12 even though some children entering kindergarten may not be 5-years of age upon starting.

Group Child Care (under 36 months)

On average, there are 13.9 spaces per 100 children aged 0-3 in Group Child Care (under 36 months), and in total there are an estimated 12,694 Group Child Care spaces in Vancouver CMA (Table 8). The highest access rates are seen in UBC (45.6 spaces per 100 children aged 0-3), Pitt Meadows (40.3 spaces per 100 children aged 0-3), Tsawwassen (37.4 spaces per 100 children aged 0-3), (Richmond (29.5 spaces per 100 children aged 0-3), and North Vancouver District (25.1 spaces per 100 children aged 0-3). Belcarra, Lions Bay, and UEL have 0 spaces per 100 children aged 0-3, but also have a very low count of children in this category, which implies little need for spaces. Both Vancouver and Surrey have the highest population counts for children aged 0-3 (20,898 and 22,245 respectively) but have two of the lowest number of spaces per 100 children aged 0-3 (Vancouver with 7.5, and Surrey with 9.8) indicating a higher need for more child care spaces in this licence type.

TABLE 8: ESTIMATED NUMBER OF CHILDREN (0-3) AND GROUP CHILD CARE (UNDER 36 MONTHS) SPACES IN METRO VANCOUVER

GEOGRAPHIC AREA	2023 ESTIMATED NO. OF CHILDREN 0-3*		ESTIMATED NO. OF CHILD CARE SPACES - GROUP CHILD CARE (UNDER 36 MONTHS) **		GROUP CHILD CARE (UNDER 36 MONTHS) SPACES PER 100 CHILDREN 0-3
	No.	%	No.	%	No.
Anmore	52	0.1%	8	0.1%	15.4
Belcarra	8	0.0%	0	0.0%	0.0
Burnaby	8,666	9.5%	1,276	10.1%	14.7
Coquitlam	4,949	5.4%	662	5.2%	13.4
Delta	3,235	3.6%	239	1.9%	7.4
Langley City	1,410	1.5%	285	2.2%	20.2
Langley Township	5,542	6.1%	1,023	8.1%	18.5
Lions Bay	40	0.0%	0	0.0%	0.0
Maple Ridge	3,579	3.9%	370	2.9%	10.3
New Westminster	3,034	3.3%	602	4.7%	19.8
North Vancouver City	2,351	2.6%	514	4.0%	21.9
North Vancouver District	2,732	3.0%	686	5.4%	25.1
Pitt Meadows	745	0.8%	300	2.4%	40.3
Port Coquitlam	2,140	2.3%	425	3.3%	19.9
Port Moody	1,159	1.3%	206	1.6%	17.8
Richmond	6,282	6.9%	1,853	14.6%	29.5
Surrey	22,245	24.4%	2,175	17.1%	9.8
Tsawwassen First Nation	107	0.1%	40	0.3%	37.4
UBC	447	0.5%	204	1.6%	45.6
UEL***	92	0.1%	0	0.0%	0.0
Vancouver	20,898	22.9%	1,573	12.4%	7.5
West Vancouver	915	1.0%	204	1.6%	22.3
White Rock	480	0.5%	49	0.4%	10.2
Vancouver CMA	91,108	100%	12,694	100%	13.9

*Source: Metro Vancouver

**Source: Licensed spaces by Fraser Health and Coastal Health, May 2023

***Source: Licensed spaces from Child Care Centres in UEL. UEL does not record data

Group Child Care (30 months to School Age)

On average, there are 38.7 spaces per 100 children aged 3-5 in Group Child Care (30 months to school age). In total, there are an estimated 27,511 Group Child Care spaces in Vancouver CMA (Table 9). The majority of municipalities tend to be above the Vancouver CMA average, with a few resting just below the average. Belcarra and UEL have 0 Group Child Care spaces, but also have very low population count of children in this category which may indicate there is little need for this child care type within these communities. In comparison to the ratio of children aged 0-3 to the number of spaces of Group Child Care (under 36 months) (Table 8), Group Child Care (30 months to school age) shows a much higher access rate (Table 9). This could be because of the different requirements for staff qualifications and a higher staff to child ratio between the two licence types (see Appendix D for specific requirements). Also, the population of children ages 3-5 is lower by 20,042 (Table 9) than the population of children aged 0-3 (Table 8), indicating that more spaces are needed to accommodate children in the 0-3 age range

TABLE 9: ESTIMATED NUMBER OF CHILDREN (3-5) AND GROUP CHILD CARE (30 MONTHS TO SCHOOL AGE) SPACES IN METRO VANCOUVER

GEOGRAPHIC AREA	2023 ESTIMATED NO. OF CHILDREN 3-5*		ESTIMATED NO. OF CHILD CARE SPACES - GROUP CHILD CARE (30 MONTHS TO SCHOOL AGE) **		GROUP CHILD CARE (UNDER 36 MONTHS) SPACES PER 100 CHILDREN 0-3
	No.	%	No.	%	No.
Anmore	42	0.1%	25	0.1%	59.5
Belcarra	5	0.0%	0	0.0%	0.0
Burnaby	6,507	9.2%	2,273	8.3%	34.9
Coquitlam	3,952	5.6%	2,085	7.6%	52.8
Delta	2,793	3.9%	725	2.6%	26.0
Langley City	1,034	1.5%	441	1.6%	42.6
Langley Township	4,553	6.4%	1,889	6.9%	41.5
Lions Bay	36	0.1%	16	0.1%	44.4
Maple Ridge	3,070	4.3%	844	3.1%	27.5
New Westminster	2,171	3.1%	1,229	4.5%	56.6
North Vancouver City	1,508	2.1%	799	2.9%	53.0
North Vancouver District	2,450	3.4%	1,428	5.2%	58.3
Pitt Meadows	649	0.9%	488	1.8%	75.2
Port Coquitlam	1,872	2.6%	751	2.7%	40.1
Port Moody	1,000	1.4%	484	1.8%	48.4
Richmond	5,368	7.6%	3,682	13.4%	68.6
Surrey	17,448	24.6%	4,846	17.6%	27.8
Tsawwassen First Nation	78	0.1%	52	0.2%	66.7
UBC	423	0.6%	509	1.9%	120.3
UEL***	87	0.1%	0	0.0%	0.0
Vancouver	14,828	20.9%	4,150	15.1%	28.0
West Vancouver	843	1.2%	622	2.3%	73.8
White Rock	349	0.5%	173	0.6%	49.6
Vancouver CMA	71,066	100%	27,511	100%	38.7

*Source: Metro Vancouver. Population estimates are rounded up from 30 months (2.5 years) to 36 months (3 years) for reporting purposes

**Source: Licensed spaces by Fraser Health and Coastal Health, May 2023

***Source: Licensed spaces from Child Care Centres in UEL. UEL does not record data

Group Child Care (School Age)

On average, there are 9 spaces per 100 children aged 5-12 in Group Child Care (school age). In total, there are an estimated 18,747 Group Child Care (school age) spaces in Vancouver CMA (Table 10). The highest ratio of children aged 5-12 per Group Child Care (school age) spaces are seen in Tsawwassen First Nation (23.8 spaces per 100 children aged 5-12), UBC (19.1 spaces per 100 children aged 5-12) Anmore (15.2 spaces per 100 children aged 5-12), and Vancouver (14.7 spaces per 100 children aged 5-12). Following the same trend as the other two Group Child Care licence types, the communities of Belcarra, Lions Bay and UEL have the lowest ratios.

With population of children 0-12 showing a low population growth to 2028 (approximately a 1.1 percent projected growth rate) and with a low child to child care space ratio for this licence type, we can infer that there will likely be an increase in population of school age children (5-12) in the near-term. As such, this could tell us that there is a greater need to create spaces for school age children to accommodate the growth of children entering this the 5-12 age range. Positively however, the Province has created a new child care licence type for school age children (School Age on School Grounds) and has prioritized funding in the New Spaces Fund program for school age space creation, which could mitigate the growth in demand in this age category over time.

TABLE 10: ESTIMATED NUMBER OF CHILDREN (5-12) AND GROUP CHILD CARE (SCHOOL AGE) SPACES IN METRO VANCOUVER

GEOGRAPHIC AREA	2023 ESTIMATED NO. OF CHILDREN 5-12*		ESTIMATED NO. OF CHILD CARE SPACES - GROUP CHILD CARE (SCHOOL AGE)**		GROUP CHILD CARE (SCHOOL AGE) SPACES PER 100 CHILDREN 5-12
	No.	%	No.	%	No.
Anmore	198	0.1%	30	0.2%	15.2
Belcarra	17	0.0%	0	0.0%	0.0
Burnaby	18,284	8.7%	1,436	7.7%	7.9
Coquitlam	12,847	6.1%	1,123	6.0%	8.7
Delta	9,402	4.5%	699	3.7%	7.4
Langley City	2,532	1.2%	145	0.8%	5.7
Langley Township	14,011	6.7%	818	4.4%	5.8
Lions Bay	115	0.1%	0	0.0%	0.0
Maple Ridge	9,305	4.4%	1,018	5.4%	10.9
New Westminster	5,458	2.6%	420	2.2%	7.7
North Vancouver City	3,995	1.9%	416	2.2%	10.4
North Vancouver District	8,773	4.2%	1,171	6.2%	13.3
Pitt Meadows	1,910	0.9%	192	1.0%	10.1
Port Coquitlam	5,432	2.6%	455	2.4%	8.4
Port Moody	3,021	1.4%	272	1.5%	9.0
Richmond	16,464	7.9%	1,657	8.8%	10.1
Surrey	53,078	25.4%	2,429	13.0%	4.6
Tsawwassen First Nation	202	0.1%	48	0.3%	23.8
UBC	1,353	0.6%	259	1.4%	19.1
UEL***	270	0.1%	0	0.0%	0.0
Vancouver	37,553	17.9%	5,504	29.4%	14.7
West Vancouver	3,932	1.9%	561	3.0%	14.3
White Rock	1,107	0.5%	94	0.5%	8.5
Vancouver CMA	209,259	100%	18,747	100%	9.0

*Source: Metro Vancouver. Population estimates are rounded up from 30 months (2.5 years) to 36 months (3 years) for reporting purposes

**Source: Licensed spaces by Fraser Health and Coastal Health, May 2023

***Source: Licensed spaces from Child Care Centres in UEL. UEL does not record data

Child Care Access in British Columbia

Not all families choose or require licensed child care (e.g., some will have a family caregiver, nanny, or other child care option); however, it is clear that the supply of licensed child care is not meeting the demand. The 2023 Statistics Canada Survey on Early Learning and Child Care Arrangements (SELCCA) found that of BC families with children 0-5 years, 58.8 percent had difficulty accessing child care[6]. Of those, the most common types of difficulties encountered in finding child care included the lack of availability in the community (74.4 percent), the affordability of the child care (47.1 percent), finding care that fits the desired work or study schedule (29 percent), finding quality child care (24.5 percent), finding licensed care (29.1 percent), and difficulty finding subsidized child care spaces or spaces eligible for child care fee subsidy (22.3 percent)[7].

According to SELCCA some of the consequences of families having difficulties finding child care include[8]:

- Having to change work or school schedules (40.5 percent),
- Working fewer hours (40.2 percent);
- Postponing return to work (35.4 percent);
- Using multiple care arrangements or a temporary arrangement (33.6 percent);
- Paying more for child care than wanted (32.2 percent);
- Deciding to work from home (19.8 percent);
- Deciding to have parent stay at home with the child (18.2 percent);
- Changing jobs, quitting job or closing business (15.1 percent); and,
- Postponing or discontinuing school or training (9.9 percent).

6 Statistics Canada. Table 42-10-0001-01 Difficulty for parents and guardians in finding a child care arrangement, children aged 0 to 5 years

7 Statistics Canada. Table 42-10-0008-01 Type of difficulty encountered by parents and guardians in finding a child care arrangement, children aged 0 to 5 years

8 Statistics Canada. Table 42-10-0009-01 Consequences of having encountered difficulties in finding a child care arrangement, children aged 0 to 5 years

Local Government Child Care Policies

One way that local governments can enable an adequate supply of child care spaces is by developing a local plan, strategy or bylaw around child care that outlines municipal policies and expectations for child care provision. 15 of 20 respondents in Metro Vancouver have approved a stand-alone child care strategy for their respective community, which is a significant increase from 2019 which showed 8 of 21 municipalities had a standalone child care strategy (Table 11), these include:

- Burnaby;
- Coquitlam;
- Delta;
- Langley City;
- Langley Township;
- New Westminster
- North Vancouver City;
- North Vancouver District;
- Pitt Meadows;
- Port Coquitlam;
- Port Moody;
- Richmond;
- Vancouver;
- West Vancouver District; and,
- UBC.

14 of 19 local governments in Metro Vancouver identify child care objectives and/or policies within Official Community Plans (OCPs). 7 of 16 respondents have a social plan that addresses child care provisions (Table 11).

TABLE 11: CHILD CARE STRATEGIES, PLANS, AND POLICIES IN METRO VANCOUVER

2019 STRATEGIES / POLICIES ON CHILD CARE	2023 ESTIMATED NO. OF CHILDREN 5-12*	
	No.	%
Child Care Strategy / Policy	15 of 20	75%
Child Care is addressed in OCP	14 of 19	74%
Child Care is Addressed in Social Plan	7 of 16	44%
Child Care is defined as Community Amenity	15 of 21	71%
Child Care Bylaw	4 of 20	20%

Source: Metro Vancouver Municipal Survey

*Number of municipalities are based off the number of municipalities that answered the question in the survey.

Over half of the communities (15 out of 21) have identified child care as a "community amenity" in policy documents to encourage the provision of child care facilities through the development approvals process (Table 11), which is up from 11 out of 21 reported in 2019.

The 2023 Survey asked respondents to identify if their municipality has a standalone child care bylaw, which was a new addition for this edition of the survey. 4 of 20 survey respondents identified that their municipality has a child care bylaw to enhance child care provision within their respective communities (Table 11).

Zoning and Business Licence Bylaws for Child Care Facilities

Local governments have two main roles when it comes to regulating child care – zoning and business licensing. Zoning for child cares refers to indicating where child care uses are permitted. Local governments are also responsible for issuing business licences. There may be different requirements for home-based businesses. Municipal business licensing of child care spaces is a separate process from health authority licensing.

17 of 20 local governments in the region permit child care facilities in single-detached residential zones and in institutional zones. Outside of these two zones, communities vary as to other zones where child care facilities may be located (see Table 12 and Appendix B). The majority of Metro Vancouver communities permit child care in multi-unit residential zones such as duplex (13 of 18 municipalities), row house and townhouse zones (13 of 18 municipalities), apartment zones (15 of 19 municipalities), and mixed use/comprehensive development zones (17 of 19 municipalities).

TABLE 12: ZONING AND BUSINESS LICENCE REQUIREMENTS FOR CHILD CARE FACILITIES IN METRO VANCOUVER

ZONING AND BUSINESS LICENCE REQUIREMENTS	NUMBER OF MUNICIPALITIES	
	No.	%
Zoning Classification That Allows Child Care		
Residential zones:		
Single-Detached	17 of 19	89%
Duplex	13 of 18	72%
Row Townhouse	13 of 18	72%
Apartment	15 of 19	79%
Mixed use / CD Zones	17 of 19	89%
Commercial zones	18 of 19	95%
Institutional	17 of 18	94%
Public Use / Assembly Zones	9 of 12	75%
Industrial zones	9 of 16	56%
Agriculture	6 of 15	40%
Child Care Zone	5 of 12	42%
Additional Zoning or Licence Requirements		
Municipal Business Licence Required	17 of 21	81%
Parking Requirements (primary use child care)	18 of 19	95%
Parking Requirements (accessory use child care)	16 of 17	94%
Non-resident staff are permitted in home-based child care (additional staff to assist resident)	17 of 19	89%
Additional Outdoor Play Space Requirements Above Provincial Regulations.	8 of 20	40%
Municipality secures child care for long-term use	12 of 19	63%

Source: Metro Vancouver Municipal Survey

*Number of municipalities is based off the number of municipalities that responded to the question in the survey

Most communities in Metro Vancouver permit child care facilities in non-residential zones other than public use or assembly zones; 18 of 19 local governments allow child care facilities in commercial zones, 17 of 18 allow child care in industrial zones (although this may not include all types of industrial zones within a community), and 6 of 15 local governments allow child care in agricultural zones (note: not all municipalities have agricultural zoned lands). Although all local governments allow child care facilities in single-detached zones, the number of child care spaces permitted varies (Table 12).

The presence of on-site non-resident staff and parking are other issues addressed by local government bylaw or licensing. Most communities (17 of 19 responses) permit home-based child care services to have non-resident staff. 18 of 19 respondents require parking for child care as a primary use and 16 of 17 require parking for child care businesses as an accessory use.

8 of 20 respondents require additional outdoor play space beyond the provincial minimums. Some require additional outdoor play space in City-owned child care facilities. It is worth noting that the City of Richmond requires city-owned child care facilities to meet the Richmond Child Care Design Guidelines, the City of White Rock has additional outdoor space requirements for commercial zones, and the City of Vancouver's Childcare Design Guidelines make several recommendations beyond provincial health and safety standards for indoor/outdoor space including additional indoor and outdoor space requirements and direct access to outdoors. The City of Vancouver also has building requirements that exceed the *BC Building Code*.

Municipalities can also secure child care for long-term use through various mechanisms such as through municipally-owned facilities, covenants, developer agreements through rezonings, density bonusing, and/or long-term leases. For example, Coquitlam, New Westminster, North Vancouver City, North Vancouver District, Port Moody, Vancouver, and UEL reported that they secure child care for long term use through Section 219 covenants, and Burnaby, Maple Ridge, and Vancouver reported the use of lease agreements to ensure long-term child care. Richmond and Burnaby identified using city-owned facilities to secure child care for long-term use.

Local Government Financial Support and Resources for Child Care Providers

Some communities offer financial and other types of resources to facilitate child care (Table 13). The most common of these is the provision of space to child care providers (15 of 20 municipalities), through either a nominal rate agreement, reduced lease rates, or space at market lease rate within city-owned buildings. Several communities offer grants for child care providers, both for operating costs (3 of 21 respondents) and/or for capital projects (7 of 20 respondents). 7 of 19 respondents offer property tax exemptions for child care facilities and 10 of 18 respondents offer municipal incentives for developers. The details of how funds for grants are established and administered, as well as the criteria for grant eligibility, are unique to each community.

Municipalities provide non-financial resources as well (Table 13). 16 of 21 respondents have a staff resources dedicated to child care work and 9 of 20 have a staff person dedicated to child care work. 13 of 21 Metro Vancouver communities provide local information to assist residents seeking child care and/or people wishing to establish and operate child care facilities (note: Health Authorities and the Union of British Columbia Municipalities also have child care planning guides available).

TABLE 13: LOCAL GOVERNMENT RESOURCES FOR CHILD CARE PROVIDERS

MUNICIPAL RESOURCES FOR CHILD CARE PROVIDERS	NUMBER OF MUNICIPALITIES	
	No.	%
Financial Support / Resources		
Municipal building space available for child care (rent-free, reduced lease, or market lease)	15 of 20	75%
Municipal Grants - for Operating Costs	3 of 21	14%
Municipal Grants - for Capital Projects	7 of 20	35%
Municipal Child Care Reserve Fund	4 of 19	21%
Property tax exemptions	7 of 19	37%
Municipal Incentives for Developers	10 of 18	56%
Other Municipal Support / Resources		
Staff resources dedicated to Child Care work	16 of 21	76%
Dedicated staff person to Child Care work	9 of 21	43%
Child Care Design Guidelines (Operator)	5 of 20	25%
Child Care Information Documents (Resident)	13 of 21	62%
Child Care Technical Guidelines (e.g., specifications for materials, millwork)	11 of 18	61%

Source: Metro Vancouver Municipal Survey

*Number of municipalities is based off the number of municipalities that responded to the question in the survey

Municipal Child Care Operations

Municipalities can also own and operate child care facilities or own facilities to rent or lease to child care operators. Of all 21 responses, 16 local governments indicated that their community owns child care facilities (Table 14). The majority of local governments that own child care facilities lease space to child care providers, with a few operating child care facilities themselves. The primary funding mechanism for municipally owned child care facilities has been through the funding programs provided under the ChildCareBC program (New Spaces Fund and Child Care Operating Funding), Community Amenity Contributions, and municipal tax funding.

10 of 14 respondents use municipal tax dollars to support the operation and maintenance of municipally-owned child care facilities, 7 of 17 respondents charge the tenant for repairs/maintenance and 16 of 19 respondents cover capital/life cycle repairs of municipally-owned child care facilities.

Local governments can also partner with child care providers in the operation of child care. The survey results show that 8 of 19 respondents partner with child care providers. The most common partnerships identified are with School Districts and non-profit societies.

TABLE 14: MUNICIPAL CHILD CARE OPERATIONS

MUNICIPAL CHILD CARE OPERATIONS	NUMBER OF MUNICIPALITIES	
	No.	%
Financial Support / Resources		
Municipally owned Child Care Facilities	16 of 21	76%
Tax dollars to support operation and maintenances of municipally owned child care facilities	10 of 14	71%
Municipality charges tenant for repairs/maintenance	7 of 17	41%
Municipality covers capital/life cycle repairs	16 of 19	84%
Municipality Partners in operation of child care	8 of 19	42%
Municipal staff has priority access to city-owned or operated child care facilities	3 of 20	15%

Source: Metro Vancouver Municipal Survey

*Number of municipalities is based off the number of municipalities that responded to the question in the survey

3 of 20 respondents provide priority access to municipal staff in city-owned or operated child care facilities. The Tsawwassen First Nation (TFN) offers child care spaces to TFN members and staff at a 10 percent discounted rate. The City of West Vancouver offers priority access at two city-owned facilities and UBC offers priority access for academic child care for UBC students, faculty and staff and for prioritizes campus neighbourhood residents for neighbourhood child care spaces.

ChildCareBC $10/Day Child Care Facilities

As part of the ChildCareBC program, the Province of British Columbia has committed to making child care more affordable for families and introduced the $10/day child care program. To date, the $10/day child care program prioritizes spaces for children ages 0-5. The 2023 Survey was updated to identify which municipalities have $10/day sites and how many $10/day sites those municipalities have within their respective communities.

Survey results show that 14 of 21 municipalities have $10/day child care facilities and 10 of 15 respondents said they are municipally-owned (Table 15). The City of Vancouver has the highest number of $10/day child care facilities at 52 facilities (38 of 52 are municipally-owned), followed by UBC with 15 facilities (14 of 15 are municipally-owned), then the Cities of Richmond and Surrey each with 13 facilities (7 of 13 in Richmond and 2 of 13 in Surrey are municipally-owned) and the City of Burnaby with 11 facilities (1 of 11 are municipally-owned) (Appendix B). Notably, the District of North Vancouver has 7 $10/day child care facilities (3 of 7 are municipally-owned) where one of those facilities is located on the Tsleil-Waututh Nation Reserve and prioritizes spaces for Tsleil-Waututh members. The majority of respondents who have $10/day child care facilities lease the space out to child care providers.

TABLE 15: MUNICIPAL $10/DAY CHILD CARE FACILITIES

MUNICIPALITIES WITH $10/DAY CHILD CARE FACILITIES	NUMBER OF MUNICIPALITIES	
	No.	%
Financial Support / Resources		
Municipalities with $10/day child care facilities	14 of 21	67%
Municipally owned $10/day child care facilities	10 of 15	67%

Source: Metro Vancouver Municipal Survey

*Number of municipalities is based off the number of municipalities that responded to the question in the survey

Local Government Challenges in Child Care Provision

The 2023 Survey added a new section to better understand the challenges faced by communities in the provision of child care. 14 responses were received and the top challenges identified include (Table 16):

- Lack of funding (10 of 14);
- Child care staffing shortages/wages (9 of 14);
- Persistent demand for new child care spaces (7 of 14);
- BC New Spaces Fund foes not provide enough funding to build new centres (5 of 14); and
- Land constraints for new child care facilities (5 of 14).
- Other challenges identified include:
- Difficulty realizing affordable child care spaces;
- Park space conflicts;
- Old facilities; and
- Difficulty meeting outdoor play space in higher-density areas.

TABLE 16: CHALLENGES EXPERIENCES BY MUNICIPALITIES IN THE PROVISION OF CHILD CARE

CHALLENGES IN THE PROVISION OF CHILD CARE	NUMBER OF MUNICIPALITIES	
	No.	%
Lack of funding to cover capital/operating/maintenance costs and rent/lease affordability challenges	10 of 14	71%
Child care staffing shortages / child care wages	9 of 14	64%
Persistent demand for new child care spaces (e.g., there is a shortage of out of school care and children under 36 months spaces in 2 municipalities)	7 of 14	50%
BC New Spaces Fund does not provide enough funding to build new centres	5 of 14	36%
Land constraints for new child care facilities	3 of 14	21%
Difficulty realizing affordable child care spaces	2 of 14	14%
Park space conflicts (e.g., City parks and School District playgrounds)	2 of 14	14%
Very old facilities	2 of 14	14%
Difficulty meeting outdoor play space in high-density areas	1 of 14	7%

Source: Metro Vancouver Municipal Survey

*Number of municipalities is based off the number of municipalities that responded to the question in the survey

Conclusions

This report shows that the ChildCareBC program is proving to have a positive impact on the creation of child care spaces since its implementation. Since 2019, there has been an increase of 20,644 spaces in Metro Vancouver which equates to a 35 percent increase in child care spaces across the region. In addition, the ChildCareBC program has and cut the cost of child care in half making child care more affordable for families across the Province. Child care in BC has taken strides to become universal for all families, which is recognized in the shift in responsibility of provincial ministry to the newly named Ministry of Education and Child Care.

Although the number of spaces has significantly increased since 2019 (excluding small communities), Metro Vancouver is slightly below the rate of child care spaces per 100 children under 12 than the Canadian average (i.e., 25.1 in Vancouver CMA compared to 29 nation-wide). Notably however, Metro Vancouver is ahead of the rate of child are spaces per 100 children under 12 when compared to the British Columbia average of 21 regulated spaces per 100 children.

Another noticeable change seen in the 2023 Survey is the much lower population projection from 2023 to 2028. Although both the 2019 and 2023 reports project a growth in children under the age of 12 in the near term, the projection from 2023 to 2028 indicates only a 1.1 percent increase, which is much lower than seen in 2019. This indicates that the number of children in the infant/toddler age brackets is projected to decline whereas the number of school age children (5-12) will grow, resulting in a higher demand for school age child care. This highlights the continued need for local governments, the Province, the not-for-profit sector, the private sector and others to collaborate on projects, programs, and policies that support the creation of new child care spaces to meet the growing demand. It also signifies a stronger need to partner with school districts to ensure sufficient space to meet existing and future demand.

The 2023 Survey shows local governments recognize that child care contributes to the social and economic well-being of communities and many are taking a range of actions to facilitate additional child care spaces in their communities. Most survey respondents permit child care facilities in a range of residential and non- residential areas. Many have a child care strategy in place and/or recognize child care as a community amenity in the development approvals process. Many provide financial or non-financial resources to support new or existing not-for-profit child care facilities.

As the Metro Vancouver region continues to grow, and increasing numbers of families choose to live in denser urban areas close to transit, locating child care in Urban Centres and along the Frequent Transit Network will become increasingly important. By siting child care opportunities in walkable, transit-accessible places “on the way” to other daily destinations, local governments can support more sustainable transportation choices, making it easier and more affordable for families to choose alternatives to personal vehicles. One example of this is co-locating child care facilities on or close to school properties so that children of different ages can be dropped off in one trip. While child care is in demand in all communities across the region, Urban Centres and other appropriate areas long the Frequent Transit Network are key locations for future child care opportunities that will support the region’s growth management, climate action, and social equity objectives into the future.

Appendices

Appendix A – Child Care Space Inventory

GEOGRAPHIC AREA	TOTAL CHILD CARE SPACES				GROUP CHILD CARE (UNDER 36 MONTHS)	GROUP CHILD CARE (30 MONTHS TO SCHOOL AGE)	PRESCHOOL (30 MONTHS TO SCHOOL AGE)	FAMILY CHILD CARE
	2023	2019	2015	2011	2023	2023	2023	2023
Anmore	91	83	n/a	n/a	8	25	20	0
Burnaby	6,433	5,062	4,820	4,456	1,276	2,273	485	225
Coquitlam	5,299	4,095	3,719	3,369	662	2,085	490	244
Delta	3,041	2,162	2,260	2,097	239	725	555	119
Langley City	1,280	830	598	197	285	441	114	28
Langley Township	5,303	3,404	2,886	2,502	1,023	1,889	684	133
Lions Bay	40	40	n/a	n/a	0	16	0	0
Maple Ridge	3,316	2,539	2,053	2,205	370	844	491	238
New Westminster	3,164	2,049	1,671	1,337	602	1,229	170	63
North Vancouver City	1,930	1,680	1,418	1,256	514	799	55	61
North Vancouver District	4,156	3,611	3,248	2,988	686	1,428	300	153
Pitt Meadows	1,260	964	648	500	300	488	151	35
Port Coquitlam	2,794	2,083	1,998	1,714	425	751	282	131
Port Moody	1,277	1,005	797	668	206	484	40	21
Richmond	8,521	5,071	5,462	4,580	1,853	3,682	683	167
Surrey	14,795	10,489	9,675	6,452	2,175	4,846	2,034	356
Tsawwassen	164	116	n/a	n/a	40	52	0	0
UBC	996	735	n/a	n/a	204	509	0	0
UEL	32	104	n/a	n/a	0	0	32	0
Vancouver	15,203	12,758	n/a	n/a	1,573	4,150	2,293	706
Vancouver+UBC+UEL	16,231	13,597	14,539	11,708	n/a	n/a	n/a	n/a
West Vancouver	1,732	1,439	1,227	1,142	204	622	167	7
White Rock	437	301	348	286	49	173	52	21
Vancouver CMA	81,264	60,620	57,367	47,457	12,694	27,511	9,098	2,708

Source: Fraser Health and Vancouver Coastal Health (data as of May 2023). 2011 data table does not show all categories. "Occasional Care" and "Child Minding" are included in the total, although not shown as separate columns.

Appendix A – Child Care Space Inventory

GEOGRAPHIC AREA	GROUP CHILD CARE (SCHOOL AGE)	SCHOOL AGE ON SCHOOL GROUNDS	RECREATIONAL CARE	MULTI-AGE CHILD CARE*	OCCASIONAL CHILD CARE	CHILD MINDING
	2023	2023	2023	2023	2023	2023
Anmore	30	0	0	8	0	0
Burnaby	1,436	252	0	390	0	96
Coquitlam	1,123	282	0	341	0	72
Delta	699	261	155	288	0	0
Langley City	145	84	130	53	0	0
Langley Township	818	500	0	256	0	0
Lions Bay	0	16	0	8	0	0
Maple Ridge	1,018		0	355	0	0
New Westminster	420	528	0	136	16	0
North Vancouver City	416	0	0	85	0	0
North Vancouver District	1,171	42	0	318	58	0
Pitt Meadows	192	24	30	40	0	0
Port Coquitlam	455	488	0	262	0	0
Port Moody	272	162	0	77	15	0
Richmond	1,657	278	0	191	10	0
Surrey	2,429	1,209	0	1,589	84	73
Tsawwassen	48	0	0	24	0	0
UBC	259	24	0	0	0	0
UEL	0	0	0	0	0	0
Vancouver	5,504	270	0	432	213	62
Vancouver+UBC+UEL	n/a	n/a	n/a	n/a	n/a	n/a
West Vancouver	561	60	0	80	31	0
White Rock	94	24	0	24	0	0
Vancouver CMA	18,747	4,504	315	4,957	427	303

Source: Fraser Health and Vancouver Coastal Health (data as of May 2023). 2011 data table does not show all categories. "Occasional Care" and "Child Minding" are included in the total, although not shown as separate columns.

*Categories "Multi-Age Child Care" and "In-Home Multi-Age Child Care" are combined for reporting purposes.

Appendix B – Municipal Survey of Child Care Policies and Initiative

MUNICIPAL SURVEY RESULTS 2023	MUNICIPAL CHILD CARE POLICIES AND INITIATIVES - 2023									
	Burnaby	Coquitlam	Delta	Langley City	Langley Twp	Lions Bay	Maple Ridge	New Westminster	North Van City	North Van District
Planning and Policy										
Child Care Strategy / Policy	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Child Care is addressed in OCP	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Child Care is Addressed in Social Plan	Yes	No	Yes	No	Yes	No	No	Yes	Yes	N/A
Child Care is defined as Community Amenity	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Staff resource dedicated to Child Care work	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
If yes, is there a point person or fully dedicated staff?	No	Yes	No	Yes	Yes	No	Yes	No	No	No
Child Care Design Guidelines (Operator)		No	No	No	P	No	Yes	No	No	No
Child Care Information Documents (Resident)	Yes	Yes	Yes	No	No	No	Yes	Yes	No	Yes
Child Care Bylaw	No	No	No	No	No	No	No	Yes	No	Yes
Child Care Technical Guidelines	No	No	No	No	No	No	Yes	No	No	No
Other Policy items for Day Care	P	Yes	N/A	No	Yes	No	No	Yes		Yes
Financing Tools										
Municipal building space available for child care	Yes	Yes		No	Yes	No	No	Yes	Yes	Yes
Municipal Grants - for Operating Costs	No	No	No	No	No	No	No	No	No	Yes
Municipal Grants - for Capital Projects	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes
Municipal Child Care Reserve Fund	No	Yes	No	No	No	No		Yes	No	No
Property tax exemptions	Yes	No	Yes	No	No	No		No	Yes	Yes
Municipal Incentives For Developers		Yes	Yes	No	No	No		Yes	No	Yes
Is child care creation supported in any other way not listed?	No	No		No	No	No		Yes	No	Yes
Other Financial Items	No	No		No	No	No		Yes	No	
Zoning: Is daycare use permitted?										
Residential zones:										
Single Detached	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes
Duplex	Yes	Yes	Yes	No	Yes	N/A	Yes	Yes	No	Yes
Row Townhouse	Yes	Yes	Yes	No	Yes	N/A	Yes	Yes	No	Yes
Apartment	Yes	Yes	Yes	No	Yes	N/A	Yes	Yes	No	Yes
Mixed use / CD Zones	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes
Commercial zones	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes
Institutional	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes	Yes	Yes
Public Assembly Zones	Yes	No	Yes			N/A		N/A	Yes	Yes
Industrial zones	No	Yes	No	No	Yes	N/A	No	Yes	Yes	Yes
Agriculture	No	No	Yes	No	Yes	N/A	No	No	No	N/A
Other - Child Care Zone (CCR)		Yes	Yes			N/A	Yes	N/A	No	No
Parking requirements - accessory use daycare		Yes	Yes	Yes	Yes	N/A	Yes	N/A	Yes	Yes
Parking requirements - primary use is daycare	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes

Note: Blank cells mean the questions were unanswered.

MUNICIPAL SURVEY RESULTS 2023	MUNICIPAL CHILD CARE POLICIES AND INITIATIVES - 2023										
	Pitt Meadows	Port Coquitlam	Port Moody	Richmond	Surrey	Tsawwassen	Vancouver	West Vancouver	UEL	UBC	White Rock
Planning and Policy											
Child Care Strategy / Policy	Yes	Yes	Yes	Yes	No		Yes	Yes	No	Yes	No
Child Care is addressed in OCP	Yes	Yes	Yes	Yes	No		N/A	No	No	Yes	Yes
Child Care is Addressed in Social Plan	No	No	N/A	Yes	No		N/A	Yes	No	N/A	N/A
Child Care is defined as Community Amenity	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Staff resource dedicated to Child Care work	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
If yes, is there a point person or fully dedicated staff?	No	No	No	Yes	Yes	No	Yes	Yes	No	Yes	
Child Care Design Guidelines (Operator)	No	No	No	Yes	No	Yes	Yes	No	No	Yes	No
Child Care Information Documents (Resident)	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Child Care Bylaw	No	No	No	Yes	No	No	No	Yes	No	N/A	No
Child Care Technical Guidelines	No	No	No	Yes	No	Yes	Yes	No	No	Yes	No
Other Policy items for Day Care	Yes	Yes	No	Yes	No	Yes	Yes		Yes	Yes	No
Financing Tools											
Municipal building space available for child care	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Municipal Grants - for Operating Costs	No	No	No	No	No	No	Yes	No	No	Yes	No
Municipal Grants - for Capital Projects	No	No	No	Yes	No	No	Yes	No	No	N/A	No
Municipal Child Care Reserve Fund	No	No	No	Yes	No	No	Yes	No	No	N/A	No
Property tax exemptions	No	Yes	No	Yes	No	No	No	Yes	No	N/A	No
Municipal Incentives For Developers	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	N/A	No
Is child care creation supported in any other way not listed?	No		Yes	No	Yes	No	Yes	No	No	N/A	No
Other Financial Items				No		No	Yes	No			No
Zoning: Is daycare use permitted?											
Residential zones:											
Single Detached	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	N/A	Yes
Duplex	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	N/A	N/A
Row Townhouse	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	N/A	N/A
Apartment	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	N/A
Mixed use / CD Zones	No	Yes	Yes	Yes	N/A	No	Yes	Yes	Yes	Yes	Yes
Commercial zones	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	No	Yes	Yes
Institutional	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes
Public Assembly Zones	Yes		No	Yes	Yes	N/A	N/A	Yes	No	N/A	Yes
Industrial zones	Yes	No	No	Yes	Yes	N/A	Yes	N/A	No	N/A	N/A
Agriculture	Yes	Yes	No	Yes	Yes	N/A	No	N/A	No	N/A	N/A
Other - Child Care Zone (CCR)	No		No	No	Yes	N/A	No	N/A	Yes	N/A	No
Parking requirements - accessory use daycare	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	No	Yes
Parking requirements - primary use is daycare	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	No	Yes

Note: Blank cells mean the questions were unanswered.

MUNICIPAL SURVEY RESULTS 2023	MUNICIPAL CHILD CARE POLICIES AND INITIATIVES - 2023									
	Burnaby	Coquitlam	Delta	Langley City	Langley Twp	Lions Bay	Maple Ridge	New Westminster	North Van City	North Van District
Business Licence Requirements										
Municipal business licence required	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
- Required only when more than XX children				Yes		No	Yes	Y=8		Y=2
Traffic management plan	Yes	No	No	No		No	Yes	Yes	Yes	Yes
Public consultation	Yes	No	No	No	No	No	Yes	No	Yes	Yes*
Other license requirements				Yes		No	Yes	Yes		Yes
*May be required if a home-based child care facility proposes between 9-10 children; required if a home-based child care facility proposes more than 10 children Note: Above section assumes no rezoning. A rezoning process may require traffic plans and public consultations as part of rezoning process.										
Regulatory Requirements										
Are non-resident staff permitted?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Municipal Building Code Requirements *	No	No	No	No	No		Yes	Yes	No	No
Outdoor Space requirements *	No	No	No	No	No		Yes	Yes	No	No
Does your municipality secure child care for long-term use?	Yes	Yes	No	No	No		Yes	Yes	Yes	Yes
*Requirements beyond those in the provincial legislation.										
Municipal Child Care Operations										
Does your municipality own child care facilities?	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Are tax dollars used to support the operation/ maintenance	Yes		Yes				No		Yes	Yes
Does your municipality charge the tenant for routine repairs/maintenance?		No	No				No	No	Yes	Yes
Does your municipality cover capital or life cycle repairs?	Yes	No	Yes	Yes			Yes	Yes	Yes	Yes
Does your municipality partner in the operation of child care?	Yes	No	Yes	No	Yes		Yes	No	No	Yes
Do municipal staff have priority access to any city-owned or operated child care?	No	No	No	No	No		No	No	No	No
$10/Day Sites										
Does your municipality have any $10/day facilities?	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes
If so, how many?	11	4			4		2	1	4	7*
Are the $10/day sites owned by your municipality?	Yes	No	No		No		No	Yes	Yes	Yes
If so, how many?	1							1	2	3
Do the cost recovery practices differ from other City-owned child care facilities?	No						Yes	N/A	No	No
*One $10/day child care facility is located in the Tsleil-Waututh Nation reserve										
Challenges in the Provision of Child Care										
Challenges are identified and discussed in the body of the report.										

Note: Blank cells mean the questions were unanswered.

MUNICIPAL SURVEY RESULTS 2023	MUNICIPAL CHILD CARE POLICIES AND INITIATIVES - 2023										
	Pitt Meadows	Port Coquitlam	Port Moody	Richmond	Surrey	Tsawwassen	Vancouver	West Vancouver	UEL	UBC	White Rock
Business Licence Requirements											
Municipal business licence required	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
- Required only when more than XX children				Y=10$^+$					No	Y=10$^+$	
Traffic management plan	No	No		No	No	No	No	Yes	No	Yes	No
Public consultation	No	No	No	No	No	No	Yes	Yes	No	Yes	No
Other license requirements	No			No	No	Yes	No		Yes	Yes	No
*May be required if a home-based child care facility proposes between 9-10 children; required if a home-based child care facility proposes more than 10 children Note: Above section assumes no rezoning. A rezoning process may require traffic plans and public consultations as part of rezoning process.											
Regulatory Requirements											
Are non-resident staff permitted?	Yes	Yes	Yes		Yes	Yes	Yes	No		Yes	Yes
Municipal Building Code Requirements *	No	No	No	Yes	No	Yes	Yes	No	No	Yes	No
Outdoor Space requirements *	Yes	No	No	Yes	No	Yes	Yes	Yes	No	No	Yes
Does your municipality secure child care for long-term use?	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	N/A	No
*Requirements beyond those in the provincial legislation.											
Municipal Child Care Operations											
Does your municipality own child care facilities?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Are tax dollars used to support the operation/ maintenance	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	N/A	
Does your municipality charge the tenant for routine repairs/maintenance?	No	No	No	Yes	Yes	No	Yes	Yes	No	Yes	No
Does your municipality cover capital or life cycle repairs?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Does your municipality partner in the operation of child care?	No		No	Yes	Yes	No	No	No	No	Yes	No
Do municipal staff have priority access to any city-owned or operated child care?	No	No	No	No	No	Yes	No	Yes	No	Yes	No
$10/Day Sites											
Does your municipality have any $10/day facilities?	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	No
If so, how many?	1	1		13	13		52	1		15	
Are the $10/day sites owned by your municipality?	Yes	No		Yes	Yes		Yes	Yes		Yes	
If so, how many?	1			7	2		38	Yes		14	
Do the cost recovery practices differ from other City-owned child care facilities?	No			No	No		No	N/A		No	
Challenges in the Provision of Child Care											
Challenges are identified and discussed in the body of the report.											

Note: Blank cells mean the questions were unanswered.

Appendix C – Regulated Child Care Spaces by Province/Territory and Percentage of Children (0-12) for whom there is a Regulated Child Care Space

GEOGRAPHIC AREA	NUMBER OF REGULATED FULL- AND PART-DAY CHILD CARE CENTRE SPACES FOR CHILDREN 0 – 5 YEARS	NUMBER OF REGULATED BEFORE- AND AFTER-SCHOOL CHILD CARE SPACES	NUMBER OF REGULATED FAMILY CHILD CARE SPACES 0 – 12 YEARS	TOTAL NUMBER OF REGULATED CHILD CARE SPACES 0 – 12 YEARS	PERCENT OF CHILDREN 0 – 12 YEARS FOR WHOM A PART- OR FULL -DAY REGULATED SPACE WAS AVAILABLE (%)
Province/Territory					
NL	4,702	2,717	623	8,042	14
PE	3,925	2,439	29	6,393	31
NS	11,959	3,589[1]	1,190	16,738	14
NB	15,222	16,214	980	32,416	34
QC	214,168	340,683	65,281	620,132	54
ON	180,758	283,780	12,734	477,272	25
MB	22,949	12,136	3,312	38,397	18
SK	13,735	1,625	2,306	17,666	10
AB	80,816	50,985	8,708	140,509	20
BC	76,214	38,419	12,729	127,362	21
YT[2]	1,070	388	210	1,869	32
NT	763	808	432	2,003	27
NU	1,052	155	40	1,247	12
CA	627,333	753,938	108,574	1,490,046	29

This includes full-day and part-day programs such as nursery school, not before- and after-school care for kindergarten-age children.

*Source: https://childcarecanada.org/sites/default/files/Early-Childhood-Education-and-Care-2021-REV-12-23_0.pdf page 272

1 The number of before- and after-school spaces for Nova Scotia does not include 672 spaces in Nova Scotia Before- and After- School, so NS spaces are somewhat under-represented.

2 Yukon does not license by age group; enrolment figures are used instead. However, the coverage (%) was calculated based on the total regulated spaces for children 0 – 12.

Appendix D – Licensed Child Care Categories in British Columbia

CHILD CARE LICENCE TYPE	LICENCE REQUIREMENTS*
Group Child Care: Under 3-years old	Ages: 0 to 36 months Max. No. of Children per group: 12 children Child to Staff Ratio: • 1-4 children: One Infant-Toddler Educator (ITE) • 5-8 children: One ITE and one ECE is required • 9-12 children: One ITE and one ECE and one ECE Assistant Staff qualifications: • Infant Toddler Educator Certificate (approximately 1300 hours of training) • Early Childhood Educator Certificate (approximately 900 hours of training) • Early Childhood Educator Assistant Certificate (completed one early childhood education course) • Setting: Community based facility or centre
Group Child Care: 2.5 years to school age	Ages: 30 months (2.5) to school age (5) Max. No. of Children per group: 25 children Child to Staff Ratio: • 1-8 children: one ECE is required • 9-16 children one ECE and one ECE Assistant is required • 17 to 25 children one ECE and two ECE Assistant is required Staff qualifications: • Early Childhood Educator Certificate (approximately 900 hours of training) • Early Childhood Educator Assistant Certificate (completed one early childhood education course) • Setting: Community based facility or centre
Group Child Care – School age before and after school care	Ages: 5-12 Max. No. of Children per group: • 24 children from Kindergarten and Grade 1, or 30 children from Grade 2 and older with no Kindergarten or Grade 1 children present Child to Staff Ratio: • One responsible adult for 12 children from Kindergarten to Grade 1 • One responsible adult for 15 children from Grade 2 and older Staff qualifications: • Responsible adults must be 19 years of age or older and able to provide care and mature guidance to children. Must also have 20 hours of child care-related training, relevant work experience, a valid first aid certificate and a clear criminal record check • Setting: Community based facility or centre

APPENDIX D – LICENSED CHILD CARE CATEGORIES IN BRITISH COLUMBIA

CHILD CARE LICENCE TYPE	LICENCE REQUIREMENTS*
School Age Care on School Grounds (new licence type)	Ages: 5-12 Max. No. of Children per group: • 24 children from Kindergarten and Grade 1, or 30 children from Grade 2 and older with no Kindergarten or Grade 1 children present Child to Staff Ratio: • One responsible adult for 12 children from Kindergarten to Grade 1 • One responsible adult for 15 children from Grade 2 and older Staff qualifications: • Responsible adults must be 19 years of age or older and able to provide care and mature guidance to children. Must also have 20 hours of child care-related training, relevant work experience, a valid first aid certificate and a clear criminal record check • Setting: School Grounds
Multi-Age Care	Ages: 0-12 Max. No. of Children per group: 8 children Child to Staff Ratio: • One ECE for 8 children Staff qualifications: • Early Childhood Educator Certificate (approximately 900 hours of training) • Setting: Community based facility or centre
In-home Multi-Age Care	Ages: 0-12 Max. No. of Children per group: 8 children Child to Staff Ratio: • One ECE for 8 children Staff qualifications: • Early Childhood Educator Certificate (approximately 900 hours of training) • Setting: In child care providers own home
Family Child Care	Ages: 0-12 Max. No. of Children per group: 7 children Child to Staff Ratio: • One responsible adult (must be licensee) for 7 children Staff qualifications: • Must be 19 years of age or older and able to provide care and mature guidance to children. Must also have 20 hours of child care-related training, relevant work experience, a valid first aid certificate and a clear criminal record check Setting: In child care providers own home
Preschool – 2.5 to school age	Typically operate September-June for four hours a day Ages: 30 months (2.5) to school age (5) Max. No. of Children per group: 20 children Child to Staff Ratio: • 1-10 children: One ECE • 11-20 children: One ECE and one ECE Assistant Setting: Community based facility or centre

CHILD CARE LICENCE TYPE	LICENCE REQUIREMENTS*
Preschool – 2.5 to school age	Typically operate September-June for four hours a day Ages: 30 months (2.5) to school age (5 Max. No. of Children per group: 20 children Child to Staff Ratio: • 1-10 children: One ECE • 11-20 children: One ECE and one ECE Assistant Staff qualifications: • Early Childhood Educator Certificate (approximately 900 hours of training) • Early Childhood Educator Assistant Certificate (completed one early childhood education course) Setting: Community based facility or centre
Occasional Care	Drop-in child care that can be for a max. 8 hours a day, no more than 40 hours per calendar month Ages: 18 months (1.5) and up Max. No. of Children per group: • 16 children (if children under 36 months present) • 20 children (if no children under 36 months present) Child to Staff Ratio: • 1 responsible adult for every 4 children (if children under 36 months present) • 1 responsible adult for every 8 children (if no children under 36 months present) • Staff qualifications: Must be 19 years of age or older and able to provide care and mature guidance to children. Must also have 20 hours of child care-related training, relevant work experience, a valid first aid certificate and a clear criminal record check • Setting: Community based facility or centre
Recreational Child Care (new licence type)	Drop-in basis for after school care or on a day of school closure. Ages: 5-12 Max. No. of Children per group: • No maximum. Floor area of space for activity must be sufficient to ensure health and safety of children. Staff qualifications: • Must be 19 years of age or older and able to provide care and mature guidance to children. Must also have 20 hours of child care-related training, relevant work experience, a valid first aid certificate and a clear criminal record check Child to Staff Ratio: • 1 responsible adult for each 12 children (Kindergarten and Grade 1) • 1 responsible adult for every 15 children (Grade 2 and up) Setting: Indoor facilities other than single family dwellings or outdoor settings such as public parks.

*Source: The Province of British Columbia. "Understanding the Different Types of Child Care in BC".

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E6

To:	Regional Planning Committee
From:	Jessica Hayes, Acting Program Manager, Housing Policy and Planning, Regional Planning and Housing Services
Date:	March 18, 2024 — Meeting Date: April 5, 2024
Subject:	**Regional Affordable Housing Strategy Update (Housing 2050: A Roadmap to Implement *Metro 2050*'s Housing Goal) – Scope of Work**

RECOMMENDATION

That the Regional Planning Committee receive for information the report dated March 18, 2024, titled "Regional Affordable Housing Strategy Update (Housing 2050: A Roadmap to Implement *Metro 2050*'s Housing Goal) – Scope of Work".

EXECUTIVE SUMMARY

This report presents the scope of work for the update to the *Regional Affordable Housing Strategy* (Housing 2050: A Roadmap to Implement *Metro 2050*'s Housing Goal), including policy context, project tasks, and timelines. The update will identify impactful policy interventions to support the housing policies and actions of *Metro 2050*, focusing on the following key areas of impact:

1. Non-market / below-market rental housing delivery and preservation;
2. Achieving the 15% regional affordable rental housing target; and,
3. Regional coordination and advocacy (e.g., housing policy alignment and simplification of regulations, centralized/supportive roles for the region, partnerships, etc.).

Since 2016, when the most recent *Regional Affordable Housing Strategy* was adopted, Metro Vancouver and its member jurisdictions have made significant progress toward the high-level housing objectives of the strategy. There have also been substantial changes to the affordable housing policy landscape across the region, the province, and the country. Despite this, an affordable housing gap remains, and quantifiable and coordinated action will be required to meet regional housing needs, and achieve the high-level housing policies outlined in *Metro 2050*, the regional growth strategy. The Metro Vancouver *Board Strategic Plan (2022-2026)* directs staff to advance *Metro 2050* housing policies through the creation of an action-oriented roadmap that will support the implementation of *Metro 2050* housing policies, and help achieve the regional target of 15 per cent affordable rental housing for newly completed housing units in Urban Centres and along transit corridors.

PURPOSE

To provide the Regional Planning Committee with the scope of work for the update to the *Regional Affordable Housing Strategy*.

63904025

BACKGROUND

In 2007, the Metro Vancouver Regional District Board adopted the first *Regional Affordable Housing Strategy* (RAHS), with a second iteration adopted in 2016 (Reference 1). RAHS was conceived as a regional strategy to provide leadership on regional housing needs, and to advance the complete communities goal of *Metro Vancouver 2040: Shaping Our Future*, the previous regional growth strategy. Developed through significant engagement with member jurisdictions and housing stakeholders, and reflective of the collaborative nature of the Metro Vancouver federation, RAHS has communicated a shared vision, goals and strategies for tackling the housing affordability challenges of Metro Vancouver since its original adoption.

In 2023, Metro Vancouver adopted *Metro 2050*, the updated regional growth strategy, which includes a standalone housing goal that identifies a number of broad and overarching housing policies and actions. The Metro Vancouver *Board Strategic Plan (2022-2026)* directs staff to advance these high-level objectives through the creation of an action-oriented regional housing strategy that will support the implementation of *Metro 2050* housing policies, and help the region achieve the regional target of 15 per cent affordable rental housing for new housing in Urban Centres and along transit corridors.

AFFORDABLE HOUSING POLICY CONTEXT

Since 2016, there have been substantial changes to the affordable housing policy landscape in Metro Vancouver, and significant progress has been made by various levels of government with regards to affordable housing, through plans and programs aimed at addressing housing supply and affordability. In particular, the adoption of Canada's first *ever National Housing Strategy* in 2017, followed by the Province of BC's *30-Point Plan for Housing Affordability in British Columbia* in 2018, and subsequently, the *Homes for People* plan in 2023 have shifted the affordable housing policy context in the region. In Metro Vancouver, nearly all member jurisdictions have adopted Housing Action Plans, and in 2023, *Metro 2050* was adopted with an increased focus on housing. These changes demand more specific and quantifiable action in terms of a regional roadmap for affordable housing intervention.

The five existing RAHS goals include:

1. Expand the Supply and Diversity of Housing to Meet a Variety of Needs;
2. Expand the Rental Supply and Balance Preservation of Existing Stock with Redevelopment While Supporting Existing Tenants;
3. Meet Housing Demand Estimates for Very Low and Low Income Earners;
4. Increase the Rental Housing Supply Along the Frequent Transit Network; and,
5. End Homelessness in the Region.

While each of these topic areas is still highly relevant in Metro Vancouver's current housing policy context, the updated regional affordable housing strategy needs to reflect a changing regulatory context and policy environment in BC, and enable greater innovation and impactful action. As such, the next iteration of RAHS is being conceived as a targeted and actionable strategy, rather than a high-level visioning document, focused on advancing *Metro 2050* housing policies through measurable policy interventions where regional coordination can have the highest impact. The RAHS update will focus primarily on non-market and below-market rental housing, outlining pathways to meet the region's housing needs with the aim of facilitating coordination of specific local and regional housing outcomes.

SCOPE OF WORK

The purpose of the project is to update the *Regional Affordable Housing Strategy*, reimagined as "Housing 2050: A roadmap to implement *Metro 2050*'s housing goal", a targeted strategy to identify impactful policy interventions that will achieve the housing policies and actions of *Metro 2050*, focusing on the following key areas of impact:

1. Non-market / below-market rental housing delivery and preservation;
2. Achieving the 15% regional affordable rental housing target; and,
3. Regional coordination and advocacy (e.g., housing policy alignment and simplification of regulations, centralized/supportive roles for the region, partnerships, etc.).

As with the original RAHS, Housing 2050 will have a rental housing focus – primarily for non-market and below-market rental housing – the central part of the housing continuum, and the part of the continuum that the market is unable to adequately address. Housing 2050 will build off of the visionary leadership and collaboration of RAHS, however, it is not intended to be a comprehensive regional housing strategy. Rather, Housing 2050 will seek to identify consensus on areas for regional collaboration, focused on impactful new directions to address the region's housing supply and affordability challenges, particularly as they relate to non-market and below-market rental housing.

The project scope includes four tasks, described below.

Task 1: Prepare a regional housing needs report

Using the standardized provincial methodology (anticipated to be released in Spring 2024), calculate total housing need for each Metro Vancouver member jurisdiction, and aggregate into a regional report identifying current and anticipated regional housing needs (for a 20-year period) by tenure, bedroom size, affordability/income level, and special needs housing types. Apply provincial methodology to regional housing needs report, resulting in an estimation of the total number of units required to meet housing needs regionally and by sub-region, based on overall housing need, and various needs across the housing continuum. If not identified in the provincial methodology, develop a method for quantifying latent demand/unmet housing needs (e.g. consideration of social housing waitlists, homelessness data).

Task 2: Conduct an affordable housing gap analysis

Next, the project will examine the current policy context for generating housing at various points across the housing continuum and establish a baseline, estimating the number of non-market / affordable housing units that would be generated with projected levels of investment, and in consideration of established and forthcoming municipal policies, to quantify the anticipated housing supply gap (for non-market/below-market rental housing in particular) under the Business as Usual (BAU) scenario.

In establishing the BAU scenario, the analysis will include:

- Estimating the number of affordable rental units anticipated to be delivered under existing housing policies in the region (e.g. units generated through inclusionary housing and density bonus policies, as captured in Metro Vancouver's Matrix of Municipal Measures database);
- Estimated number of affordable rental units delivered through existing provincial and federal funding programs (e.g. standard CMHC and BCH programs, and accelerated programs such as the Housing Accelerator Fund); and,
- Consideration of 5-Year provincial housing targets and recommended proportions for rental housing and below-market units established for Metro Vancouver member jurisdictions to date.

Utilizing the findings of current and future housing needs identified in the regional housing needs report, the gap analysis will quantify the level of effort and investment required to close the affordable housing gap, based on estimated regional housing needs and demand[1] by income category, and housing characteristics.

Task 3: Identify affordable housing policy alternatives
The objective of this phase of work will be to evaluate existing policy actions contained within RAHS that are innovative and impactful to carry forward into Housing 2050 as a means of advancing targeted housing delivery, and implementing the high-level housing goals of *Metro 2050*. In addition, the objective will be to identify a series of impactful policy interventions that are within the control of individual member jurisdictions, or that could be accomplished collectively as a region, working cooperatively, quantifying (order of magnitude) the number of additional affordable housing units that could be produced, beyond the BAU scenario for each identified policy.

As part of this task, an analysis of policy alternatives will be undertaken, including through engagement with stakeholders, considering factors such as cost-effectiveness, feasibility, expected outcomes, leverage, integration with related provincial and federal initiatives, and potential barriers to implementation. The outcome will be to quantify the impact of each approach in reducing the affordable housing gap, and to identify the remaining gaps along the housing continuum which will require coordinated regional advocacy and senior government intervention to achieve.

Task 4: Develop the Housing 2050 Strategy
The final task will be to draft Housing 2050, which will include actionable items within the control of the region and its member jurisdictions. The strategy will include clear implementation linkages to *Metro 2050*, and the 15% regional affordable rental housing target. Housing 2050 will attempt to quantify the anticipated costs and timelines required to close the region's affordable housing gap, and a monitoring and reporting strategy to integrate with Metro Vancouver's established monitoring of *Metro 2050* progress and the Metro Vancouver Housing Data Book.

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[1] Estimation of Housing Needs will be based on the standardized provincial methodology. Depending on the methods, this analysis may also require an estimation of additional housing demand based on projected population growth and latent demand.

Housing 2050: A Roadmap to Implement *Metro 2050*'s Housing Goal will also include:

- Elaboration of the *Metro 2050* and 15% Regional Affordable Rental Housing Target definitions of affordability;
- Clear identification of Metro Vancouver's actionable regional roles and responsibilities with regards to regional housing policy, including identification of new supportive roles (e.g. regional homelessness coordination, central administration of inclusionary housing units, regional data strategy for monitoring and reporting (e.g. live data collection for units generated through inclusionary or density bonus policies); and,
- Linkages to the *Metro Vancouver Housing 10-Year Plan* and related actions.

TIMELINE

The project timeline will begin in the second quarter of 2024. Tasks 1 and 2 of the project will be completed by the end of 2024, with work continuing into 2025, and Housing 2050 adoption anticipated by the end of Q3 2025. The proposed timeline is outlined below, and identifies target dates for project milestones, as well as associated tasks and deliverables for each task in the project:

Quantifying needs (Q2-Q4 2024)

- Task 1: Regional Housing Needs Report
- Task 2: Affordable Housing Gap Analysis

Identifying and evaluating policy alternatives (Q1 2025)

- Task 3: Housing 2050 Issues and Options Paper
    - RPAC and RPAC Housing Subcommittee Workshop
    - Regional Planning Committee Workshop

Developing the strategy (Q2-Q3 2025)

- Task 4a: Draft Housing 2050: A Roadmap to Implement *Metro 2050*'s Housing Goal
- Task 4b: Adopt Housing 2050: A Roadmap to Implement *Metro 2050*'s Housing Goal

ALTERNATIVES

This is an information report. No alternatives are presented.

FINANCIAL IMPLICATIONS

The Board-approved 2024 Housing Policy and Planning budget includes $75,000 to support regional housing policy projects, including the components of the *Regional Affordable Housing Strategy* update that will take place in 2024 (e.g., regional housing needs report and/or housing gap analysis). These funds are intended to support retaining consultant support to complete the majority of the technical analysis in 2024. It is anticipated that additional budget may be required to complete additional phases of the project scope in 2025.

CONCLUSION

The *Board Strategic Plan (2022 – 2026)* identifies the need for an action-oriented regional housing strategy that will support the implementation of *Metro 2050* housing policies, and help the region achieve the target of 15 per cent affordable rental housing for new housing in Urban Centres and along transit corridors, given significant changes in the affordable housing policy landscape since 2016. The project will include four key tasks, including the preparation of a regional housing needs report, an affordable housing gap analysis, evaluation of policy alternatives, and the development of a new strategy. The project timeline spans 2024-2025, and will include engagement with member jurisdictions and key stakeholders throughout all phases of the project.

REFERENCES

1. Regional Affordable Housing Strategy, 2016 (metrovancouver.org)

63904025

To: Regional Planning Committee

From: Edward Nichol, Senior Planner, Regional Planning and Housing Services

Date: March 15, 2024 Meeting Date: April 5, 2024

Subject: **Regional Hazard, Risk, and Vulnerability Analysis Options Assessment – Scope of Work**

RECOMMENDATION

That the Regional Planning Committee receive for information the report dated March 15, 2024, titled "Regional Hazard, Risk, and Vulnerability Analysis Options Assessment – Scope of Work".

EXECUTIVE SUMMARY

This report provides the scope of work for a project to consider and analyze options for a future regional-scale Hazard, Risk, and Vulnerability Analysis (HRVA). Given the new risk assessment requirements for local authorities outlined in the *Emergency and Disaster Management Act*, alignment with *Metro 2050* and *Climate 2050* policy direction, and the significant resources that would be required to develop a regional HRVA, an options analysis will be undertaken to identify how a coordinated regional approach could most effectively provide value, support both local and regional resilience efforts, and fill implementation gaps. The project is expected to be completed by the end of 2024 and the findings will be provided to the Regional Planning Advisory, the Regional Emergency Planners, the Regional Planning, the Climate Action, and the Flood Resiliency Committees, and MVRD Board.

PURPOSE

To provide the Regional Planning Committee with the scope of work for a project to explore options for a regional-scale HRVA, or similar type of assessment.

BACKGROUND

Regional Planning Work to Date

Policy action 3.4.2(a) of *Metro 2050,* directs Metro Vancouver to take a more proactive role in working with partners to collaboratively develop and share information and data related to hazards, risks, and vulnerabilities (Reference 1). Metro Vancouver staff have begun implementing this action through a Natural Hazard Data Inventory completed in 2022 (Reference 2), and a Regional Multi-Hazard Mapping Project completed in 2023 (Reference 3). While the Mapping Project shows the *extent* of four selected hazards (i.e., coastal flood, riverine flood, earthquake, and wildfire) across the region under various scenarios, it did not include an assessment of exposure, vulnerability, or risk.

New Provincial Legislation and Risk and Resilience Assessment

On November 8, 2023, the provincial *Emergency and Disaster Management Act* received Royal Assent, replacing the *Emergency Program Act* (Reference 4). The new Act and associated regulations govern how emergencies and disasters are managed in British Columbia. While the Act establishes the overall framework, regulations are being developed by the Province that will provide finer details on key areas identified in the statute. Until the new regulations are in place, regulations made under the former *Emergency Program Act* remain in force (until they are repealed).

Under the new legislation, local authorities, defined as a municipality, a regional district (within the boundaries of any electoral areas only), and any treaty first nation, will need to complete risk assessments that consider:

- the degree of risk posed by a hazard;
- the likelihood of the hazard leading to an emergency;
- the potential scope and scale of an emergency;
- available Indigenous and local knowledge;
- potential impacts from expected climate change or extreme weather events; and
- impacts on people, animals and places that may be disproportionately impacted by emergencies and may be more vulnerable due to physical location or prescribed circumstances.

The Province is currently undertaking a Disaster and Climate Risk and Resilience Assessment. It is anticipated that the framework and results of this assessment will inform the risk assessment requirements for local authorities outlined in the *Emergency and Disaster Management Act* and forthcoming regulations. Metro Vancouver staff are actively engaging with staff from the Ministry of Emergency Management and Climate Readiness, as well as the Climate Action Secretariat, to better understand the new provincial legislation and risk assessment process, and will provide the members of the Regional Planning Advisory Committee, and the Regional Planning Committee and MVRD Board with further information related to this as it becomes available.

PROJECT SCOPE

Rationale

Developing a regional-scale HRVA (or equivalent assessment) will require extensive technical work, as well as substantial engagement and coordination with internal departments and external agencies. Before committing to this type of process, an options analysis will be completed to identify how a coordinated regional approach could most efficiently and effectively provide value, support both local and regional resilience efforts, and fill any implementation gaps. In addition to the new provincial legislation, the forthcoming risk assessment requirements for local authorities, and *Metro 2050* policy direction, all seven of the MVRD Board-endorsed *Climate 2050* Roadmaps contain an action to work with partners to develop a regional climate risk and vulnerability assessment.

Objective

The objective of this project will be to scope and analyze options for a future HRVA (or similar type of assessment) that would:

- build on the results of the Regional Multi-Hazard Mapping Project completed in 2023;
- focus on climate change impacts and natural hazards;

- inform regional planning analysis, projects, and models;
- explore how regional resilience efforts can be best supported and coordinated; and
- align with provincial legislation and risk assessment processes.

Key Tasks
The project will be undertaken with consultant support. It is anticipated that this project will include, but not necessarily be limited to, the following tasks:

- Design and scope ~3 separate options for a regional-scale HRVA (or equivalent analysis) with advantages and disadvantages, recommendations, and implementation considerations clearly identified;
- Engage with internal Metro Vancouver departments, external agencies and partners, and relevant Metro Vancouver committees as needed;
- Analyze provincial legislation and risk assessment processes and consider opportunities for alignment, gap-filling, and coordination;
- Assess regional and local resilience initiatives and consider opportunities for alignment, gap-filling, and coordination;
- Incorporate best practices; and
- Consider the implications for future Regional Planning policy and project work.

PROJECT TIMELINE
A consultant will be retained in the spring of 2024 to lead the work. It is estimated that the work will be completed in late 2024. Periodic project updates can be provided to the Regional Planning Committee, as appropriate, and the final project results will be provided to the Regional Planning Advisory, the Regional Emergency Planners, the Regional Planning, Climate Action, and the Flood Resiliency Committees, and the MVRD Board.

ENGAGEMENT
This report was presented to the Regional Planning Advisory Committee at its meeting on March 15, 2024, for information. No feedback was provided by Committee members.

ALTERNATIVES
This is an information report. No alternatives are presented.

FINANCIAL IMPLICATIONS
This work will be undertaken as part of the MVRD Board-approved 2024 Regional Planning budget. The budget allocated to this project is $50,000.

CONCLUSION
This report provides the scope of work for a project to consider and analyze options for a future regional-scale HRVA or similar type of assessment. This project will identify how a coordinated regional approach would most efficiently and effectively provide value, support both local and regional resilience efforts, and fill implementation gaps. The scope of this project aligns with work completed to date by the Regional Planning division, policy direction from *Metro 2050* and *Climate 2050*, and the new risk assessment requirements for local authorities outlined in the *Emergency*

and Disaster Management Act. The project is expected to be completed by the end of 2024 and the findings will be provided to the Regional Planning Advisory, the Regional Emergency Planners, the Regional Planning, the Climate Action, and the Flood Resiliency Committees, and the MVRD Board.

REFERENCES

1. Strategy 3.4 of *Metro 2050*
2. Natural Hazard Data Inventory, Regional Planning Committee staff report dated February 27, 2023
3. Regional Multi-Hazard Mapping Project, Regional Planning Committee staff report dated February 12, 2024
4. *Emergency and Disaster Management Act*

64116671

To: Regional Planning Committee

From: Eric Aderneck, Senior Planner, Regional Planning and Housing Services

Date: March 15, 2024 Meeting Date: April 5, 2024

Subject: **Economic Value of Industrial Lands Study Update – Scope of Work**

RECOMMENDATION
That the Regional Planning Committee receive for information the report dated March 15, 2024, titled "Economic Value of Industrial Lands Study Update – Scope of Work".

EXECUTIVE SUMMARY
Metro Vancouver is now updating the 2019 Economic Value of Industrial Lands Study to incorporate the latest data available, including employment counts from the 2021 Census and land uses from the 2020 Regional Industrial Lands Inventory.

The *Regional Industrial Lands Strategy* (RILS) was approved by the MVRD Board in 2020. It sets out 34 actions and recommendations that continue to be implemented. To support the development of RILS, Metro Vancouver commissioned the *Industrial Lands: Economic Impact and Future Importance Study* completed in 2019 documenting the economic value and employment contribution of industrial lands in the region. The Study provided a better understanding for Metro Vancouver and its member jurisdictions of the importance of industrial lands to the regional economy, and informed the completion of the RILS, its ongoing implementation, and the development of *Metro 2050.*

PURPOSE
To provide the Regional Planning Committee with a scope of work for the Economic Value of Industrial Lands Study update.

BACKGROUND
Industrial lands are an important part of the region's land base and economy. The Metro Vancouver region has a limited supply of industrial lands and a strong demand for industrial space, which has resulted in extremely low vacancy rates, with high rental rates and land prices. To support the preparation of the Regional Industrial Lands Strategy, approved in 2020, Metro Vancouver commissioned InterVISTAS Consultants to complete the 2019 *Industrial Lands: Economic Impact and Future Importance Study* (Reference 2). Metro Vancouver is now updating the Study.

INDUSTRIAL LANDS ECONOMIC IMPACT STUDY
The 2019 *Industrial Lands: Economic Impact and Future Importance Study* examined the economic impact of the Metro Vancouver region's industrial lands on the regional, provincial, and national economies. Specifically, the study investigated the following:

- Defining 'economic impact';
- Establishing an economic impact methodology;

- Economic impact of industrial lands in Metro Vancouver;
- Interdependencies with non-industrial lands and activities;
- The importance of industrial activities in diversifying the economy;
- Alternative industrial land locations outside of the Metro Vancouver region; and
- The consequences of an insufficient supply of industrial lands in the Metro Vancouver region.

The Study documented that:

- Industrial lands represent 4 percent of the region's land base;
- These lands accommodate 27 percent of jobs in the region, with direct employment representing 364,100 jobs;
- These jobs pay about 10 percent higher wages than the regional average; and
- Annual business activity contributes $9 billion in taxes to various levels of government.

No stand-alone statistical sources accurately capture employment taking place on the region's industrial lands. Consequently, the employment (and wage) information contained in the 2019 Study was obtained by undertaking a custom analysis of the Statistics Canada 2016 Census, augmented by the Bank of Canada's inflation calculator. This information was cross-referenced with Metro Vancouver's 2015 *Regional Industrial Lands Inventory* to ensure data was captured for the activities occurring within these lands. More current data is now available.

Scope of Work for the Update

In support of the ongoing advancement and implementation of RILS, Metro Vancouver has again contracted InterVISTAS Consultants to update the *Industrial Lands: Economic Impact and Future Importance Study*. This update entails compiling the most recently available data, including: Census (2021), *Regional Industrial Lands Inventory* (2020), *Industrial Intensification Study* (2021), *Regional Industrial Lands Strategy* (2020), *Metro 2050* (2023), and other sources.

Specifically, this will include updating the following components:

- The industrial lands context in Metro Vancouver;
- The most current regional planning policy framework;
- Economic impact analysis;
- The economic model with custom multipliers and ratios from the 2021 Census dataset;
- The tax model to reflect 2021 tax rates; and
- The key messages from the 2019 study.

Furthermore, the update will incorporate recent related findings about industrial lands in the region determined through other work by InterVISTAS as well as other sources. For example, the 'Economic Impact Study of the Critical Shortage of Industrial Land in Metro Vancouver' was completed in 2023 for the Greater Vancouver Board of Trade and NAIOP Vancouver, and provided some additional information about industrial lands, although that analysis was based on 2016 Census data (Reference 3). Updating and supplementing the Metro Vancouver study will build on all available sources, use current data, including from the 2021 Census), and supplement other studies, to address industrial lands from a different perspective; namely the Study will support Metro Vancouver and member jurisdiction policy objectives.

NEXT STEPS

This report was presented to the Regional Planning Advisory Committee at its meeting on March 15, 2024, for information. No feedback was provided by Committee members.

This study update will be completed by InterVISTAS Consultants within the year 2024, shared with the Regional Planning Advisory Committee, advanced to the Regional Planning Committee and MVRD Board, and published on the Metro Vancouver website. The results and updated data will be used to inform future industrial lands initiatives and related employment and economic matters, as well as the ongoing implementation of RILS. The results of this update will help to profile and communicate the importance of industrial land uses and associated economic and employment activity.

ALTERNATIVES

This is an information report. No alternatives are presented.

FINANCIAL IMPLICATIONS

A budget of $30,000 associated with this project is included in the MVRD Board-approved 2024 Regional Planning budget. This budget will be used to retain the consultant to update the Study.

CONCLUSION

To support the development of the *Regional Industrial Lands Strategy* Metro Vancouver commissioned a study documenting the economic value and employment contribution of industrial lands in the region. Completed in 2019, the Study provided a better understanding of the importance of industrial lands to the regional economy, and informed the completion of the RILS, its ongoing implementation, and the development of *Metro 2050.* Metro Vancouver is now updating the 5-year-old economic impact study to incorporate the latest data available. It will be completed by the end of 2024.

REFERENCES

1. Metro Vancouver Regional Industrial Lands Strategy, 2020
2. Metro Vancouver Industrial Lands: Economic Impact and Future Importance, 2019
3. Economic Impact Study of the Critical Shortage of Industrial Land in Metro Vancouver, 2023

64109395

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E9

To: Regional Planning Committee

From: Jonathan Cote, Deputy General Manager, Regional Planning and Housing Development, Regional Planning and Housing Services

Date: March 15, 2024 Meeting Date: April 5, 2024

Subject: **Manager's Report**

RECOMMENDATION
That the Regional Planning Committee receive for information the report dated March 15, 2024, titled "Manager's Report".

REGIONAL PLANNING COMMITTEE 2024 WORK PLAN
The Regional Planning Committee's Work Plan for 2024 is attached to this report (Attachment 1). The status of work program elements is indicated as pending, in progress, ongoing or complete. The listing is updated as needed to include new issues that arise, items requested by the committee, and changes to the schedule.

DROUGHT PREPARATION FOR AGRICULTURE AND LOCAL GOVERNMENTS
The Ministries of Water, Land and Resource Stewardship and Agriculture and Food are working to prepare local governments and agricultural producers for the expected significant upcoming 2024 drought. These efforts include reaching out local farmers and municipal staff to share data, resources and information on how to forecast for drought conditions and on what pre-emptive actions can be made prior to a drought occurring. Some of the resources include the following:

- British Columbia Drought Information Portal (Reference 1)
- British Columbia Snow Basin Indices (Reference 2)
- British Groundwater Observation Well Network (includes a groundwater level data interactive map and a real-time water data map) (Reference 3)
- British Columbia Drought and Water Scarcity Response Plan (Reference 4)
- Drought information, resources and response for BC website (Reference 5)
- Farmwest website (public portal to access agriculture-related resources including weather information and weather-based decision aid calculators).

Provincial Agriculture Water Infrastructure Program
Through the Investment Agricultural Foundation, the Ministry of Agriculture and Food has created an Agriculture Water Infrastructure Program (Reference 7) intended to provide cost-sharing funding to adapt to climate change through water infrastructure investment. The goal of the $20 million program is to improve water security in agricultural areas and food security in British Columbia. Applications are open to, among others, irrigation and improvement districts and local governments that supply water for agriculture.

Drought Engagement Workshop
Metro Vancouver, in partnership with the Ministries of Water, Land and Resources Stewardship and the Agriculture and Food, will be hosting a Provincial and Local Government drought engagement workshop on April 30, 2024. This workshop is intended to communicate about the urgency of the anticipated upcoming 2024 drought, identify the role of the Province and determine what collective action can be taken with local governments to address the drought and water scarcity issues in the region. A Drought Engagement Survey (Reference 8) has been prepared by the Province, the results of which will help inform the agenda for the April 30, 2024 workshop. Additional details about the workshop will be shared with Member Jurisdiction staff through the Regional Planning Advisory Committee once they have been confirmed.

AMSTERDAM SUPPORTS THE SHIFT TO A PLANT-BASED DIET
As part of a growing wave of cities around the world that have been signalling an understanding that food can't be ignored when it comes to dealing with the climate crisis, The Dutch capital is increasingly encouraging its residents to shift more towards a plant-based diet. Livestock agriculture is responsible for 14.5 to 20 percent of global greenhouse gas emissions. Having long been a leader in cycling infrastructure, Amsterdam has joined a growing list of cities to joined the Plant Based Treaty, an agreement modelled after the Fossil Fuel Non-Proliferation Treaty that 26 cities have signed on to (including Los Angeles, Edinburgh and 15 cities in India, where 40 percent of the population is already vegetarian). Amsterdam's goal is to have 60 percent of the protein in its residents' diets plant-based by 2030. The consumption of more plant-based proteins is a positive climate action that reduces emissions, as well as being better for our health. Amsterdam is the latest city to back Plant Based Treaty (Reference 9).

2024 SUSTAINABILITY INNOVATION FUNDING (SIF) APPROVED – RENTAL HOUSING BLUEPRINT
On February 23, 2024, the MVRD Board, on the recommendation of the Caucus of Committee Chairs, officially approved $2,130,000 of requested SIF funding from 2024 to 2026 for the project titled "Rental Housing Blueprint: Streamlining Multi-Family Affordable Rental Housing Delivery Through Standardization and Modern Construction Methods" (Reference 10).

SUSTAINABILITY INNOVATION FUND – "EXTENDED REALITY MODELLING PLATFORM" UPDATE
In 2023, the MVRD Board approved the "Extended Reality Modelling Platform" as part of the Sustainability Innovation Fund. A component of the project is to explore how virtual reality platforms could be used to enhance public engagement. In collaboration with the Centre for Digital Media, Metro Vancouver is working with a group of five graduate students to develop a virtual reality (VR) experience that showcases key elements of Metro Vancouver infrastructure across the region.

This VR experience is being developed for Metro Vancouver's Pacific National Exhibition (PNE) activation. Using a combination of a 3D map of the region (similar to google earth) and 360 video shot on location, the experience will take users into areas of our region that are normally inaccessible. The collaboration began in January of this year and a prototype version of the experience is on track for completion by the end of March.

ATTACHMENT

1. Regional Planning Committee 2024 Work Plan

REFERENCES

1. British Columbia Drought Information Portal
2. British Columbia Snow Basin Indices
3. British Groundwater Observation Well Network
4. British Columbia Drought and Water Scarcity Response Plan
5. Drought information, resources and response for BC
6. Farmwest
7. Agriculture Water Infrastructure Program
8. Drought Engagement Survey
9. Amsterdam is the Latest City to Back Plant-Based Treaty
10. 2024 Regional District Sustainability Innovation Fund Applications

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Attachment 1

Regional Planning Committee 2024 Work Plan

Report Date: March 15, 2024

Priorities

1st Quarter	Status
Where Matters II - Final Report	Completed
Childcare Inventory Report - Update	In Progress
Metro 2050 Climate Policy Enhancement Project - Report	Completed
Regional Multi-Hazard Mapping Project – Final Report	Completed
Tree Canopy Cover and Impervious Surfaces Update – Final Report	In Progress
Industrial Lands Bring to Market Initiative – Scope of Work	Completed
Metro 2050 Urban Centres and Corridors Target Update – Scope of Work	Completed
Regional Food Systems Strategy Update – Scope of Work	Completed
Inclusionary Housing Policy Review – Final Report and Regional Policy Models	Completed
What Works: Municipal Measures for Sustaining and Expanding the Supply of Purpose-Built Rental Housing Update	In Progress
Matrix of Municipal Measures for Housing Affordability and Diversity - Update	In Progress
Regional Affordable Housing Strategy Update (Housing 2050) – Scope of Work	In Progress
Metro 2050 Implementation Guideline Industrial & Employment Lands	Completed
Housing Data Book update – Presentation	Completed
Regional Growth Strategy Amendments, Regional Context Statements, and Sewerage Area Amendments (as applicable)	Ongoing
2nd Quarter	**Status**
Housing + Transportation Cost Burden Study Update – Final Report	Pending
Agriculture Data Book - Presentation	Pending
Agricultural Land Use Inventory - Update	Pending
Economic Value of Industrial Lands Update – Scope of Work	In Progress
Hazard Risk and Vulnerability Blueprint – Scope of Work	In Progress
Regional Green Infrastructure Network – Update	Pending
Projections Update (population, dwelling units and employment) - Report	In Progress
Regional Growth Strategy Amendments, Regional Context Statements, and Sewerage Area Amendments (as applicable)	Ongoing
3rd Quarter	**Status**
Payment for Ecosystem Services on Agricultural Lands - White Paper	Pending
Ecological Health Framework Progress Report	Pending
The Walkability Index Update – Presentation	Pending
Regional Growth Strategy Amendments, Regional Context Statements, and Sewerage Area Amendments (as applicable)	Ongoing
4th Quarter	**Status**
Regional Food Systems Strategy Engagement - Update	Pending
Economic Value of Industrial Lands Update – Final Report	Pending
Regional Parking Strategy – Final Report	Pending
Regional Affordable Housing Strategy Update (Housing 2050) – Issues and Options Discussion Paper	Pending
Performance measures dashboard - Presentation	Pending
MV extended reality modelling project update – Update	Pending
Regional Growth Strategy Amendments, Regional Context Statements, and Sewerage Area Amendments (as applicable)	Ongoing

F1 Information Item

metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

To: Mayors Committee

From: Heather McNell, Deputy Chief Administrative Officer, Policy and Planning, and Jonathan Coté, Deputy General Manager, Regional Planning and Housing Development, Regional Planning and Housing Services

Date: February 23, 2024 Meeting Date: March 14, 2024

Subject: **Provincial Housing Legislation: Provincial Advocacy and Supportive Roles**

RECOMMENDATION

That the MVRD Board:

a) Direct staff to provide an 'opt in' opportunity for member jurisdictions for Metro Vancouver to undertake the Housing Needs Reports as per the provincial methodology and requirements;
b) Direct staff to advance and coordinate 'opt in' opportunities for co-operative procurement of consultants for member jurisdictions necessary for implementing the new provincial housing legislation; and
c) Advance advocacy actions to the Province directed towards: infrastructure programs and funding to ensure that sufficient infrastructure is in place to accommodate the increases in population and housing projected; better alignment with Metro 2050; and stronger support for non-market and affordable housing.

EXECUTIVE SUMMARY

In early November 2023, the Province of BC introduced legislation intended to stimulate the infill and intensification of housing in single-detached neighbourhoods and transit-oriented areas. Since the release of the new housing legislation, Metro Vancouver has been working with member jurisdictions and the Province at multiple levels to engage, support and receive feedback regarding the potential impacts of the legislation and regulations, as well as considering potential roles for Metro Vancouver in supporting the implementation in the region.

Engagement with, and continued advocacy to, the Province will be critical to mitigate the shared concerns that are being raised by local governments. While Metro Vancouver has an important role to play in helping to coordinate a regional response to the legislation, advocacy efforts will be multi-faceted, and will involve separate efforts from individual local governments and the Union of BC Municipalities (UBCM). Feedback from across the region has highlighted three advocacy areas that would be relevant and appropriate for Metro Vancouver to advance to the Province: infrastructure investments; improved alignment with *Metro 2050,* the regional growth strategy; and greater support for non-market/affordable housing.

To support member jurisdictions in implementing the legislation and to make best use of resources, feedback was also sought on areas where Metro Vancouver is able to support its members. Considering that member jurisdictions are sensitive to infringement on local jurisdiction, staff have identified three balanced roles where Metro Vancouver could assist: Housings Needs Reports; co-operative procurement for consulting support; and regional modelling/mapping.

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PURPOSE

To provide the Mayors Committee and MVRD Board with an update on: a) the new provincial housing legislation, b) the feedback that Metro Vancouver has received through engagement with member jurisdictions, and c) recommendations for Metro Vancouver supportive actions including advocacy to the Province.

BACKGROUND

At the Mayors Committee meeting on December 15, 2023, the Committee requested that Metro Vancouver host a special Council of Councils meeting focused on the provincial housing legislation. Further direction was provided to report back to the Committee and Board in early 2024 with options regarding: a coordinated regional response to the legislation changes; strategies to pursue regional advocacy; and the identification of supportive roles that Metro Vancouver can play to support member jurisdictions.

ENGAGEMENT/FEEDBACK

Since the release of the provincial housing legislation in November 2023, Metro Vancouver has been working with member jurisdictions and the Province at multiple levels to share information, understand the implications, identify common themes and questions, and assist in coordinating a regional response. Given the strong interest from member jurisdictions, this issue has been the focus of discussions at meetings for the Regional Administrators Advisory Committee (RAAC), Regional Planning Advisory Committee (RPAC), Regional Engineers Advisory Committee (REAC), Regional Transportation Advisory Committee (RTAC), and the Regional Finance Advisory Committee (RFAC).

Through this engagement, Metro Vancouver received a significant amount of feedback from member jurisdictions. The feedback has been mixed, but a number of common themes and issues have emerged from the engagement including concerns that:

- the timelines associated with the legislative changes are challenging, and will stretch the capacity of municipalities and the consulting sector in the region;
- the legislation will exasperate pre-existing deficiencies in provincial investments for new schools, health care and emergency services, utilities and public transit;
- the new development financing framework will not provide local governments with the adequate tools needed to fund community amenities;
- the legislation will have very different and potentially negative impacts on the delivery of housing for areas with substantial greenfield development areas; and
- local governments will not have the support to address the localized impacts on utilities and infrastructure that result.

This feedback provides guidance as to the roles Metro Vancouver could take in supporting member jurisdictions’ implementation of the legislation.

Council of Councils Meeting

On February 3, 2024 Metro Vancouver hosted a Council of Councils meeting focused specifically on the new provincial housing legislation. The meeting was well attended with 118 elected officials from member jurisdictions participating in the session. The Minister of Housing, the Honourable Ravi Kahlon, also attended the meeting, which provided members an opportunity to directly engage with the Minister. A wide range of questions were raised but concerns regarding the impacts that increased growth pressures would have on infrastructure (utilities, transit, education, and health) was a central focus of many of the questions directed towards the Minister.

The meeting also provided an opportunity to gauge the general outlook elected officials in the region have regarding the new housing legislation. An online survey tool was used during the meeting to help capture the sentiments of the elected officials who attended the meeting. Below are the highlights of the results from the online survey:

Question #1: Which of the following statements best describe your view of the Provincial legislative changes? The Provincial legislative changes are:
(Participants were able to select more than one answer)

Rushed with many unresolved questions.	57%
A good starting point with more work needed.	47%
Unnecessarily infringing on the jurisdiction of local governments.	37%
Needed to meet historic housing demand.	33%
Positive change that will better link transportation and land use planning.	30%

Question #2: What are the most significant challenges for the region introduced by the new legislation?
(Participants ranked each option on a scale of 1-5, results show % of participants that ranked each option as either a 4 or a 5)

Funding and delivering public services (including health, education and public transportation) in tandem with development.	94%
Infrastructure planning and increased or unknown additional infrastructure costs.	86%
Reduced ability to leverage community amenities (including delivering non market housing) through development approval process.	80%
Lack of staffing capacity to achieve timelines mandated by provincial legislation.	75%
Unintended consequences from potential changes in the location and pattern of development.	58%
Potential misalignment with Regional Growth Strategy environmental targets including tree canopy cover.	45%
Potential for increased pace of growth beyond projections.	45%

Question #3: To support members in implementing the legislation and to make best use of resources Metro Vancouver should explore:
(Participants ranked each option on a scale of 1-5, results show % of participants that ranked each option as either a 4 or a 5)

Support joint procurement tools to reduce duplication of consulting services.	72%
Developing model bylaws, templates, and model guidelines which could be used or adopted by members to assist in implementation.	59%
Producing Housing Needs Reports regionally on behalf of all members.	51%
Creating and maintaining a shared regional model of OCP capacity and zoned capacity.	47%

METRO 2050 ALIGNMENT
Since the release of the legislation, Metro Vancouver staff have been working to analyze the impacts on *Metro* 2050, the regional growth strategy. Building a diverse and affordable housing stock is a key *Metro 2050* objective. There is general alignment between the intent of the legislation and the housing goals and shared regional vision outlined in *Metro 2050*. However, staff's review and analysis has identified a number of concerns and gaps that have the potential to lead to misalignment between provincial policy and land use planning at the regional level. Below is a short summary of the most significant areas of concern that have been identified:

- Putting growth in the right places is a core guiding principle in *Metro 2050.* Spreading development more broadly by upzoning single-detached neighbourhoods (greenfield and infill) may make it more challenging for local governments to meet the shared regional transit-oriented intensification policies and Urban Centre/FTDA targets. Although the legislation requires that this development occur within the Urban Containment Boundary, many of the impacted single-detached neighbourhoods are located in greenfield locations and/or in outlying parts of the region, away from the major transit network. The blanket approach to increasing housing density in these locations could make these neighbourhoods more car dependent and increase congestion, and make it more difficult to meet the region's greenhouse gas emission reduction targets. In these locations, the new legislation may also make it more difficult and costly to support the efficient provision of infrastructure. Spreading growth to outlying single-detached neighbourhoods in the region cannot be considered strategic infill.

- Significant regional coordination and consensus over the past four years has underpinned the development of the housing and transit-oriented development policies of *Metro 2050*. The new legislation has created Transit Oriented Areas (TOAs) which have not utilized or referenced the established regional spatial geography (e.g., Urban Centres, Frequent Transit Development Areas (FTDA), and Major Transit Growth Corridors). This new geography, based on 200, 400 and 800m concentric rings around rapid transit stations, will likely create unnecessary confusion in implementation and could potentially lead to a misalignment between provincial policy requirements and regional planning goals and targets. In many areas the growth concentration locations identified in *Metro 2050* are larger in area compared to TOAs, and better aligning these typologies could have resulted in more intensification of housing in transit-oriented locations in which regional consensus already exists. The failure to align the typologies of *Metro 2050* and the provincial legislation is a missed opportunity and may not contribute to focusing growth in all of the transit-oriented locations identified in *Metro 2050*.

- *Metro 2050* includes a regional target that at least 15 percent of new housing units be affordable rental within all Urban Centres and FTDAs. Leveraging the development of affordable housing units through new development with policies such as negotiated inclusionary zoning and density bonusing is one of the strongest tools local governments have to help achieve this regional target. The new development financing framework introduced by the province will reduce the ability of municipalities to leverage non-market/affordable housing units through new development. The new framework may also limit local government’s ability to leverage stronger tenant relocation policies for those impacted by redevelopment, which is another important strategy included in *Metro 2050*. The Ministry of Housing has acknowledged this concern and have indicated that they would be bringing forward subsequent legislation in early 2024 to help address these issues.

- *Metro 2050* includes a new target to increase the regional tree canopy cover within the Urban Containment Boundary to 40 percent by the year 2050. Enhancing the urban tree canopy improves community resilience by intercepting rainwater, moderating the urban heat island effect, and improving health outcomes. As the region densifies it will become more challenging to not only expand the tree canopy cover but to retain the canopy that exists as well. The spreading out of ground-oriented growth through the intensification of single-detached neighbourhoods as allowed by the new legislation will likely make it more difficult to achieve the region’s tree canopy policy direction and target.

PROVINCIAL ADVOCACY

Engagement with member jurisdictions and elected officials since the introduction of the new legislation has led to a number of common concerns and regionally significant issues being identified. Although it is not anticipated that the provincial government will make any significant moves to step back from the new legislation, continued engagement and advocacy with the Province will be critical to mitigate the shared concerns and issues that are being raised by local governments in the region. While Metro Vancouver has an important role to play to help coordinate a regional response, advocacy efforts will be multi-faceted and will involve separate efforts from individual local governments and UBCM. Capturing concerns from local governments across the province, UBCM plans to advocate to the province on behalf of its members, guided by the feedback collected at the February 2024 Housing Summit held in Vancouver, and by the results of the delegate survey (Reference 1). Based on discussions and feedback from member jurisdictions, three advocacy areas have been identified that would be relevant and appropriate for Metro Vancouver to advance to the Province:

1) Infrastructure Investment

Local governments have long advocated for adequate, predictable long-term funding from the provincial and federal governments for critical infrastructure. Now, there are concerns that the new provincial legislation will exasperate the infrastructure challenges in the region.

It will be imperative that senior levels of government address how housing-enabling infrastructure will be funded to support current growth trends and targets. Metro Vancouver, in its capacity as a federation, can advocate for the provincial and federal governments to increase funding supports for local governments to address this growing demand on infrastructure. This would complement Metro Vancouver’s Intergovernmental Relations Strategy, which seeks increased funding in support of Metro Vancouver’s critical infrastructure projects.

2) Improved Alignment with Metro 2050

There are a number of concerns and noted gaps that have the potential to lead to misalignment between provincial policy and *Metro 2050*. Some of the regional targets set in *Metro 2050* may become more difficult to achieve following the implementation of the new provincial housing legislation. To address these issues, the following strategies and actions are proposed:

- At a staff level, continue to work with and engage provincial staff to work towards improved alignment over time between *Metro 2050* and provincial legislation.
- Make adjustments to Regional Planning projects (e.g., Urban Centres and FTDA Target Update, Parking Strategy, Regional Affordable Housing Strategy) to consider and mitigate impacts stemming from the legislation.
- If necessary, engage with the Board to develop additional strategies for political engagement.

3) Support for Non Market & Affordable Housing

The new provincial housing legislation is focused primarily on increasing the market supply of housing in the province. Increasing housing supply and building a diverse housing stock is important to help address the region's housing challenges. However, the legislation does not address the high need and lack of supply of non-market affordable, particularly rental housing in Metro Vancouver. Further provincial advocacy will be required to push for increased provincial investment in non-market housing and to ensure that local governments have the tools available to support the development of affordable housing in their communities. Metro Vancouver staff propose focusing these advocacy efforts in the following areas:

- Enabling Inclusionary Zoning: The new legislation reduces the tools available to municipalities to address critical community needs for affordable housing with the changes to development financing tools. The Province has indicated that it is exploring introducing new "inclusionary zoning" legislation. Metro Vancouver is currently preparing a model regional inclusionary zoning framework. The Province should be encouraged to proceed with enacting new legislation that enables inclusionary zoning and to work closely with the region to ensure that the legislation is well aligned with that framework.
- Stronger Tenant Protections: Increased development activity will result in an increase in existing tenants in older buildings being displaced as a result of redevelopment. Many municipalities have introduced policies to ensure tenants are provided with assistance in these circumstances. Pre-zoning, however, would remove the ability of local governments to require developers to provide tenant assistance beyond what is required under the *Residential Tenancy Act* (i.e., four month's notice and one month's rent). The *Residential Tenancy Act* should be reviewed to ensure appropriate compensation is provided to tenants who are displaced due to redevelopment.
- Increased funding for Non-Market Affordable Housing: The legislative changes may result in additional housing supply, but will not result in creating much needed affordable housing units. The Province should work closely with Metro Vancouver's member jurisdictions to ensure that collaborative strategies, and commensurate funding, are provided to meet the number of non-market units suggested under the Provincial Housing Target Orders.

SUPPORTIVE ROLES FOR METRO VANCOUVER

To support member jurisdictions in implementing the legislation and to make best use of resources, Metro Vancouver has suggested some supportive roles the regional district could take on to support its members. These options have been discussed at both the staff and political levels. Feedback on these supportive roles has been mixed. While there is a general recognition that the legislation will stretch the capacity of local governments and support from Metro Vancouver would be welcomed, some member jurisdictions have expressed concern over an infringement on local jurisdiction. Considering this feedback, Metro Vancouver staff have identified three balanced roles where Metro Vancouver could assist member jurisdictions with implementing the new legislation:

1) Housing Needs Reports

In April 2019, legislation took effect requiring that all local governments in BC prepare Housing Needs Reports (HNRs) describing their current and anticipated housing needs. The first report deadline was in April 2022. For the first round of provincially-required HNRs, Metro Vancouver provided assistance to member jurisdictions by collecting and issuing close to 50 distinct types of data required by the Province, and providing the information in a report format. This data report was used by member jurisdictions to inform the analysis of local housing needs in their communities. However, the significant variation in the methods used to estimate total housing need led to HNRs across the region not being consistent, or comparable regionally or provincially. As a result, and as part of the recently announced suite of legislative changes, the Province has indicated that local governments will be required to use a standardized methodology when completing HNRs going forward. The new methodology and instructions for HNRs is not yet available, however, based on the information released by the Province to date, it is expected that the interim HNRs that are required to be complete by January 1, 2025 will be a relatively straightforward data-driven exercise. Once the instructions are available, and should the update be framed as an objective and data-driven exercise, Metro Vancouver is well-positioned to support member jurisdictions by generating the reports on their behalf, similar to the supportive role that has been provided in the past.

2) Co-operative Procurement of Consultants

To reduce the duplication and cost of consulting services associated with implementing the province’s new requirements by individual local governments, Metro Vancouver can play a coordinating role in procurement for its member jurisdictions. In the past Metro Vancouver has similarly managed procurement that involves several member jurisdictions for some of its transportation corridor studies that cross jurisdiction boundaries. A similar approach could be applied in this case.

Any co-operative procurement would be voluntary only, and could be initiated by member jurisdiction Planning staff identifying for Metro Vancouver staff what implementation work they would be interested in partnering on with Metro Vancouver in terms of shared procurement. Co-operative procurement participation could range from a minimum of two interested member jurisdictions, to region-wide studies that involve all member jurisdictions. Each member jurisdiction would be expected to fund a respective portion of the total amount for each study based on scale and scope of the work; it is not intended that Metro Vancouver would contribute financially.

Local governments can use the recent grant they received from the Province's Local Government Housing Initiatives funding program towards such consulting services. The associated grant program scope and guidelines state: "Funding can be used for regional projects that cover two or more planning areas (i.e., municipalities, electoral areas, local trust areas). A municipality may contribute from its funding to a regional project if that municipality is a participant and the funding is dedicated for planning purposes".

3) Regional Modelling / Mapping

The development of a new regional growth scenario to reflect the new housing legislation will be critical to better understanding the impacts that the new legislation will have on Metro Vancouver and its member jurisdictions. The Planning Analytics team at Metro Vancouver will be doing this work in support of regional utility and transit planning, but this data will likely be useful to member jurisdictions as well. Using the existing digital model, Metro Vancouver will be undertaking the following:

- Simulating the most plausible land use conversions between 2024 and 2050 as influenced by new provincial legislation;
- Estimating the number of newly generated units by type;
- Estimating the number of hectares that will be intensified by land use class;
- Comparing growth scenarios pre and post legislative changes in terms of the impacts on urban expansion, density, dwelling type diversification, etc.; and
- Building regional and municipal parcel-based maps based on multiple criteria, to determine the probability of intensification.

The results from these activities will be critical to supporting regional utility and transit planning, and will be shared with member jurisdictions for their further analysis and local infrastructure planning efforts once complete.

ALTERNATIVES

1.That the MVRD Board:

a) Direct staff to provide an 'opt in' opportunity for member jurisdictions for Metro Vancouver to undertake the Housing Needs Reports as per the provincial methodology and requirements;
b) Direct staff to advance and coordinate 'opt in' opportunities for co-operative procurement of consultants for member jurisdictions in implementing the new provincial housing legislation; and
c) Advocate to the Province for: infrastructure programs and funding to ensure that sufficient infrastructure is in place to accommodate the increases in population and housing projected; better alignment with Metro 2050; and stronger support for non-market and affordable housing.

2.That the Mayors Committee receive for information the report dated February 23, 2024 titled "Provincial Housing Legislation: Provincial Advocacy and Supportive Roles" and provide alternate direction to staff.

FINANCIAL IMPLICATIONS

The proposed actions and next steps listed in this report can be accommodated within the existing work plan and Board-approved budget for the Regional Planning and Housing Services and External Relations departments. If further advocacy actions or supportive roles are identified, Metro Vancouver staff would report back to the MVRD Board with any updated financial implications.

CONCLUSION

Recently passed provincial housing legislation will result in significant and historic changes to the planning framework for British Columbia. Since the release of the new legislation, Metro Vancouver staff have been working with member jurisdictions at multiple levels to engage, support and receive feedback regarding the potential impacts. The impacts will be wide ranging and affect planning work at both the local and regional levels. Metro Vancouver is well positioned to help the federation develop a coordinated regional response and can play an important role to help support member jurisdictions with the changing planning landscape and new provincial requirements.

REFERENCES

1. Local Government Delegate Survey Results - 2024 UBCM Housing Summit (ubcm.ca)

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