



metrovancover

Evaluation of Regional Ecosystem Connectivity

2025

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Executive Summary

Understanding the connectivity of green spaces is critical for conserving biodiversity in our region. This analysis evaluates landscape connectivity in Metro Vancouver by assessing the spatial arrangement of habitat patches and the probability of movement between them. The Probability of Connectivity (PC) metric quantifies overall connectivity, while the delta Probability of Connectivity Index (dPC) measures the contribution of individual patches to the network.

This spatial analysis evaluates the habitat requirements of 11 representative species: Southern red-backed vole, Townsend's vole, red-back salamander, long-toed salamander, muskrat, great blue heron *ssp. fannini*, brown creeper, rufous hummingbird, Savannah sparrow, dark-eyed junco, and pileated woodpecker. These 11 species were selected as, collectively, they exhibit a broad range of terrestrial life history strategies and traits. These species represent amphibians, mammals, and birds with a variety of home range sizes, dispersal patterns, and tolerances to human impacts. The identified habitat patches represent the most favourable habitats used by a guild of species. Each guild of species is represented by a focal species.

This study used a spatial prioritization model called Zonation to evaluate the value of natural areas for supporting and connecting wildlife habitat across the Metro Vancouver Region. The results identify where important “key-hub” patches are located for each of the 11 representative focal species. Key hub patches are those areas that play a crucial role in maintaining connectivity within the landscape. The value of the patches was also assessed to highlight unprotected areas, regardless of ownership, that could be opportunities for protection to maintain ecosystem connectivity across the region.

Findings indicate that bird species exhibit higher connectivity than terrestrial species. The dark-eyed junco has the most connected network, followed by the Savannah sparrow and pileated woodpecker. Other species, show significantly lower connectivity, with the lowest values observed in the Townsend's vole and Southern red-backed vole.

The dPC analysis highlights that bird species rely heavily on stepping-stone patches to maintain connectivity, whereas terrestrial species depend more on intrapatch connectivity. This suggests that Metro Vancouver's landscape is better connected for birds than for other species, emphasizing the need for targeted conservation efforts to improve connectivity for non-avian species.

The north shore mountains provide large continuous natural areas with a variety of habitats. This area includes many of the most significant habitat patches in the region. Most of the key-hub patches associated with the red-backed salamander and brown creeper are on the north shore mountains. The muskrat, long-toed salamander and the great blue heron are all dependent on aquatic habitats. The muskrat and great blue heron require access to foreshore habitat. Most of their key and key-hub patches are found along large, connected shorelines throughout Metro Vancouver. The muskrat and long-toed salamander require access to riparian habitat and have less available habitat compared to the

other species. The Townsend's vole and Savannah sparrow thrive in grasslands, characterized by low-lying vegetation, and wetland habitats. In Metro Vancouver, agricultural lands provide suitable habitat for both species. Dark-eyed juncos exhibit large daily dispersal patterns and a high tolerance to human impacts. They prefer edge/shrub communities and can occupy a variety of habitats. These traits make the dark-eyed junco highly adaptable and successful in natural areas as well as semi-modified habitat patches found within Metro Vancouver's urban areas.

The software program Zonation was used to combine and identify priority areas for all 11 species. At a regional scale, the largest and most connected natural areas identified include the extensive forests in the northern reaches of Metro Vancouver. This area includes natural ecosystems that have been largely protected for our water supply and as parks, as well as rugged and inaccessible terrain.

The southwest marine foreshore is highly valued and provides protected, connected estuaries, intertidal wetlands, and mud flats that are dynamic and rich in food sources for both terrestrial and aquatic species. Inland from the ocean, the arms of the Fraser River extend through Metro Vancouver. The results of this analysis highlighted the lack of high value habitat along the shorelines of many of the reaches of the Fraser River. The highest ranked, stepping stone, patches are agricultural lands adjacent to riparian or forest patches in south-eastern Metro Vancouver, or forest patches adjacent to protected natural areas in the District of North Vancouver, West Vancouver, Coquitlam, Maple Ridge, and Bowen Island. The results of this analysis show that connectivity across agricultural areas is relatively uniform. The vegetated fields allow wildlife to move across the landscape without major barriers, providing a moderate level of connectivity throughout.

The findings from this analysis are illustrated on maps that are scaled to the region as well as each Metro Vancouver member jurisdiction. These maps are intended to provide high-level information that can be used to guide planning, development, and land acquisition decisions throughout the region. Many key-hub patches identified by this modeling exercise are not currently protected and they are vulnerable to the impacts of land development. Future analysis should be considered as our understanding of species home range sizes, dispersal patterns, and tolerances to human impacts increases and as habitat data for more species becomes available. Additional studies could include representative species of intertidal foreshore areas or focus on understanding the connectivity of freshwater habitats in Metro Vancouver.

1.0 Introduction

Highly connected ecosystems better support biodiversity compared with fragmented landscapes. They provide more ecosystem services, bolster community resilience, and they are more adaptable and resilient to the impacts of climate change, development, and other stressors. As urban areas densify, it becomes increasingly important to understand where valuable habitat patches exist and how they are connected together. Urban greenspace most commonly exist as a fragmented patchwork created by development, roads, utilities, and other land uses¹. Habitat fragmentation can negatively impact ecosystem services and reduce the dispersal ability of plants and animals, as well as the long-term flow of genes and viability of wildlife metapopulations². Quantifying the connectivity of urban greenspaces improves our understanding of the landscape's ability to meet the habitat requirements of a variety of species.

Metro Vancouver is a federation of 21 municipalities, one electoral area, and one treaty First Nation that plans for and delivers regional utility services, including water, sewers and wastewater treatment, solid waste management, regulates air quality, provides affordable housing, manages a regional parks system, and plans for urban growth. To support the implementation of *Metro 2050*, the Regional Growth Strategy, Metro Vancouver Regional Planning staff are working with member jurisdictions, First Nations and other agencies to identify the Regional Green Infrastructure Network (RGIN). *Metro 2050* also states that "Member jurisdictions will seek to acquire, restore, enhance, and protect lands, in collaboration with adjacent member jurisdictions and other partners, that will enable ecosystem connectivity in a regional green infrastructure network." The RGIN consists of interconnected habitat patches and corridors, and builds on previous work including a Regional Connectivity Analysis completed by Diamond Head in 2020. Protecting the RGIN, where possible, across jurisdictional boundaries will support the movement of species across the landscape, maximize ecosystem services, and moderate climate change impacts.

A Technical Advisory Committee of local ecological and spatial analysis experts was established to help guide the development of the RGIN. One of the Committee's suggestions was to update the Regional Connectivity Analysis. Since the original analysis performed in 2020, the Sensitive Ecosystem Inventory, land cover classification, and protected area datasets were updated. Additionally, the Committee suggested adding more focal species that would represent urban and agricultural habitat features. Preliminary research was conducted to determine the parameters for two to five additional focal species groups to complement the eight species previously represented.

The goals of this analysis were to:

1. Identify important habitat patches for each of the 11 focal species;
2. Understand how these habitat patches overlap;

¹ Cen et al., 2015; Irwin & Bockstael, 2007

² Hanski and Gilpin, 1991; Clergeau and Burel, 1997; Ferreras, 2001; Angelone and Holderegger, 2009; Dixo et al., 2009

3. Identify regionally significant patches that best support all of the focal species;
4. Identify patches that are critical for regional connectivity; and
5. Identify important patches that are unprotected.

This report provides a summary of the process used to carry out this analysis as well as results. These results are intended to provide high-level information to help guide planning, development, and land acquisition decisions throughout the region.

2.0 Methodology

Methodological options were thoroughly researched as part of earlier phases of the project. This report summarizes both original methods and how the process was refined during the 2024 update.

2.1 Choosing focal species

A total of 11 focal species were selected for this analysis, representing a range of habitat types. This includes the eight species from the 2020 analysis, and three new species. All focal species were selected in collaboration with the RGIN Technical Advisory Committee and Metro Vancouver staff to ensure a range of species, habitat types, modelling and life history parameters.

First, potential focal species were explored. Since this analysis focuses on terrestrial connectivity, freshwater and marine species were excluded; however, species that use these environments were still included if they live their adult life on land. Forty-five terrestrial candidate regional indicator species were initially selected for further review in 2020, showcasing a diversity of life history characteristics. This included 29 birds, 10 mammals and 6 amphibians/reptiles.

A variety of primary and secondary sources were reviewed to determine habitat types, maximum and minimum dispersal distances, minimum patch size, life history parameters, and dispersal limitations. Habitat was typed based on land cover type, forest composition & age, core/edge, and by proximity to marine/freshwater features. Modelling parameters required for this analysis included the median and maximum dispersal and minimum patch size required for survival. Factors that limit dispersal were also identified such as roads and major rivers. This list of species and their life history parameters was reviewed and updated as part of this process, where new data was available.

Focal species were then removed based on:

- **Availability of modeling parameter data** (those species for which, after a sustained research effort, we could not reasonably attribute modelling parameters)
- **Length of dispersal distances** (tens to hundreds of km were deemed too long and unsuitable for modelling at the scale of the Metro Vancouver region)
- **Habitat types** (very generalist use of habitat types were removed because their landscapes would be hyper-connected)

Through consultation with the RGIN Technical Advisory Committee, it was later determined that two land cover classes (agricultural land and urban landscapes) were largely absent in the initial connectivity modelling of Metro Vancouver. Five potential focal species (4 birds and 1 mammal – dark-eyed junco, downy woodpecker, pacific wren, Savannah sparrow, and Townsend’s vole) were identified using the same selection process and updated background data as the first eight focal species. Three additional focal species from this group—Townsend's vole, Savannah sparrow, and dark-eyed junco—were selected in collaboration with Metro Vancouver staff. Research on the habitat patch requirements for these three species proved to be the most reliable and accurate.

The final species selected, and their life requirements, are summarised in Table 1. These “focal species” are meant to represent a diversity of habitat requirements and life history characteristics. As such, focal species patches should be considered as representations of the most favorable habitat for a guild of species that is represented by each focal species with similar habitat needs and life history traits.

Table 1. Eleven focal species selected (three additional focal species bolded) for this connectivity study, their life history traits, and patch habitat requirements. (F-female, M-male)

Species Common Name	Patch Habitat Requirements			Life History Parameters			
	Median Dispersal (m)	Max Distance (m)	Minimum Patch Size (ha)	Average Lifespan (yrs)	# of Offspring per Year or Clutch Size	Maximum Body Length (m)	Average Body Mass (g)
Red-Backed Vole	220	500	0.1	0.5	4.5	0.11	25
Red-Backed Salamander	1.0	36	1.0	<10	5	0.115	-
Long-toed Salamander	200	3,200	30	6	110	0.17	7.5
Muskrat	57	4,000	3.0	3.5	15	0.7	1,200
Great Blue Heron <i>ssp. fannini</i>	2,000	10,000	1.0	23	2.9	1.4	2100 (F)
Brown Creeper	88	2,110	2.3	-	6	0.13	8
Rufous Hummingbird	31	2,000	0.3	1-8	2	0.1	3.4
Pileated Woodpecker	1,650	18,700	1.0	4	3 to 5	0.5	290
Townsend’s vole	6.4	43	0.05	-	5	0.225	64 (M) 51.8 (F)
Savannah sparrow	885	2,825	0.1	-	3-4	0.15	15-28
Dark-eyed junco	2110	15000	2.4	7	4	0.16	19

The most recent (2020) Metro Vancouver Land Cover Classification and Sensitive Ecosystem Inventory (SEI) were the primary geospatial data inputs used to create habitat patches. A network of high value habitat areas was identified for each species using the parameters listed in the table. Buffers of habitat were erased along roads for species sensitive to urban barriers. Rivers and other watercourses were also accounted for as a barrier, preventing dispersal for the species that cannot fly and without a water component of their life history strategy. Quality rasters were created for each species based on the size of patches, core and edge condition modifiers, water features and riparian habitat. Some other modifications were made for species with specific habitat requirements. A literature review indicated that the great blue heron was unlikely to use forest habitat above 500 m and that the red-backed salamander was highly averse to all human disturbances. Further masks were created to modify the habitat patches for these species.

Some shallow marine areas and intertidal foreshore/mudflats were included in the analysis, as they are important for two of the 11 species. They were included to account for the importance of the connections between the marine foreshore and upland forests. They do not reflect marine species habitat needs as no marine species guilds were included in this analysis.

2.2 Identifying habitat patch importance per focal species guild

The Conefor Sensinode software package (Conefor) was used to run a network analysis for each of the 11 focal species. Habitat mapping, life requirements, and a quality rating were used as inputs to model connectivity importance. Conefor quantified the importance of habitat areas and links for the maintenance or improvement of connectivity. Outputs from this model include metrics that measure connectivity in various ways.

The following terms are key outputs of the first phase of the study (see Glossary for terms and acronyms).

Probability of Connectivity Index (PC): This is a metric that quantifies landscape connectivity by considering both the spatial arrangement of habitat patches and the likelihood of movement between them. The PC metric describes the amount of reachable habitat in a landscape both among and within patches. This can be interpreted as the probability that “...two animals randomly placed within the landscape fall into areas that are reachable from each other” (Saura & Pascual-Hortal, 2007a p.93).

delta Probability of Connectivity Index (dPC): This metric measures the individual contribution of a specific habitat patch to the overall connectivity of the landscape. It represents the change in the PC index when a particular patch is removed, thereby assessing the importance of that patch in maintaining landscape connectivity. This metric is composed of three components. One of those is called **dPCconnect** which is an indicator of the patch's function as a stepping stone or corridor that enhances connectivity between other patches.

The outputs from the Conefor Sensinode analysis are used to identify important habitat areas across the landscape. The role of these patches is discussed using three terms:

Key Patches: These are habitat patches that significantly enhance overall landscape connectivity. Their importance is quantified using dPC. A high dPC value indicates that the patch is crucial for maintaining connectivity. These are the habitat areas that the model has identified as being most important for each species.

Hub Patches (stepping stones): These patches serve as central nodes within the habitat network, often characterized by their large size or strategic location. They provide substantial habitat areas and facilitate movement across the landscape. Hub patches are areas that are most important for each species as stepping stones for maintaining connectivity across a landscape. The removal of these patches has a disproportionately large negative effect on connectivity with nearby patches.

Key-Hub Patches: Patches that combine the attributes of both key and hub patches are termed key-hub patches. They are vital due to their significant area and their role in connecting different parts of the landscape.

2.3 Evaluating connectivity importance

The Conefor analysis identified key-hub patches throughout Metro Vancouver for each of the 11 focal species. Next, a prioritization software called Zonation was used to analyse all of the species' habitat collectively and to prioritize their value toward regional connectivity. For more details refer to Appendix 3. This section of the study looked to understand:

- How these patches overlap;
- Where regionally significant patches are that best support all of the focal species;
- Where the most critical patches for regional connectivity are; and
- Which of these patches are most at risk of development to help prioritize their protection

As part of the analysis, a protected areas layer was used to help identify the most important patches to connectivity that were at risk of development or degradation. This layer was derived from a 2023 Parks Protected Areas layer and updated using the municipal open data sources to enhance the connectivity analysis. This update included verifying and integrating it with BC Parks, Ecological Reserves, and Protected Areas, new Metro Vancouver parkland acquisitions, polygons from the Canadian Protected and Conserved Areas Database (CPCAD) that were previously excluded, and data from the BC NGO Conservation Lands Atlas. Additionally, all parks were considered protected, even if they may not protect natural areas within them (i.e. urban recreational parks were not differentiated from natural areas parks).

There were two processes associated with this connectivity analysis (illustrated in Figure 1):

1. **Analyze Conefor results** to identify important patches for the 11 focal species guilds.
2. **Process Zonation rasters to identify regionally important areas for connectivity** for the greatest number of species. Rerun with the Protected Areas layer to identify priority areas outside of already protected land.

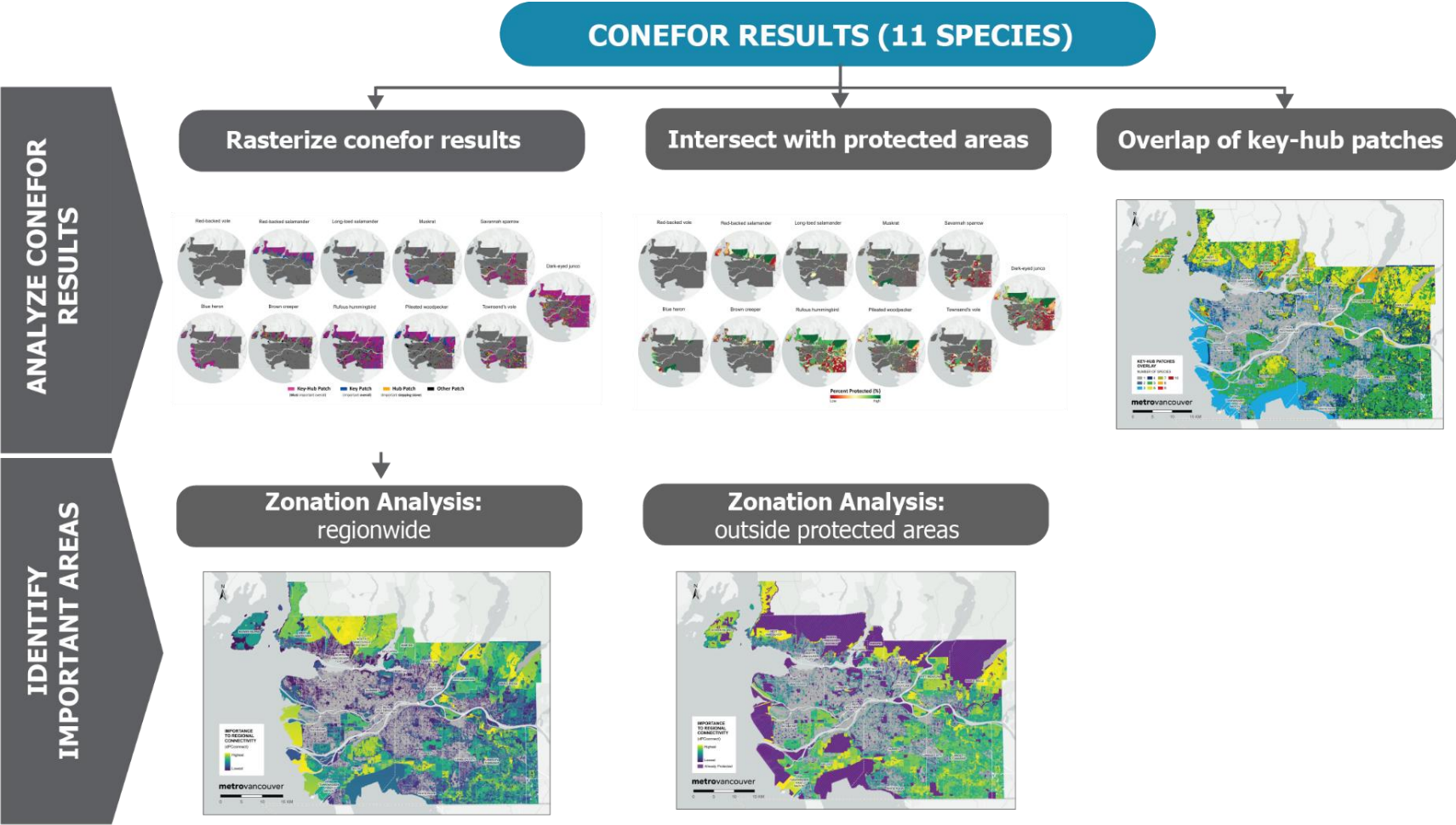


Figure 1. Methodology workflow for the 2024 update to the Metro Vancouver Evaluation of Regional Ecosystem Connectivity study.

Outputs from the connectivity evaluation were used to identify important areas for connectivity within Metro Vancouver using Process Zonation (Zonation). Zonation ranks traits based on how much overlap exists among different maps and datasets. Ranking can also be influenced by adding strength to certain parameters such as the importance of an individual species or habitat type. In this project, we used equal weights for all 11 focal species as each species is important for conservation purposes.

Ecosystem connectivity between the 11 focal species was compared by analyzing connectivity metrics produced by the Conefor analysis. The areas with the highest connectivity distribution for the most species would receive the highest ranking. These areas would be considered more important in terms of connectivity.

The next Zonation process was to identify areas of high connectivity most at risk of landscape development. This was analyzed by comparing interpatch connectivity, important stepping-stone patches, and existing protected areas within Metro Vancouver. Protected Areas include those being protected through dedication as a municipal, regional, or provincial park along with any other areas that municipalities included in their open data parks/protected area GIS. Protected areas were negatively weighted in the model to increase the ranking and target high value habitat areas that are not currently protected as parkland.

Two final maps were produced. One represents a combination of dPC and dPCconnect. This identifies the important areas in terms of connectivity values regionwide. The second represents a combination of dPCconnect and protected areas. This identifies the important areas located outside protected areas that contribute the greatest to regional connectivity. More details are provided in Section 3.2.

3.0 Results and Discussion

3.1 Individual species results and discussion

3.1.1 Probability of Connectivity (PC) results

This metric quantifies landscape connectivity by considering both the spatial arrangement of habitat patches and the likelihood of movement between them. This evaluates the probability that two habitat patches are functionally connected, accounting for factors such as patch area and inter-patch distances.

The results from this analysis indicate that the dark-eyed junco has the most connected network, with an overall (PC value of 0.2 (Figure 2). The Savannah sparrow followed with the second-highest overall connectivity value, with a PC of 0.13. The pileated woodpecker, Rufous hummingbird, blue heron, red-backed salamander, brown creeper, and muskrat showed lower levels of overall connectivity with values of 0.002, 0.001, 0.0009, and 0.0008 respectively. The long-toed salamander, Townsend's vole, and Southern red-backed vole showed the lowest connectivity values of 0.0001, 0.00008, and 0.0000004.

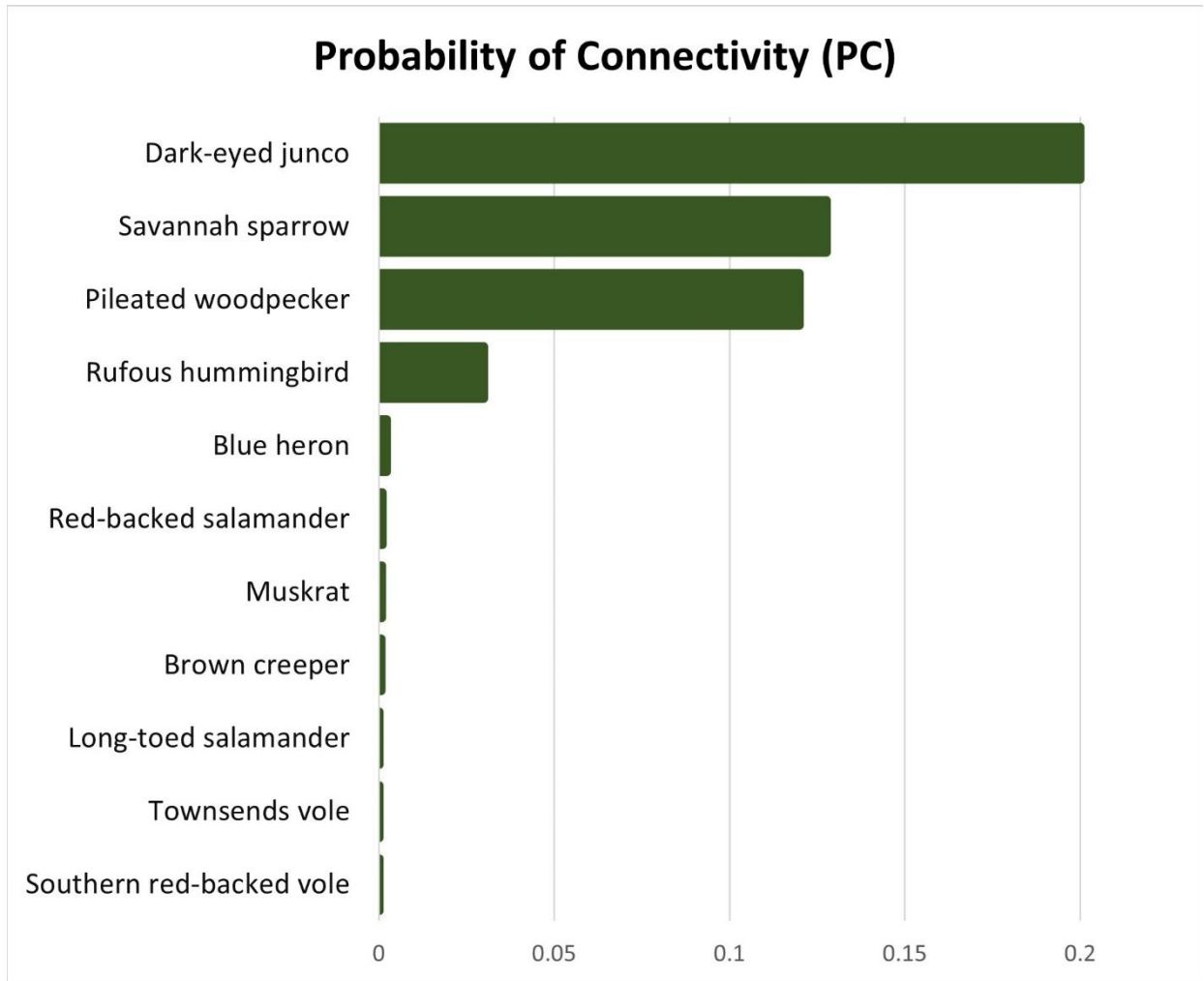


Figure 2. Probability of Connectivity (PC) values represent how well the landscape is connected for the 11 focal species in Metro Vancouver.

3.1.2 delta Probability of Connectivity Index (dPC) results

The delta Probability of Connectivity Index (dPC) is a metric that measures the individual contribution of a specific habitat patch to the overall connectivity of the landscape. It represents the change in the PC index when a particular patch is removed, thereby assessing the importance of that patch in maintaining landscape connectivity. This metric is composed of three components. One of which is *dPCconnect* an indicator of the patch's function as a stepping stone or corridor that enhances connectivity between other patches.

Figure 3 highlights the components that dPC consists of: *dPCintra*, a measure of intrapatch connectivity, *dPCconnect*, the importance of a patch for connecting other patches together, and *dPCflux*, a measure of how connected a patch is to the network.

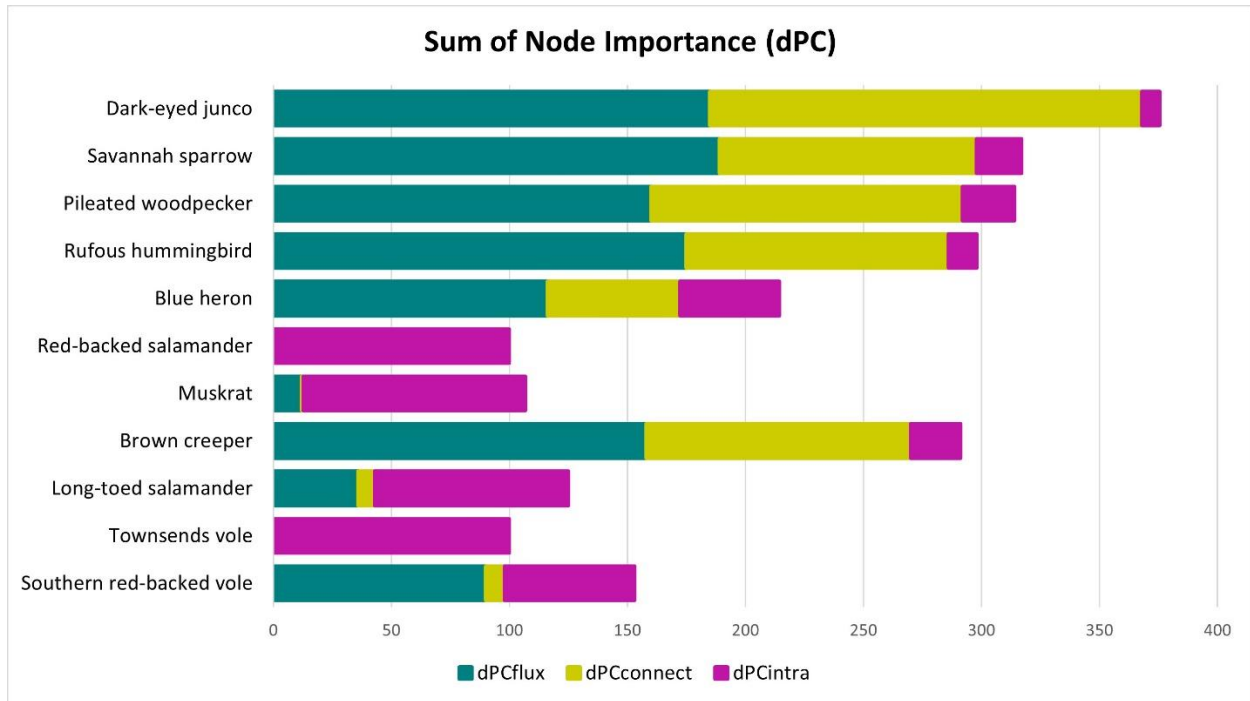


Figure 3. Sum of node (patch) importance for 11 species in Metro Vancouver. The length of each bar represents the sum of dPC which is comprised of patch connectedness (dPCflux), stepping stones (dPCconnect), and intrapatch connectivity (dPCintra).

All five bird species have higher sum dPC values than non-bird species (Figure 3). This indicates the presence of more critical habitat areas for connectivity compared to the other seven species. The five bird species are characterized by a large portion of dPCconnect making up the sum dPC value, denoting the importance of stepping stones in the network of the five bird species compared to the other species. This suggests that Metro Vancouver provides habitat that is better connected for birds than terrestrial species.

Conversely, the remaining seven species have lower dPC values overall, with the sum of dPC largely comprised of dPCintra (within patch connectivity). These two factors indicate low network connectedness, a reliance on intrapatch (within patch) connectivity, and more isolated patches in their overall network.

3.1.3 Understand how these habitat patches overlap – Key and hub patches

In the Conefor analysis, key patches, hub patches, and key-hub patches are identified based on their contributions to landscape connectivity. **Key patches** are those with high dPC values, indicating they significantly enhance connectivity and provide critical habitat. **Hub patches** are large or strategically located patches that act as central nodes/linkages. These hub patches are important stepping-stone corridors, facilitating species movement, and maximizing dispersal throughout the network. **Key-hub patches** combine these attributes, serving as both critical connectors and substantial habitat providers. These key-hub patches are likely sources of species emigrants to other patches. Habitat patches are illustrated in Figure 4.

Species with a high abundance of large key-hub patches (pink) include the rufous hummingbird, dark-eyed junco, Townsend's vole, pileated woodpecker, and Savannah sparrow. The long-toed salamander, brown creeper, muskrat, pileated woodpecker, Rufous hummingbird, dark-eyed junco, and Townsend's vole have large key patches (blue) that are not considered hubs (figure 4). While these areas are critical to the individual species for within-patch and between-patch connectivity, removing these patches will not have a disproportionately large negative effect on the species connecting to nearby patches. This may indicate redundancy in the system, which increases resilience in the network as other adjacent/nearby areas offer the same level of connectivity between patches as these key patches. Species with a high abundance of hub patches (stepping-stone corridors, orange) include the dark-eyed junco, Savannah sparrow, pileated woodpecker, and brown creeper.

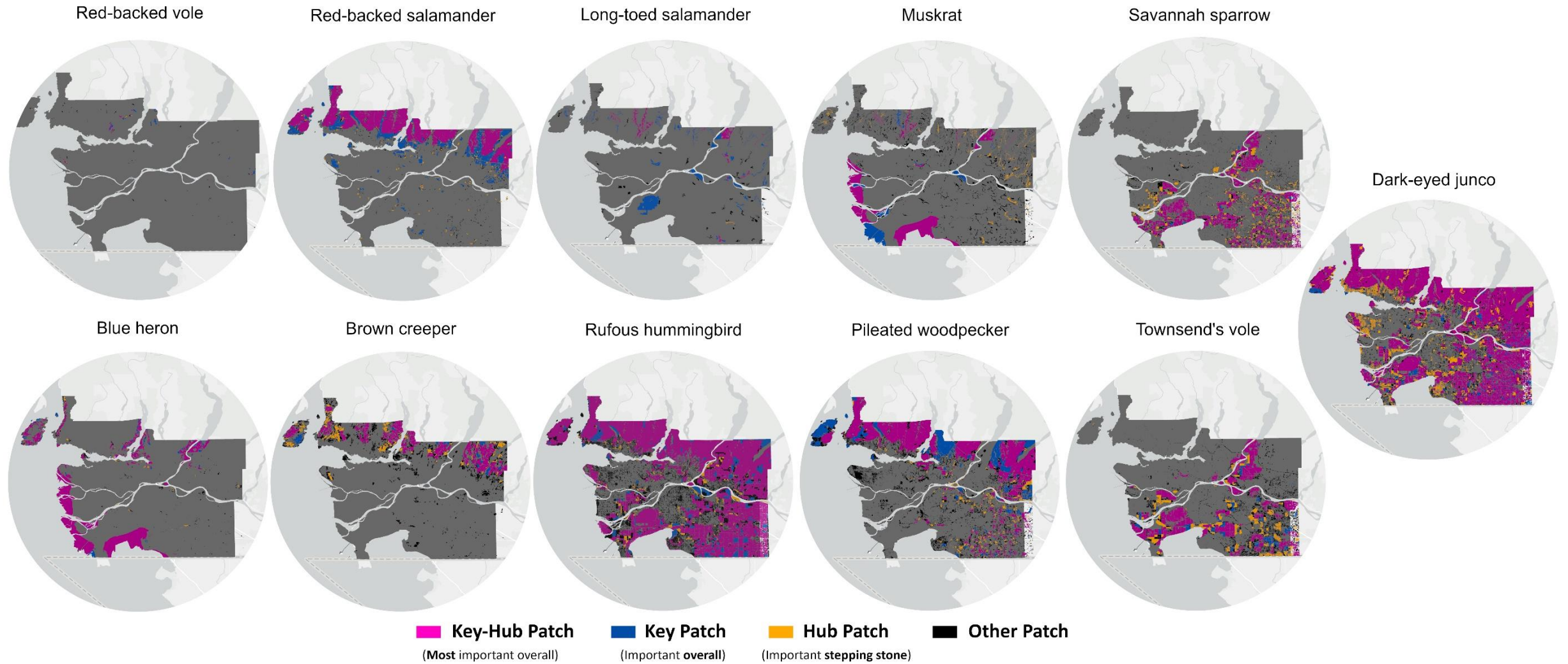


Figure 4. Key and hub patches for all 11 species modelled. Key patches are shown in blue, hubs in orange, and overlap in pink. Patches that are neither key nor hub are black.

3.2 Overall Connectivity Results and Discussion

3.2.1 Identify patches that are critical for overall regional connectivity using Zonation

After identifying the key, hub, and key-hub patches per species, the resulting habitat patches needed to be prioritized within the larger network. Two methods were employed to identify the regionally most important patches for connectivity for all 11 representative species.

Critical Key-hub patches for all species

First, to highlight important connectivity habitat for all 11 species, the overlap between **key-hub patches** was mapped (Figure 5).

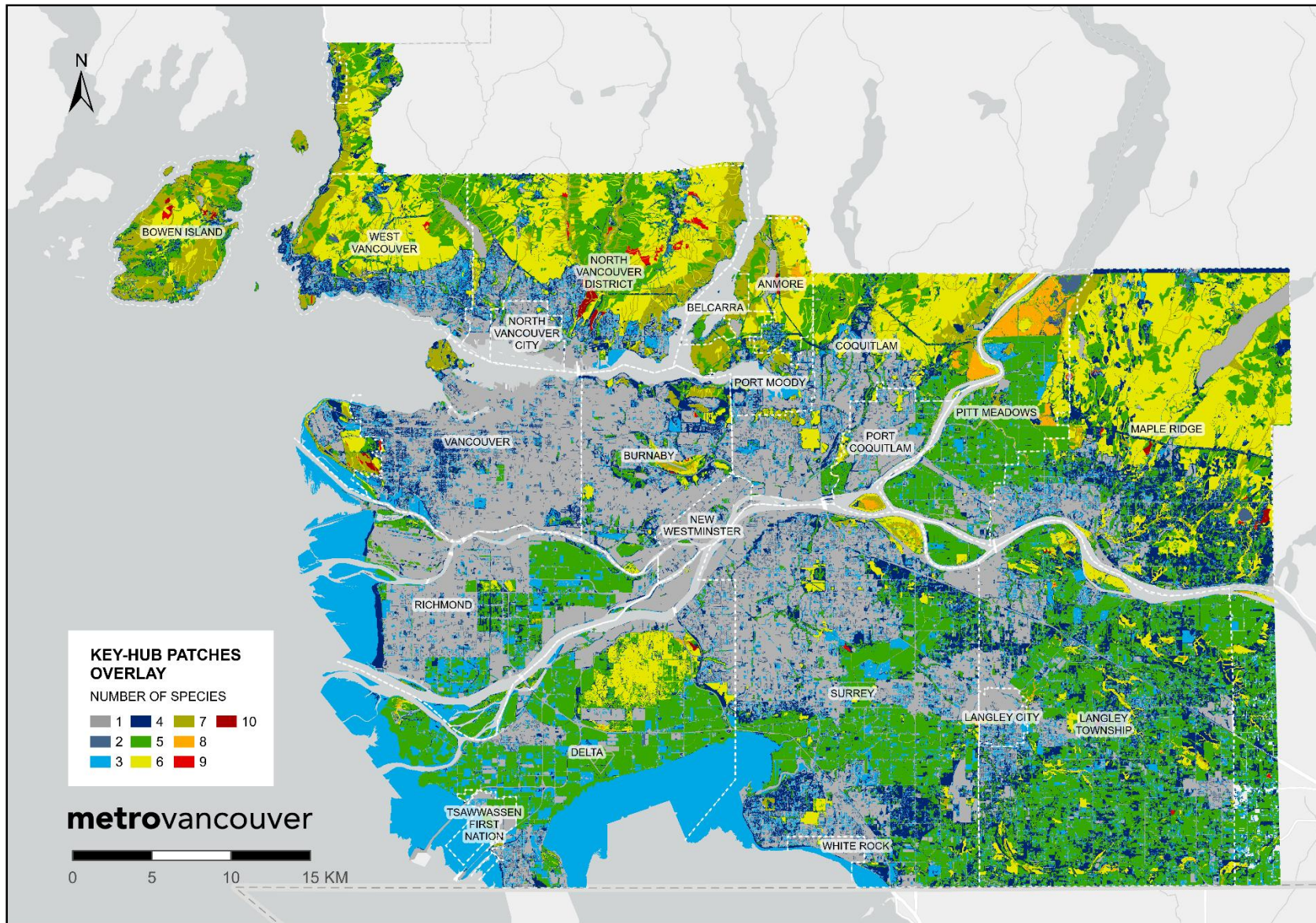


Figure 5. Overlap of key-hub patches for all 11 focal species.

The largest patches with the most species use overlap are located in the north of Metro Vancouver, specifically in the north of Bowen Island, near Lynn Valley in North Vancouver, in the northeast near Pitt Addington Marsh, Pinecone Burke Provincial Park, Minnekhada Regional Park, Golden Ears Provincial Park, and Maple Ridge. These natural areas, shown in yellow, olive, and orange, contain key hub patches for 6-8 focal species. These patches, shown in red, contain significant key-hub patches for 9 or 10 of the focal species. The south of Metro Vancouver also has areas with high species overlap, however, these areas are smaller and further apart. The large continuous areas in the south are typically protected parkland, such as Pacific Spirit Park, Burns Bog, and Surrey Bend Regional Park. These parks contain significant key-hub patches for 6 to 10 focal species.

While overlaying key-hub patches per species provides insight into the patches that provide habitat for the highest number of species, it does not incorporate the relative importance of the key-hub patches per species. The overlay does not differentiate between key-hub patches for each species; all key-hub patches are treated equally across the 11 species.

Critical Hub Patches (Stepping-stones) for all species

The second method used to identify the regionally most important patches for connectivity for all 11 focal species was mapping the overlap between **hub patches** (stepping-stone) (Figure 6). This method rated which patches are critical stepping-stones for the most focal species within the connectivity network.

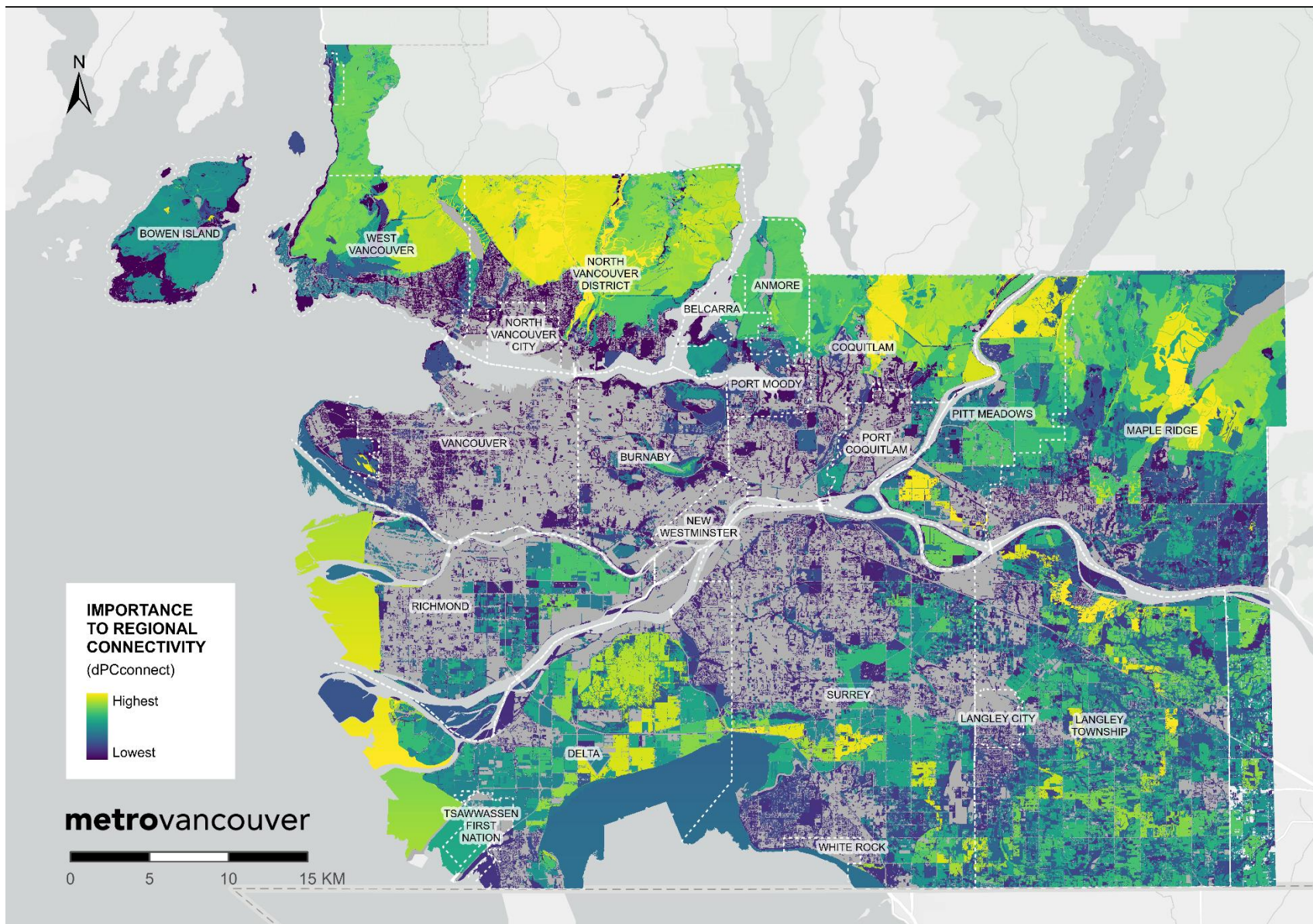


Figure 6 Conservation prioritization based on stepping-stone (hub patch) importance (dPCconnect), with all patches with the same weighting.

The results from this analysis rate the large, intact, natural areas--that are known to provide high habitat value--as the highest importance for stepping-stone/corridors for all species. These results further support these areas as the most important patches for all focal species connectivity across the region.

The largest and most highly connected natural areas identified include the extensive forests that interface with the north side of Metro Vancouver (Figure 6). This area represents the interface of natural ecosystems that have been largely protected for our water supply and as parks or include rugged and inaccessible terrain. These areas are continuous and well connected with the extensive natural areas that continue to the north.

Patches in the network that are smaller and less continuous but are still rated moderately high to the highest importance include agricultural lands in the south of Metro Vancouver (Delta, Surrey, Langley Township). Even though these patches may not provide a significant amount of habitat on their own they play an important role in connecting species to other habitat patches. The loss of these habitat patches would have a disproportionately large effect on regional connectivity overall. These patches received a lower rating before the inclusion of the three new focal species (Savannah sparrow, Townsend's vole, and dark-eyed junco). These focal species occupy agricultural lands and urban areas which introduced a more comprehensive analysis of regional connectivity. While these patches are typically small and experienced historical landscape alteration, they offer value to species adapted to using those landscape characteristics. Additionally, these patches may provide critical stepping-stone corridors for species less sensitive to human disturbance. Therefore, excluding these areas may underestimate habitat connectivity in Metro Vancouver.

Most large natural areas are highlighted as moderate to high value. These are mostly protected as parks as shown in Figure 7. Examples include Stanley Park, Pacific Spirit Regional Park, Tynehead Regional Park, Burnaby Lake Regional Park, Burnaby Mountain Conservation Area, Campbell Valley Regional Park, Belcarra Regional Park, Mundy Park, Burns Bog Ecological Conservancy Area, Surrey Bend Regional Park, Richmond Nature Reserve, Colony Farm Regional Park, Green Timbers and Sunnyside Acres Urban Forests. Some of these areas are not rated as highly as may be expected; however, this is likely due to how continuous and connected the natural areas of the North Shore Mountains are. While many of these natural areas are intact and healthy, they are still isolated and not directly connected to other large natural areas. It is important to consider these fragmented areas during land use planning as these islands are inherently more at risk of having isolated populations that may experience genetic drift.

While this analysis does not include freshwater or marine species, it does include species that make use of these areas for habitat. As such, high value and highly connected habitat has been identified along the marine foreshore and mudflats that interface with the west and south sides of Metro Vancouver (Figure 6). This is in stark contrast to Figure 5, where only 2 species were identified as using this habitat. These areas, however, are prioritized as playing an important connectivity role in the region and providing high value habitat for the species that do make use of it. A number of foreshore habitat areas however, came out as less important for regional connectivity than one might expect. This is due to the

inclusion of these foreshore areas solely on how they connect to terrestrial habitat and how they are used by the selected focal species. The emphasis on the terrestrial environment undervalues these foreshore areas as it excludes the importance for marine species and shorebirds. Unprotected foreshore areas were removed from the final map to avoid misinterpretation and to focus on terrestrial habitats (Figure 7).

3.2.2 Identify important patches that are unprotected as parkland (at risk of landscape development)

The large, connected habitat patches at the north edges of Metro Vancouver are consistently identified as the most regionally important for overall connectivity (key-hub patches and hub patches). This output inhibits identifying unprotected and smaller key-hub patches critical for connectivity in urban and rural communities. The Protected Areas layer removes large, connected, protected habitat patches to highlight key-hub habitat patches (most important to connectivity) that are unprotected and may be at risk of landscape development (Figure 7).

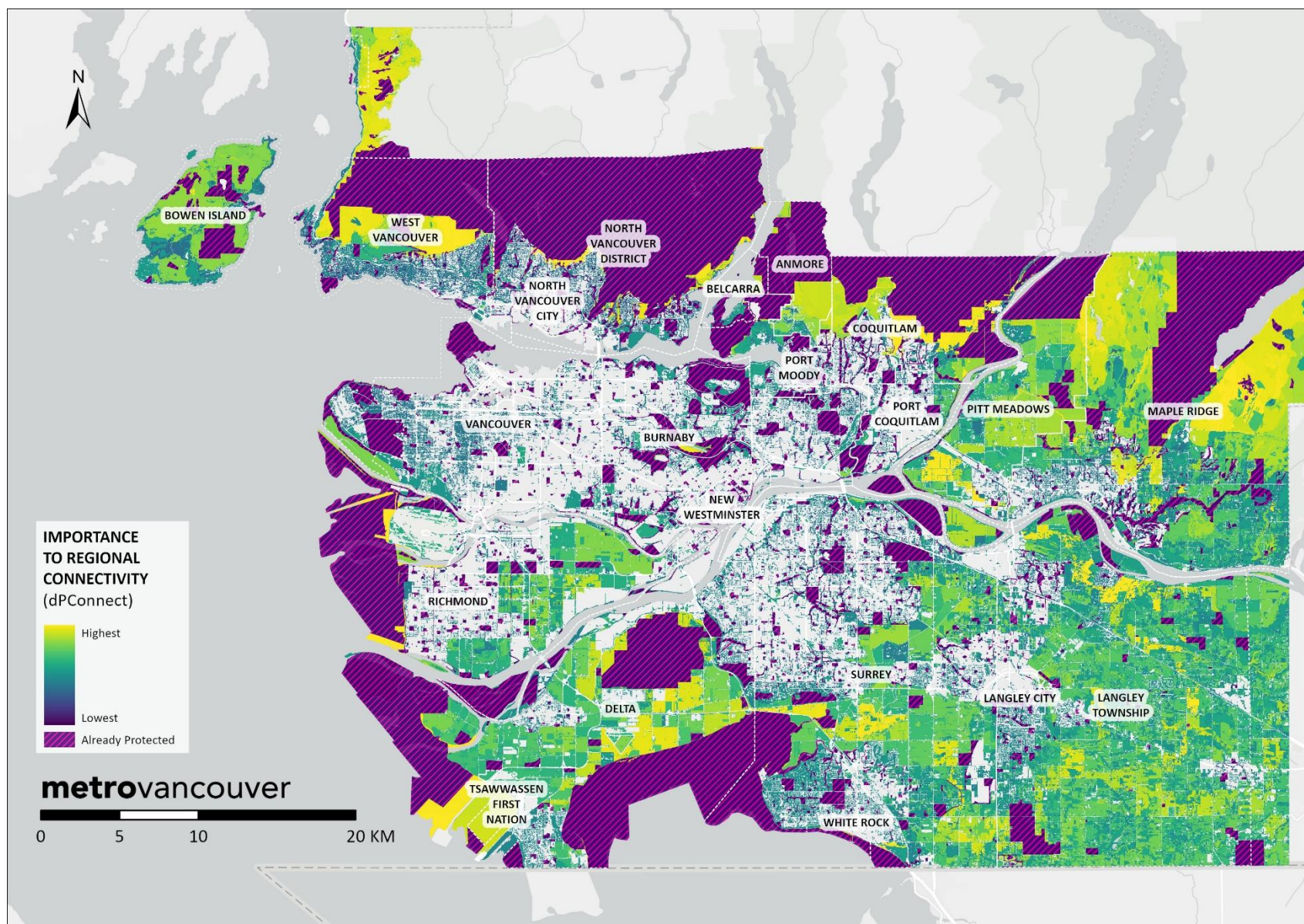


Figure 7 Conservation prioritization based on stepping stone (Hub patch) importance (dPCconnect), with lower rating applied to protected areas.

This analysis shows that many existing parks identified as high-value connectivity patches are already protected. These protections have prevented degradation and fragmentation of these areas retaining intact, highly connected, patches for multiple species used in this analysis. Some of these existing parks are also part of green infrastructure networks developed by local municipalities.

While many key-hub patches are protected as parkland, some important patches are not. Patches of habitat that are protected as parkland to a lesser degree include the western portion of Bowen Island, which represents key-hub patches for the red-backed salamander and rufous hummingbird, and the area to the east of Golden Ears Provincial Park, which contains key-hub patches for the red-backed salamander, rufous hummingbird, pileated woodpecker, brown creeper, and the dark-eyed junco (Figure 5).

Many patches adjacent to large continuous natural areas (classified as key-hub patches) are unprotected. These patches are subsequently rated high to highest in importance for regional connectivity, acting as a critical link between source populations and the rest of the network. Loss of these patches due to landscape development or habitat degradation could disrupt species dispersal and immigration, leading to fragmented/isolated populations, reduced survival and recruitment rates, and increased genetic drift, which may negatively impact wildlife populations within Metro Vancouver over time.

Agricultural areas provide a moderate capacity to support wildlife life processes and movement, particularly for birds. These regions, concentrated in southern Metro Vancouver, are rated moderate to highest of importance for species connectivity and contain key-hub patches for the rufous hummingbird, Townsend's vole, Savannah sparrow, and dark-eyed junco (Figure 5). Although agricultural areas were not considered protected in this analysis, lands within the Agricultural Land Reserve are protected from many types of development, are often permeable, and contain vegetation. While this offers a level of protection typically absent from urban areas, it does not guarantee the preservation of native ecosystems.

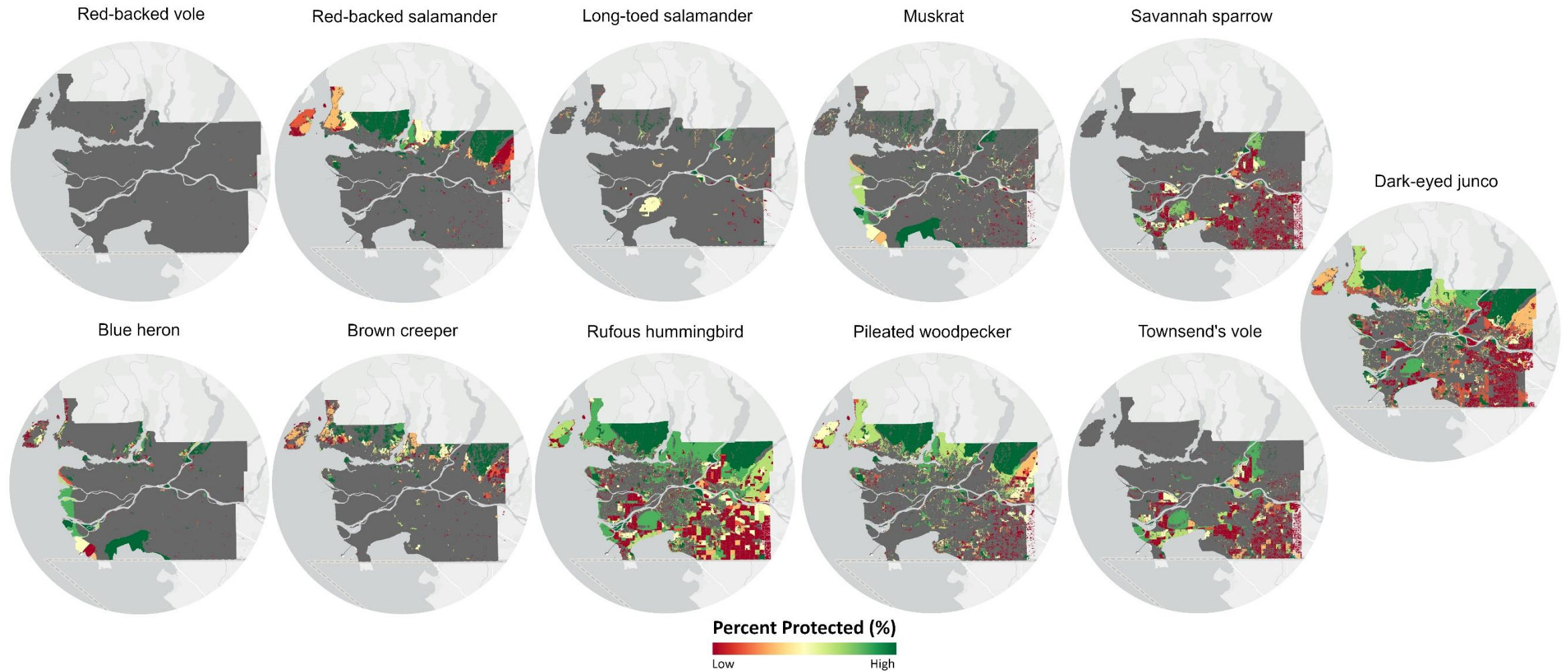


Figure 8. Habitat patches for all 11 species displayed by percent protected area. Protected Areas include those being protected through dedication as municipal, regional, or provincial park.

3.3 Summary

The highest value key-hub patches were identified throughout Metro Vancouver. They were identified per species (Figures 4 & 5), using a species overlay (Figure 7), and using dPCconnect, with and without the protected layer (Figure 8). For detailed Metro Vancouver member jurisdiction maps, refer to Appendix 4. These maps use zonation and DPC connect to incorporate key-hub patches for all 11 species and identify the most important patches for regional connectivity at a local level.

Often times existing parks were identified as high value connectivity patches. These areas have been protected from degradation and represent intact patches for multiple species used in this analysis. Some of these existing parks are also part of green infrastructure networks developed by local municipalities. Through agricultural areas, there is a broad moderate capacity to support wildlife movement, particularly for birds. While these areas were not identified as protected for the purposes of this analysis, lands located within the Agricultural Land Reserve are protected from many types of development, are often pervious, and contain vegetation. This offers a level of protection that is often absent from urban areas; however, it does not ensure that native ecosystems remain intact.

Modeling Assumptions, Uncertainties, and Data Constraints This analysis was completed using prioritization software that provides a consistent output for all of Metro Vancouver, with minimal reliance on professional judgement, thereby reducing the potential for bias. The results illustrate the relative value of the fragmented habitat that remains within our urban areas to the extensive natural areas that extend north from our cities. The use of models, however, does have limitations, and assumptions were made.

Results are limited by the accuracy of the input habitat mapping, the focal species chosen, and the understanding of their life requirements. The lifecycle characteristics of each species were based on existing scientific findings. It was often difficult to derive the exact habitat patch size and dispersal information of a species. There is always variability among individuals and populations of a species, and we were limited to species that have been studied extensively, and for which data was available in scientific literature. Another limitation is the use of Euclidean (straight-line) distances to model links between patches. More sophisticated software can generate least-cost resistance paths, which are more realistic pathways for species movement; however, for species such as birds this may be an accurate presentation of how they move through space, and Euclidean distances were considered sufficient for this study.

In the absence of presence/absence data, land cover classes were used as proxies for species habitat. This analysis was largely a desktop-exercise, with the use of local expert knowledge of the study area applied in determining these habitat types. Inherently, there will be some inaccuracies between the modelled patches and the actual presence of species in those patches. Interspecific interactions can also affect how each species uses the landscape; this is especially true for territorial species and development-sensitive species. Finally, the landscape is continually changing and some of this data may

not be accurate to current day conditions. These uncertainties must be considered when evaluating the results of this study.

The addition of agricultural and urban areas “de-emphasized” the importance of some of the Pacific flyway-type habitats, weighting/ranking.

4.0 Summary of Results and Next Steps

This regional study was undertaken to evaluate the value of natural areas for supporting and connecting a diversity of terrestrial wildlife habitat across Metro Vancouver. This study aims to guide decision-makers in identifying and prioritizing habitat patches most valuable for regional connectivity.

Evaluating the value of natural areas for the health of wildlife is complex. There are variables that affect species from the scale of the population to the individual. The climate and ecosystems it affects are dynamic and continually changing. This model attempts to prioritize important habitat and the impact patch loss will have on the connectivity of other areas. It provides a repeatable, quantitative assessment of habitat value while minimizing the influence of professional bias.

An overlay has been produced of all key-hub patches for the 11 representative focal species; areas in red represent regionally significant key-hub patches that provide important habitat for 9 or 10 of the species modelled. These areas are likely biodiversity hotspots and should be protected to preserve biodiversity in the Region as it continues to grow.

Interpretation of the key-hub maps should include the collective outputs as well as the individual species. While overlaying all of the key-hub patches together provides valuable collective information, it does not account for the relative importance of the key-hub patches per species. Decisions for land use should consider at-risk species such as the blue-listed Great Blue Heron. They should also consider species that have few remaining key-hub patches such as the red-backed vole.

When interpreting the vulnerability of habitat areas, it is important to consider the presence of protected areas. For this analysis, protected areas refer specifically to those dedicated as municipal, regional, or provincial parks. Land use designations, such as the Conservation and Recreation Regional Land Use Designation, are not included in this layer. The focus is on dedicated parks, wildlife management areas, and ecological conservancy sites. Additionally, conservation covenants compiled by the Nature Trust of BC in 2020 are included. However, lands protected through other means, such as Agricultural Land Reserves (ALR) or Development Permit Areas, are not part of this layer. Additionally, all parks were considered protected, even if they may not protect natural areas within them (i.e. urban recreational parks were not differentiated from natural areas parks).

There are many key-hub patches that have been identified by this modeling exercise that are not currently protected and are vulnerable to the impacts of development. The outputs of this modeling exercise should be used by land managers when considering the protection of areas for wildlife habitat. This analysis should be considered again in the future as our understanding of species home range sizes, dispersal patterns and tolerances to human impacts is further refined and additional input habitat data is made available for a wider range of species.

Future studies could look to include species which better represent the intertidal foreshore areas. They could also focus on understanding the connectivity of freshwater habitats in Metro Vancouver, as this

study was focused on terrestrial species. In addition, the study chose to weigh all species equally; future studies could incorporate additional species or look to prioritize species at risk of extirpation or extinction. The patches identified in this study could be used to help understand the importance of patches to a Regional Green Infrastructure Network (RGIN); however, the implementation of this network should consider values beyond connectivity such as land use designation, the presence of sensitive habitat features and species at risk. The RGIN could also look for opportunities to improve connectivity through habitat enhancement, incorporating areas that have value by nature of their location, but are currently largely developed (ex. along the Fraser River).

Glossary

Connectivity: The degree to which species can move through landscapes, habitats, and ecosystems without barriers or impediments. This movement enables species interactions and genetic flow that is critical in maintaining biodiversity, ecosystem health, and resilience.

Ecosystem services: The benefits people obtain from healthy ecosystems, such as shading, cooling, flood control, water purification, carbon storage and sequestration, pollination, and food, as well as mental health and well-being.

Focal Species: A species that is selected for study because it has characteristics that can represent a broader group or guild of species. Focal species serve as representatives for a group or guild of species that have similar habitat requirements, life history traits, and ecological function.

Hub Patches (stepping stones): Hub patches are areas that are most important for each species as stepping stones for maintaining connectivity across a landscape. The removal of these patches have a disproportionately large negative effect on connectivity with nearby patches. Hub patches are determined using dPCconnect and dNC. Any patches with a dNC < 0 were identified as hub patches whose removal would increase habitat fragmentation.

Key Patches: Key patches are the most important areas for each species, and overall connectivity, as determined by dPC, which combines within-patch and between-patch connectivity to determine overall patch importance.

Key-Hub Patches: Key-hub patches are patches that meet the requirements of both key patches and hub patches and are the most important patches to protect from a connectivity perspective.

Probability of Connectivity (PC): PC can be interpreted as the probability that “...two animals randomly placed within the landscape fall into areas that are reachable from each other” (Saura & Pascual-Hortal, 2007a p.93). **In other words, the PC metric describes the amount of reachable habitat within a landscape both among and within patches.** The following are metrics within PC:

dPC: dPC is a metric of PC, and measures the effect of node removal on overall network connectivity. dPC combines within-patch and between-patch connectivity to determine overall patch importance, identifying key patches within the landscape.

dNC: dNC is a measure of how important a patch is for maintaining component integrity. The value of dNC becomes more negative with the importance of the patch

dPCconnect: dPCconnect is the measure of a patch’s importance for connecting *other* patches together.

Appendix 1 Connectivity Metric Definitions

DHC: Diamond Head Consulting

dPC: dPC is a metric of PC, and measures the effect of node removal on overall network connectivity. dPC combines within-patch and between-patch connectivity to determine overall patch importance, identifying key patches within the landscape.

dNC: dNC is a measure of how important a patch is for maintaining component integrity. The value of dNC becomes more negative with the importance of the patch

dPCconnect: dPCconnect is the measure of a patch's importance for connecting *other* patches together.

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MV: Metro Vancouver

Probability of Connectivity (PC): PC can be interpreted as the probability that "...two animals randomly placed within the landscape fall into areas that are reachable from each other" (Saura & Pascual-Hortal, 2007a p.93). **In other words, the PC metric describes the amount of reachable habitat within a landscape both among and within patches.**

Connectivity metrics calculated using Conefor, adapted from Saura and de la Fuente (2011).

Metric Name	Formula/Explanation	Description
Probability of Connectivity (PC)	$PC = \frac{\sum_{i=1}^n \sum_{j=1}^n a_i \cdot a_{ij} \cdot p_{ij}^*}{A_L^2}$ $= \frac{PCnum}{A_L^2}$	PC is the probability that “... two animals randomly placed within the landscape fall into areas that are reachable from each other.” Probabilities between patches are based on median dispersal distances having a probability of 0.5. The patch attribute, <i>a</i> , is the area-weighted quality of a patch.
dPC	$dPC(\%) = \frac{PC - PC'}{PC} \times 100$ <p>and</p> $dPC = dPCintra + dPCflux + dPCconnector$	Measures the effect of node removal on overall network connectivity (PC). dPC is the percent contribution of a node (<i>k</i>) to PC. The value of PC after removing node <i>k</i> (PC') is subtracted from the overall value of PC. The difference between the two values is then expressed as a percentage of PC. dPC is composed of three node importance metrics explained below.
dPCintra	Available habitat provided by a patch (<i>k</i>) itself: $a_i \times a_j$ when $i = j = k$ (a_k^2). Where <i>a</i> is area-weighted quality.	dPCintra is the percent contribution of a patch to intrapatch (within-patch) connectivity . It is not affected by number of links or link probabilities.
dPCflux	Area-weighted dispersal flux from a patch (<i>k</i>) to or from all other patches in a network: $a_i \times a_j \times p_{ij}^*$	dPCflux measures how connected a patch is in the network . dPCflux depends on the area-weighted quality of a patch and its position in the network. It differs from dPCconnector in that it doesn't measure how important a given node is for connecting <i>other nodes</i> together, but rather how connected an individual node is itself to the rest of the network.
dPCconnector (Stepping Stone Importance)	Contribution of patch <i>k</i> to the connectivity of neighbouring patches. The sum of $a_i \times a_j \times p_{ij}^*$ for any number of pairs of patches, <i>i</i> and <i>j</i> , around a given patch <i>k</i> . Patch <i>k</i> must be part of the best path between <i>i</i> and <i>j</i> .	dPCconnector is a measure of how important a patch is for connecting other patches together. It can be thought of as stepping stone importance. dPCconnector is independent of a patch's area-weighted quality, and depends only a patch being part of the <i>best</i> path for dispersal (i.e. when $p_i \times p_j$ is highest).
NL (Degree)	e_k where <i>e</i> is the number of links for a given patch, <i>k</i> .	The number of links (also called edges) of a given patch. Node (patch) degree distributions can help to characterize a network into different typologies.
Number of Components (NC) and dNC	The number of components in the network (NC). dNC measures the importance of a patch for maintaining component integrity.	Components are groups of connected patches. In a component every patch is connected to every other patch by at least one link. Isolated patches are also components. NC allows for component ID but also individual patch membership in a component. For dNC, increasingly negative values denote greater patch importance.

Appendix 2 Detailed Methodology – Phase 1

NOTE: This appendix is a reproduction of the Phase 1 Methodology Report. It has not been systematically updated after the completion of phase 2.

For a general overview of the connectivity modelling methods used in this study, please see the Metro Vancouver pilot connectivity study conducted by Williams *et al.* (in Ruan *et al.*, 2017³), and the Regional Greenspace Connectivity User Guide (Nicoletti & Clark, 2018⁴). The methods below detail new or different steps taken in the expanded modelling analysis for RFSQ 19-361.

These methods are also best reviewed in concert with the Species Parameters and Selection criteria deliverable, the Excel file 191223_FocalSpp_w_SelectionCriteria.xlsx.

4.1 Tasks 1 and 2: Define a method or criteria to determine 7 to 10 suitable focal species for connectivity analysis and selection of focal species.

Deliverable: *Species Parameters and Selection Criteria*. Includes focal species list, species attributes, species selection criteria, quantitative visualizations, and calculations of modeling parameters. Sources for research also included.

1.1.1 Species research and data organization methods

The first goal in our analysis was to identify focal species for connectivity modelling. Candidate focal species were drawn from regional indicator species identified in a 2003 report for the Ministry of Water, Land and Air Protection (Lee & Rudd, 2003) as well as the extensive list of native species and their associated habitat included in Surrey’s Biodiversity Conservation Strategy (BCS) (Diamond Head Consulting & City of Surrey, 2014). From our initial survey we chose 45 species with a diversity of connectivity and life history characteristics that fit into three broad classes: Birds (29), Mammals (10), and Amphibians/Reptiles (6).

Each species was researched using information from the Lee & Rudd and Surrey BCS reports, as well as peer-reviewed journal articles, Natureserve.org profiles, field guides, and species at risk documentation, among other sources. The Santini *et al.* (Table S1, 2013) table of dispersal distances for a number of mammal species, which itself cites multiple primary sources, was also used. Conefor modelling and life history parameters were documented (Table 2) as well as habitat types used for creating habitat patches and assigning habitat quality (Table 3). Sources used for each species are included in the tabular ***Species Parameters and Selection Criteria*** deliverable, with an accompanying folder of source material. Instructions and criteria for data collection are also included in this deliverable.

³ <https://metrovancover.org/advisory-committees/rpac-environment-subcommittee/Documents/UBCLandCoverConnectivity.pdf>

⁴ Available through Metro Vancouver.

Modelling and Life History Parameters

In general, a combination of natal⁵ and foraging dispersal distances, home range, and territory size were used to calculate the quantitative modelling parameters. Dispersal distances and minimum patch sizes were calculated using weighted averages from sample populations where possible. If less than 1ha, home ranges were considered as potential minimum patch sizes, otherwise minimum patch size was estimated from foraging dispersal, defended territory size, or other contextual information.

Dispersal data for many species was limited, necessitating the use of single sources and/or small samples in some cases, or the use of inferences regarding dispersal based on home ranges in others (for e.g. assuming the radius of a circle of a minimum foraging area). The process of assigning maximum and minimum dispersal distances was further complicated by a range of dispersal types reported for each species; for example, it was common to find migratory distances for birds that were generally too long (100s-1000s of kms) for regional connectivity modelling, while natal or foraging dispersal distances were much rarer. Indeed, data availability was one of the main drivers of focal species selection.

Table 2 Modelling and life history parameters collected for each candidate focal species. Median and maximum dispersal and minimum patch size are the essential parameters required for Conefor modelling. Dispersal limitations make networks more realistic by removing links that species are unlikely to actually use. Life history parameters informed species selection criteria to ensure a diverse selection of focal species. They could also be used in future multivariate statistical analyses for alternate species selection and to characterize the diversity of candidate species chosen.

Species Common Name	Patch Habitat Requirements			Life History Parameters			
	Median Dispersal (m)	Max Distance (m)	Minimum Patch Size (ha)	Average Lifespan (yrs)	# of Offspring per Year or Clutch Size	Maximum Body Length (m)	Average Body Mass (g)
Red-Backed Vole	220	500	0.1	0.5	4.5	0.11	25
Red-Backed Salamander	1.0	36	1.0	<10	5	0.115	-
Long-toed Salamander	200	3,200	30	6	110	0.17	7.5
Muskrat	57	4,000	3.0	3.5	15	0.7	1,200
Great Blue Heron <i>ssp. fannini</i>	2,000	10,000	1.0	23	2.9	1.4	2100 (female)
Brown Creeper	88	2,110	2.3	-	6	0.13	8
Rufous Hummingbird	31	2,000	0.3	1-8	2	0.1	3.4
Pileated Woodpecker	1,650	18,700	1.0	4	3 to 5	0.5	290

Life history parameters were recorded in the event they were useful when conducting a multivariate analysis of species to select them for modelling. In the end this sort of analysis (such as a PCA, RDA or

⁵ Dispersal of individuals from their birth site to their breeding site.

cluster analysis) was not deemed necessary, however, life history parameters were included in the final focal species selection criteria.

Habitat Type Assignment

Habitat types and modifiers were designed around the Metro Vancouver 2014 Land Cover Classification (Williams, Matasci, Coops, & Gergel, 2018) and the Metro Vancouver Sensitive Ecosystem Inventory, the two primary geospatial datasets used for patch creation (Table 3). The exception was the edginess requirement type, which was determined using internal buffers applied separately for each relevant species (Rufous hummingbird, southern red-backed vole and the western red-backed salamander). Edginess requirements were determined by reviewing a species' life history. If a species preferred core or edge habitat this was noted as a condition modifier for species habitat. Shrub was included in the forest edge category because shrub was likely to be a land cover class encapsulated by forest edges, though the edge type could also contain any other forest class. The geospatial identification of core and edge is detailed below.

The first step in determining habitat types was to assign a different letter to each land cover type. Land cover types used by a species were tallied with Xs, which were cumulative from the perspective of patch creation. For example, if a species had Xs marked for both Mixed and Coniferous forest, both of those habitat types would be used to create habitat patches for a species. Other habitat types were assigned at least one of three alphabetical codes: **C**, **R**, and **I**.

C, for *Condition Modifier*, denotes that a species prefers that habitat type and/or the type is particularly important in a species' life history, and should be more heavily weighted when calculating patch quality (discussed below). **R**, for *Restrictive*, denotes that a species only uses that habitat type. For example, a species that uses only riparian grass-herb habitat would have an X in the grass-herb class and an R in the riparian class. Rs could be placed in more than one class to create cumulative habitat restrictions. **I** stands for *Inclusive*, and denotes a habitat type used by a species but is neither preferred nor restrictive. R and C were regularly placed together in a habitat type to indicate that a species was both restricted to a certain type, and that it should be given extra weighting when calculating patch quality.

Table 3 Habitat types and condition modifiers collected for each focal species. Habitat types were separated into forest and non-forest. Land cover categories were taken from Metro Vancouver’s 2014 Landcover. All other classes were taken from Metro Vancouver’s SEI except for edginess, which was determined using buffer distances.

Forested Types	Land cover	All Forest (LC and Age Class)
		Mixed Coniferous Deciduous
	Age (C = condition modifier, R = restrictive, I = inclusive)	Old Mature Young
	Edginess Req. (C = condition modifier, R = restrictive)	Core Edge/ Shrub
Other SEI classes (C = condition modifier, R = restrictive, I = inclusive)	Woodland Riparian Wetland	
Non-Forested Types	Landcover	All Non-Forest (LC)
		Shrub Grass-Herb Soil
Other SEI classes (C = condition modifier, R = restrictive, I = inclusive)	Riparian Wetland Estuarine Intertidal/ shallow sub-tidal Sparsely Vegetated Old Field Other fields/ agriculture	

4.1.1 Creating a shortlist of potential focal species

Data availability of modelling parameters became the main determinant of accepting a species into a shortlist of focal species. Those species for which, after a sustained research effort, we could not reasonably attribute modelling parameters were removed as focal species candidates.

Of the species remaining, those with very long median and maximum dispersal distances (tens to hundreds of km) were also removed, as they were deemed unsuitable for modelling at the scale of the Metro Vancouver region. Further removals were done for species that had modelling parameters less suited to our analysis – for example, species with longer dispersal distances and very generalist use of habitat types were removed because their landscapes would be hyper-connected. Following these steps resulted in a short list of potential focal species consisting of 5 birds, 5 mammals, and 6 amphibians or reptiles.

Once a shortlist was established, habitat types used by each species were tallied, and their frequency of occurrence reviewed to establish which habitats were more or less commonly used. Habitat types that were rarely (3 or less occurrences) used by the shortlisted species were noted. Rare type usage was then used as an input into the final focal species selection criteria.

4.1.2 Developing criteria to categorize potential focal species and guide final selection

Selection criteria were developed to make a final selection from the focal species shortlist. In total, ten criteria were developed, along with a landcover summary statement and other contextualizing notes. Three indicators represented habitat usage, which was summarized into a short statement and then coded as i) forest, ii) non-forest or iii) rare cover (or any combination of the three) (Table 4). Note that rare in this case is relevant only for the habitat types used by the shortlisted species, rather than rare in the context of habitat types that exist in the Metro Vancouver region. Rarity in this case is also not a commentary on whether or not a species is a habitat generalist or specialist, but was used to add weight to habitat types that would have little or no representation should a species be removed from the shortlist.

Table 4 Habitat usage indicators and landcover summary statements for two example focal species of the eight modelled. Rare_cover denotes whether a species used a relatively rare landcover type among the shortlisted focal species, and was included to ensure a range of habitat types were included.

Common Name	Scientific Name	LC_summary	forest	nonforest	rare_cover
Brown creeper	<i>Certhia americana</i>	mature and old forest only, condition modifiers for woodland, riparian and wetland sites	Y		
Great Blue Heron ssp. <i>fannini</i>	<i>Ardea herodias fannini</i>	mature riparian and coastal forest (10km buffer) only, wet non-forest only except old fields	Y	Y	Y

Modelling and life history parameters were summarized into seven categorical criteria (Table 5). These parameters either had their quantitative values categorized into three classes (e.g. short, medium and long median dispersal) or were synthesized into new categories altogether, such as for sensitivity to development.

Table 5 Focal species selection criteria developed from modelling and life history parameters (7 in total). Species habitat usage was also coded for their use of forest, non-forest and rare habitats. Rare habitats were determined by a relative ranking of habitats used by the shortlist of candidate focal species.

Med. Dispersal: short (<50), medium (50-500), long (>500)	Sensitivity to barriers (low, medium, high)	Sensitivity to development (low, medium, high)	Min patch sizes: small (< 0.5ha), medium (0.5-3ha), large (>3ha)	Habitat: generalist, specialist, rare types used	Offspring: few, med, many	Longevity: short, medium, long
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For both the short and long list of focal species candidates, reasonable class breaks were determined for quantitative parameters such as median dispersal, minimum patch size, number of offspring and longevity using their respective frequency distributions. Other criteria were derived using a more qualitative review of the shortlisted species parameters – for example, sensitivity to development was determined by assessing if links among patches were limited by roads or water, as well as a broader review of a species’ sensitivity to disturbance and habitat preferences. Similarly, whether a species is a habitat generalist or specialist was informed both by a quantitative tally of the habitat types used, as well as a contextualization of habitat usage and life history using information from our species sources.

Maximum dispersal was omitted in the selection criteria because median dispersal was thought to be more descriptive and relevant for the probabilistic modelling used by the PC index. For example, though the muskrat’s network will have patches connected together by links as long as its maximum dispersal of 4000m, its median dispersal distance of only 57m has a probability of success of 0.5. Because Conefor uses an inverse distance-weighted method to calculate dispersal probabilities for links among patches, the probability of success for the muskrat’s maximum dispersal distance will be very small. Therefore, links that are as long or shorter than a species’ median dispersal will be considered far more likely for most species, rather than maximum dispersal, as modelled.

After the criteria were developed, a criteria table was created and populated with the shortlisted focal species candidates. From these, the final focal species were selected to ensure a range of habitat types, modelling and life history parameters were included. An effort was made to include at least one sub-category (e.g. short, medium, long) for each criterion while also considering the ease and utility of modelling. This goal was achieved for each criterion except for the “sensitivity to development” and “offspring” criteria, for which only two categories were fulfilled by the final focal species selection. Ultimately, the selection was made using a subjective interpretation of the available data informed by a range of quantitative, categorical and qualitative data.

4.2 Task 3: Create a list of example species represented by each focal species

Deliverable: *Example Species List.* A list or table detailing groups of multiple species (minimum of 5 per focal species), with the same or similar habitat needs and dispersal distances. Each group is headed by one of the focal species selected in Task 1.

Species with similar habitat requirements, dispersal characteristics and ecological roles or needs were selected for each focal species. At least five of these example species were selected per focal species. Though redundancy or overlap of species’ ecological roles and niches has been demonstrated to exist, and is a key concept in ecological resilience theory, we present the example species list with a caveat: namely, all species are unique in some way by definition. Deciding on the right balance of habitat, dispersal and ecological function to decide whether an example species is represented by a focal species (and vice versa) is subjective. Regional experts may disagree with our assessments and propose changes, which we welcome. We believe the example species list should be a living document, updated as more information becomes available.

With those caveats in mind, example species were selected according to their similarities to the 8 focal species. We used three general categories or criteria to select example species. Habitat requirements and dispersal characteristics chiefly guided our selection of example species, while factors like taxonomic similarity, trophic level and ecological role supplemented our decision making:

1) Habitat requirements

- We grouped focal and example species by use of forested habitat or use of both forested and non forested habitat.
- We examined the unique habitats of both focal species and example species habitat.
- We matched the unique habitat preferences of the focal species to those of the example species.

2) Dispersal characteristics (median dispersal, minimum patch size)

- We categorized the 8 focal species and 40 example species into 3 classes of median dispersal (short <50m, medium 50-500m, long >500m) and 3 classes of minimum patch size (small <0.5 ha, medium 0.5-3ha, large >3ha).

3) Other considerations

- We ensured that each group of example species encompassed at least one species of another taxa than the focal species taxa.
- We also considered trophic level, functional roles and interspecific interactions when considering species. For example, though the northern flicker has a longer dispersal distance and minimum patch size than the Pacific Wren (one of the focal species modelled in the Pilot Study). However, both species are insectivorous, and the flicker might create cavities used by the Pacific Wren as nesting habitat, an example of a possible commensal relationship between the species. The species are, therefore, likely to co-occur in mature forest with an abundance of decaying trees.

4.3 Tasks 4 and 5: Run Conefor Analysis for Species and Collate Deliverables

4.3.1 Pre-processing

Using the Conefor Sensinode software package and Metro Vancouver’s spatial data (land cover and SEI), DHC ran a network analysis for each of the chosen focal species. Geoprocessing methods to create habitat patches followed a similar methodology to the Metro Vancouver connectivity pilot study from 2017 (Williams et al. in Ruan et al., 2017).

The MV 2014 Landcover and SEI polygons were the primary geospatial data sources used to create habitat patches. For most terrestrial habitats SEI polygons were used to select MV landcover rather than the SEI polygons on their own. The exception was for the intertidal/estuarine SEI class which was outside the MV landcover footprint. SEI polygons were also selected from all three decile classes for

most of the habitat types. As with the pilot study, roads were erased from species patches before running Conefor.

Further masks were created from a 500m elevation contour and from built-up areas to erase from the great blue heron and red-backed salamander species patches, respectively. Built-up polygons were selected from MV landuse with some manual review and selection. The decision to remove patches using these masks was based on the literature review conducted for each species which indicated that the great blue heron was unlikely to use forest habitat above 500m and that the red-backed salamander was highly disturbance averse. The small minimum patch size of the salamander also meant that more patches that fit its habitat requirements were likely to be found in more built-up areas.

Quality rasters were created individually for each species considering the condition rating provided in SEI. Quality ratings were increased for areas considered core and edge habitat. Buffer distances were chosen considering species dispersal ability and minimum patch size, which led to the following edge and core habitat buffers: (1) a 100m internal buffer to determine core habitat for the red-backed salamander; (2) a 100m internal buffer to determine edge habitat for the Rufous hummingbird; and (3) an internal 50m buffer to determine edge habitat for the red-backed vole.

A 2m spatial resolution was used for the condition rasters. Condition values ranged from 1-10, with a minimum of values from 1-7, depending on the number of modifiers added for each species. Area-weighted quality was then assigned to patches as per the Metro Van Pilot Study. The SEI condition values range from 1-5 and there are only 4 possible condition modifiers that can be added for either forest or non-forested habitat. However, because most SEI classes were taken from all three deciles of the SEI, occasional overlaps among the SEI polygons were likely to occur. This was seen as advantageous, because if multiple preferred habitat types of a species existed in close proximity the quality of that habitat would likely be higher.

4.3.2 Subset Landscapes

Subset landscapes, used to create reduce processing times for species with many patches and longer dispersal distances, are shown in Figure 9. Note that there are some overlaps of the landscapes for certain Fraser river, Pitt River and Indian Arm Islands. After testing whole-region runs for each focal species, we found that only two species required subset landscapes: the pileated woodpecker and Rufous hummingbird.

For these two species, subset landscape patches were selected with a 3000m buffer around each landscape. Doing so reduced the likelihood of creating artificial landscape boundaries by preventing patches neighbouring a subset landscape from being cut off. The neighbouring patches can then also be identified as overlap patches and their regional importance assessed.

The 3000m buffer distance is longer than the hummingbird maximum dispersal, and shorter than the woodpecker maximum dispersal. This means that the 3000m buffer around each subset landscape

contains all the possible neighbouring patches that the hummingbird could disperse to in a single event. This is not the case for the woodpecker, but its long maximum dispersal distance corresponds to a relatively unlikely event as modelled, and the 3000m buffer distance is almost twice that of its median dispersal. This indicates that overlap patches within the 3000m buffer around each subset landscape are almost certainly part of a maximum product probability route across the region for the woodpecker. Use of components (groups of connected patches) for subset landscapes were also investigated, but too few components existed for these species; i.e. 1 or 2 components comprised the entire landscape and, therefore, too many patches to model efficiently.

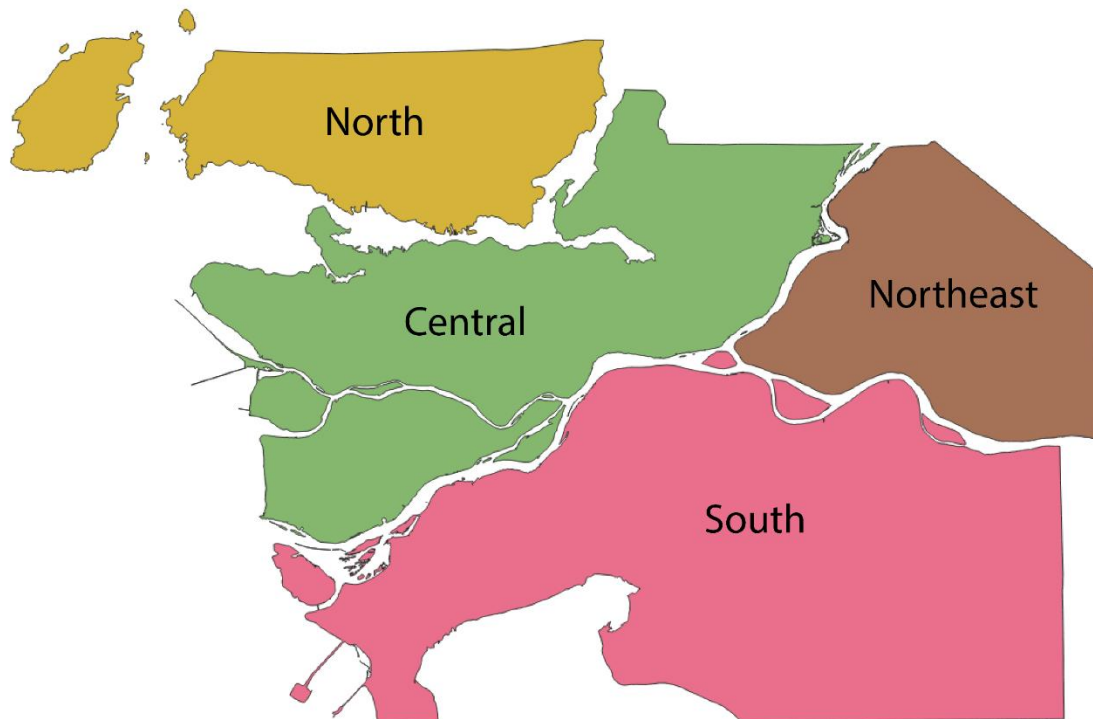


Figure 9 Subset landscapes used for the pileated woodpecker and Rufous hummingbird. Overlaps exist among the landscapes for some islands in the Fraser and Pitt Rivers as well as Indian Arm. Divisions between landscapes are major water bodies to choose the most realistic landscape borders possible. Patches for each landscape were selected with a 3000m search distance beyond each subset landscape boundary to enable the identification of overlap patches.

4.3.3 Running Conefor

Area-weighted quality (AWQ) is assigned to each patch in order to account for habitat quality when running Conefor. The intent of AWQ is to produce a more realistic habitat model than one based on patch area alone. For a discussion on how Conefor incorporates patch quality into its metric calculation, the reader is directed to Table 13 in Ruan et al. (2017) and Saura and Tourné (2009).

Once AWQ was assigned to each patch, each species' landscape connectivity was modelled using Conefor. Straight-line (Euclidean) links were used, as least-cost path creation proved to be too slow

given the project deadline. Whole region runs were done for most species with individual patch results. Conefor parameters were largely similar to those of the pilot study, yielding the PC and IIC metrics and their components, as well as the number of components and links, among others. As with the pilot study, individual node importances were obtained, while link importances were omitted due being highly processing intensive.

Two notable differences from the pilot study Conefor runs are related to the maximum landscape attribute (A_L) and the use of probability thresholds for the subset landscapes. In the pilot study, maximum landscape attributes were calculated based on the subset landscape area alone, and did not include the area of overlap patches. This arguably led to an underestimate of the maximum landscape area for the pilot study, slightly affecting the comparability of the overall IIC and PC metrics among species (note, however, that A_L does not affect EC(PC) values or individual patch importances (e.g. dPC). For this expanded analysis, A_L included the area of overlap patches, which, due to the use of the 3000m buffer, were sometimes considerable.

Probability thresholds of 0.2 were also used for the woodpecker and hummingbird runs for all subset landscapes in order to increase processing efficiency. Links with dispersal probabilities below that threshold were removed from consideration when calculating patch importances for the PC metric – the most process intensive part of each Conefor model run. Both the woodpecker and hummingbird had many patches on the landscape with hundreds of thousands of links among those patches, so while the longest links were removed from patch importance consideration, the effect of using a probability threshold of 0.2 was small. A comparison of overall results for the hummingbird's central landscape between a run using a probability threshold of 0.2 for PC, and one without a threshold, showed no difference in PC values to 4 significant figures (with rounding the two results are 0.0086 and 0.0087).

6.1.7. Conefor Metric Selection

Connectivity was measured using the Probability of Connectivity (PC) index and its component metrics (Saura & Fuente, 2011; Saura & Pascual-Hortal, 2007a) as well as the number of components in a network. PC can be interpreted as the probability that "...two animals randomly placed within the landscape fall into areas that are reachable from each other" (Saura & Pascual-Hortal, 2007a p.93). **In other words, the PC metric describes the amount of reachable habitat within a landscape both among and within patches.** PC uses probabilities of dispersal between patches (p_{ij}) and the area-weighted quality of patches (a) to determine an overall connectivity measure for a network. The probability of successfully moving from one patch to another was set at 0.5 for each mammal's median dispersal distance, a standard assumption made for dispersal success.

The importance of any given patch in a network is dPC , calculated as the percent contribution of that patch to overall PC for a network. dPC itself is the sum of three other node importance metrics: dPC_{intra} , which measures within-patch connectivity; dPC_{flux} , which measures how connected a patch is to the rest of the network; and $dPC_{connector}$, which measures how important a patch is for connecting *other patches* together (i.e. stepping stone importance). These node importance metrics can also be

summed for each patch in the network (e.g. *sum dPCconnector*) and compared to understand the overall relative importance of, say, stepping stones in a network. It should be noted that, though the node importance metrics are calculated as percentages, their sum will often be greater than 100.

Task deliverables: Species patches with individual patch results attached, condition rasters, elevation and built-up no-habitat masks, and roads/watercourses barrier shapefiles. Overall and individual patch results for each species and subset landscape (where applicable). Output data layers from Conefor analysis. ArcGIS maps with results displayed to aid interpretation. Any ancillary data required for further technical analysis will also be included, in consultation with Metro Vancouver.

Appendix 3 Detailed Methodology – Phase 2

The first phase of the original study identified key-hub patches throughout Metro Vancouver for each of the eight focal species. The second step of this study was to use a spatial analysis software to analyse all of the species' habitat collectively and to prioritize their value towards regional connectivity. The prioritization software Zonation was used to complete this analysis. The inputs for this model included the habitat analysis completed in Phase 1, as well as a Protected Areas layer.

The Protected Areas layer was developed by DHC and contains all areas in Metro Vancouver that are already protected as parkland. This layer was derived from a 2013 Parks Protected Areas layer, supplemented by Metro Vancouver's Parks data. Areas identified as "Protected Areas" were those being protected through dedication as municipal, regional, or provincial park, wildlife management area, ecological conservancy area, or park reserve. Conservation covenants, as collated by the Nature Trust of BC in 2020, were included. Lands protected through other means (ex. Agricultural Land Reserve (ALR), Development Permit Areas, etc.) were not included. Additionally, all parks were considered protected, even if they may not protect natural areas within them (i.e. urban recreational parks were not differentiated from natural areas parks).

There were three tasks associated with this connectivity analysis (illustrated in Figure 1):

1. **Analyze Conefor results** to identify important patches for the 8 focal species.
2. **Process Zonation rasters to identify important areas** for the greatest number of species. Rerun with the Protected Areas layer to identify priority areas outside of already protected land.
3. **Identify major connectivity routes** by digitizing key pathways over the Zonation results.

4.4 Task 1 – Create a prioritized multispecies habitat network

Conefor results from Phase 1 were analyzed to characterize patches, species networks, and identify sites of high connectivity value for each of the eight focal species. This analysis included the identification of the most important patches (key patches) for each species and overlaying these patches to determine which areas provide the greatest value. Areas that are protected as parks were overlaid with these findings to determine which areas are most at risk.

Key patches are the most important area for each species as determined by dPC, which combines within-patch and between-patch connectivity to determine overall patch importance. *Hub patches* are the most important patches for each species for maintaining the connectivity of their respective networks. Hub patches were determined using dPCconnect, which is the measure of a patch's importance for connecting *other* patches together (i.e., stepping stone importance), and dNC, which is a measure of how important a patch is for maintaining component integrity. The value of dNC becomes more negative with the importance of the patch. Any patches with a $dNc < 0$ were, therefore, identified as hub patches whose removal would increase habitat fragmentation.

First, we identified key patches and hub patches for each species based on frequency distribution of dPC and dPCconnect, with a default threshold of 95th percentile (i.e., a cut-off value of 0.95 for dPC and dPCconnect). The default cut-off value was adjusted for species with fewer patches, including: long toed salamander (0.85 dPC, 0.9 dPCconnect) and red-backed vole (0.8 dPC, 0.9 dPCconnect).

Second, we used key-hub patches identified in the first step to do an overlay of important patches for the 8 focal species. We created binary raster for each species: 1 for cells with dPC/dPCconnect values > 0 and 0 for remaining cells across the study site. Afterward, we added 8 binary rasters together to gain a final raster output that shows important sites on the landscape in terms of connectivity for the most species.

Finally, we overlaid these patches with areas that are protected areas layer to determine which ones are currently not at risk. This layer was created from the ParksProtectedAreas2013 layer and Metro Vancouver's Parks data (Agricultural Land was excluded from protected areas). Summary statistics were produced including the percent of each patch that is protected.

4.5 Task 2 – Identify important areas for the greatest number of species using Zonation

Zonation raster analyses were completed to identify important areas in terms of connectivity for the greatest number of species. The outputs from Conefor were rasterized for input into Zonation. A protected area raster was created and given a weight of -1 indicating areas that are already protected. A 5-meter spatial resolution was used for all rasters during this analysis.

Zonation takes raster inputs and ranks each cell based on a given cell removal rule, weights for species that use different habitats, and other indicators such as removal masks (i.e., weighted protected areas, land values). In this project, we used Core-Area Zonation (CAZ) removal rule, with equal weights for all species because we considered all 8 species are equally important for conservation purposes, and represent 8 unique life history parameters. Protected areas were weighted deliberately so that the outputs would highlight the important habitat areas that are not currently protected.

Zonation identified areas that have a high proportion of connectivity distribution (dPC or dPCconnect values) of each species across the landscape. The software removed cells that had smallest connectivity distribution for each species first. The last site to remain in the landscape were the cells with the highest connectivity distribution for the greatest number of species. Zonation assigned ranking values, ranging from 0 – 1, to cells across the landscape based on the order that the cells were removed. The cells removed first received lower values and are considered less important. The cells removed last received higher values and are considered more important in terms of connectivity.

Zonation raster processing included multiple iterations in consultation with Metro Vancouver's staff. There are two sets of final maps produced. These were created from the following combinations of inputs:

- 1 Combination of dPC and dPCconnect. This identifies the important areas in terms of connectivity values regionwide.
- 2 Combination of dPCconnect and protected areas. This identifies the important areas located outside protected areas that contribute the greatest to regional connectivity.
- 3 Incorporate land cost to identify “low-hanging fruit” for parkland acquisition

We incorporated the cost of land (hereafter cost) into the zonation analysis to identify areas that are most efficient to both conserve and acquire. A cost layer was created using the regional land use and cost point data provided by Metro Vancouver. Both total and average land costs were calculated and assigned to land use polygons, and then rasterized to use as inputs into zonation analysis. However, the initial results of including cost indicated no important difference compared to outputs of zonation analyses without cost (i.e., as described in Task 2). In some cases, the analysis with cost can be misleading as some fragmented areas came through with very high importance. This likely because it is difficult to account for the variation of cost across an area as big as Metro Vancouver using just land use and cost point data. Therefore, we omitted the cost layer from the final stage of analysis.

4.6 Task 3 – Review results and identify key areas for connectivity and ‘stepping-stone’ habitat patches

Using the results of the zonation analysis, an attempt was made to identify important regional connectivity corridors throughout Metro Vancouver. In some cases, clear, high value routes were evident. In many cases, particularly in the agricultural areas, they were not clear enough to definitively identify a preferred route. Providing a region wide connectivity network will require interpretation by a professional biologist, and therefore the incorporation of values. It was decided that this report should provide the outputs of the model and that the interpretation will be completed in a subsequent phase.

Appendix 4 Member Jurisdiction Maps – Importance of Connectivity at the Local Scale

In order to identify important patches for connectivity in each Metro Vancouver member jurisdictions local-scale maps were produced. These maps build off Figure 7, using a combination of dPCconnect and protected areas. Protected areas were defined as being protected through dedication as municipal, regional, or provincial park, wildlife management area, ecological conservancy area, or park reserve. Conservation covenants, as collated by the Nature Trust of BC in 2020, were included. Lands protected through other means (ex. Agricultural Land Reserve (ALR), Development Permit Areas, etc.) were not included in this layer.

These maps can help organizations identify patches most important for connectivity that are currently outside protected areas and therefore at risk. These patches would be good candidates for protection using available tools (ex. by land acquisition and park dedication, Development Permit Areas, etc.).

The regional raster layer was clipped to each member jurisdiction boundary (2023), and the original importance ranking generated by the Zonation analysis was retained. The clipped member jurisdiction raster was then displayed using the same color scheme as the regional Zonation maps. The final member jurisdiction maps provide additional insight and more focused results on important locations at a local scale (i.e., by keeping the same ranking and adjusting the colour to only the local scale, some areas that have higher levels of connectivity importance at a local scale can be identified that may not be visible when viewed at the regional scale).

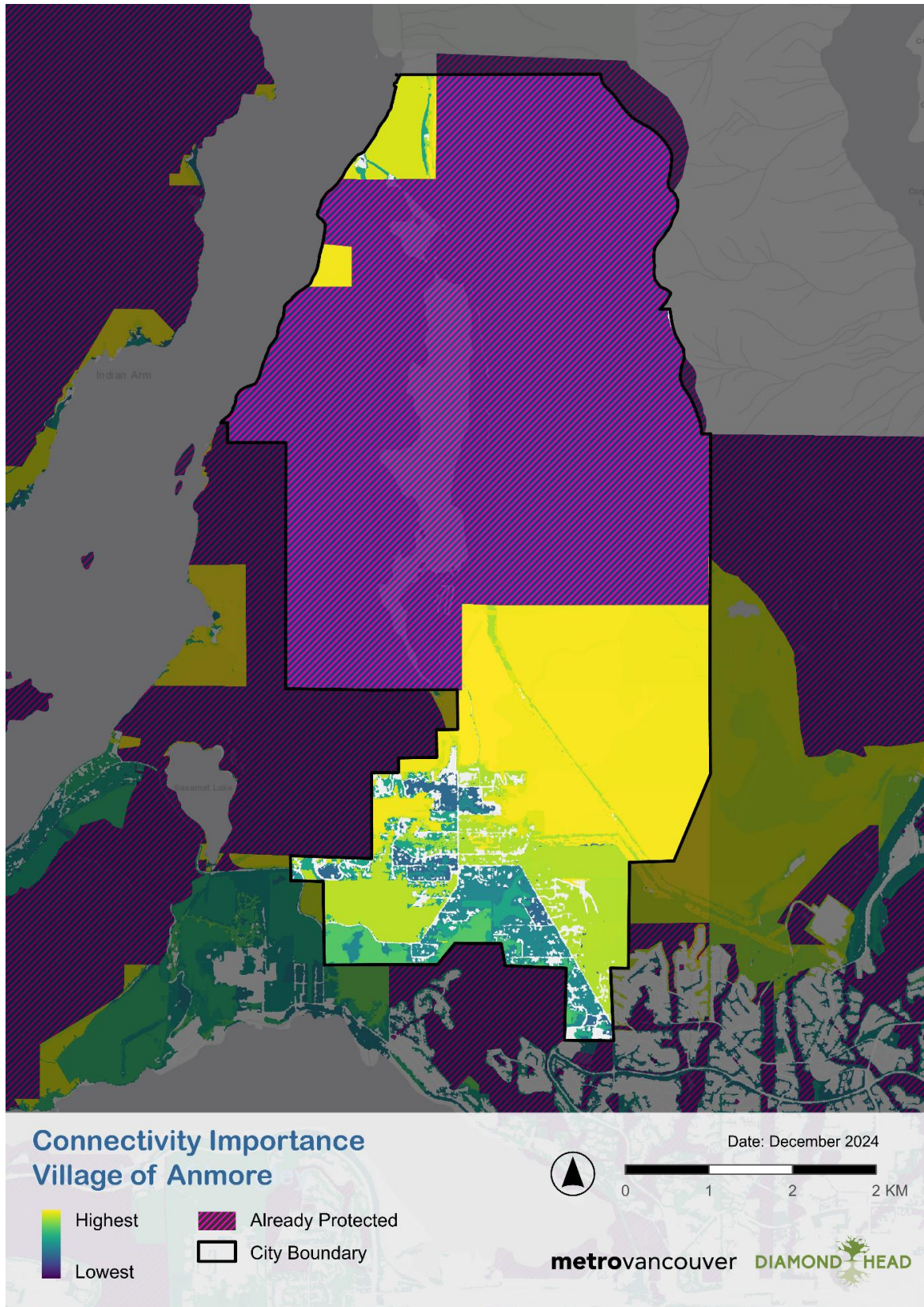


Figure 10 Connectivity Importance Village of Anmore.

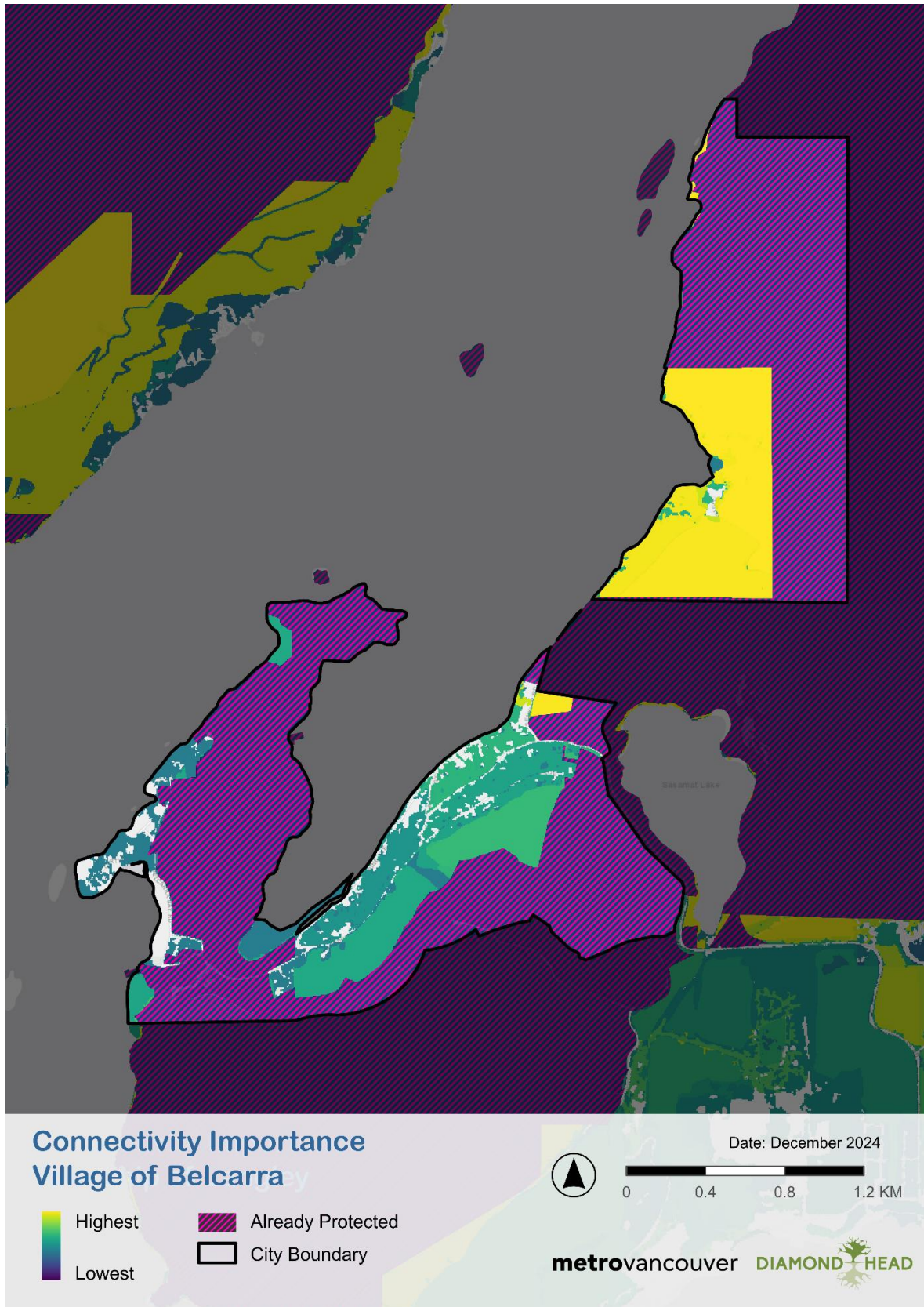


Figure 11 Connectivity Importance Village of Belcarra.

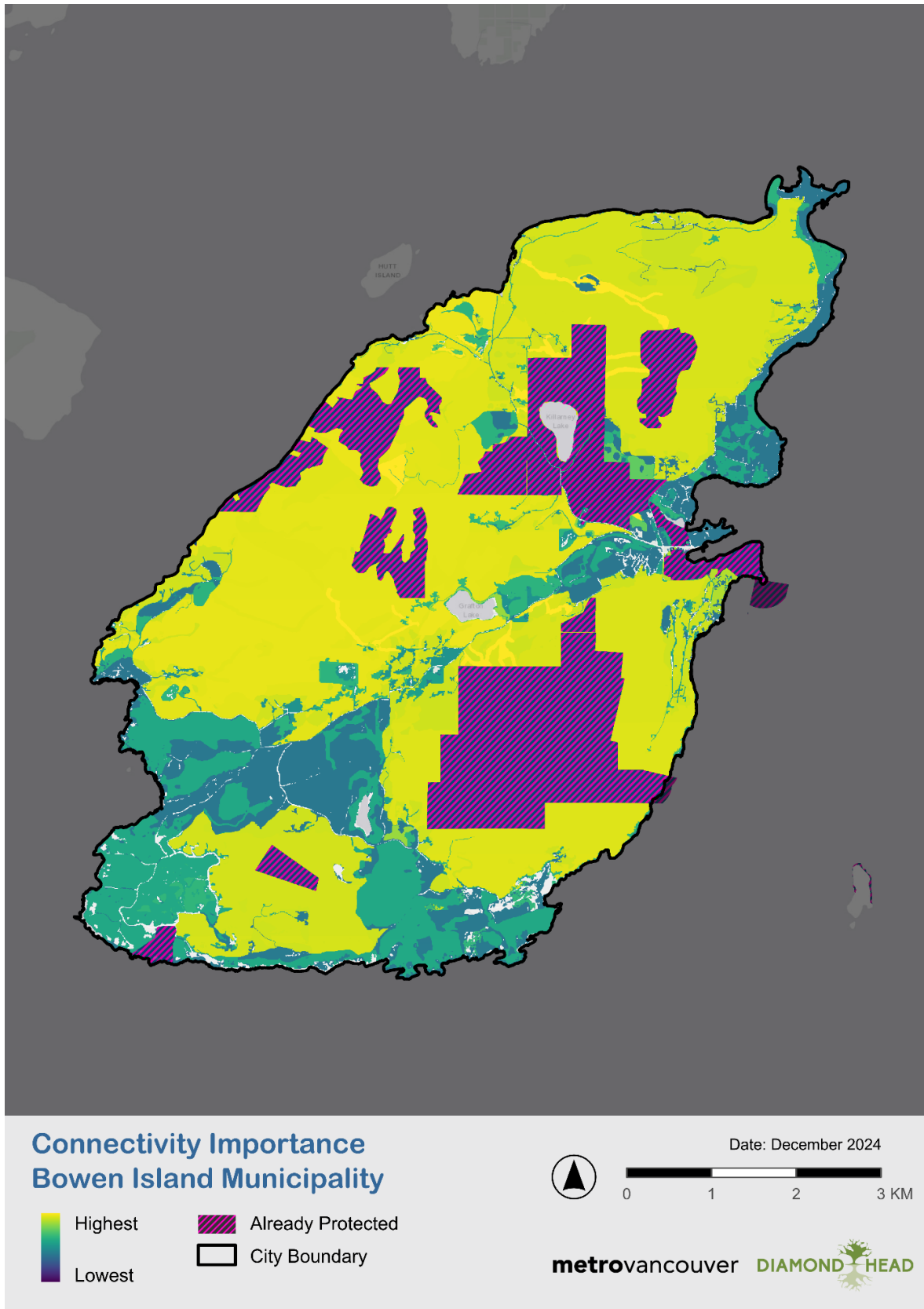


Figure 12 Connectivity Importance Bowen Island Municipality.

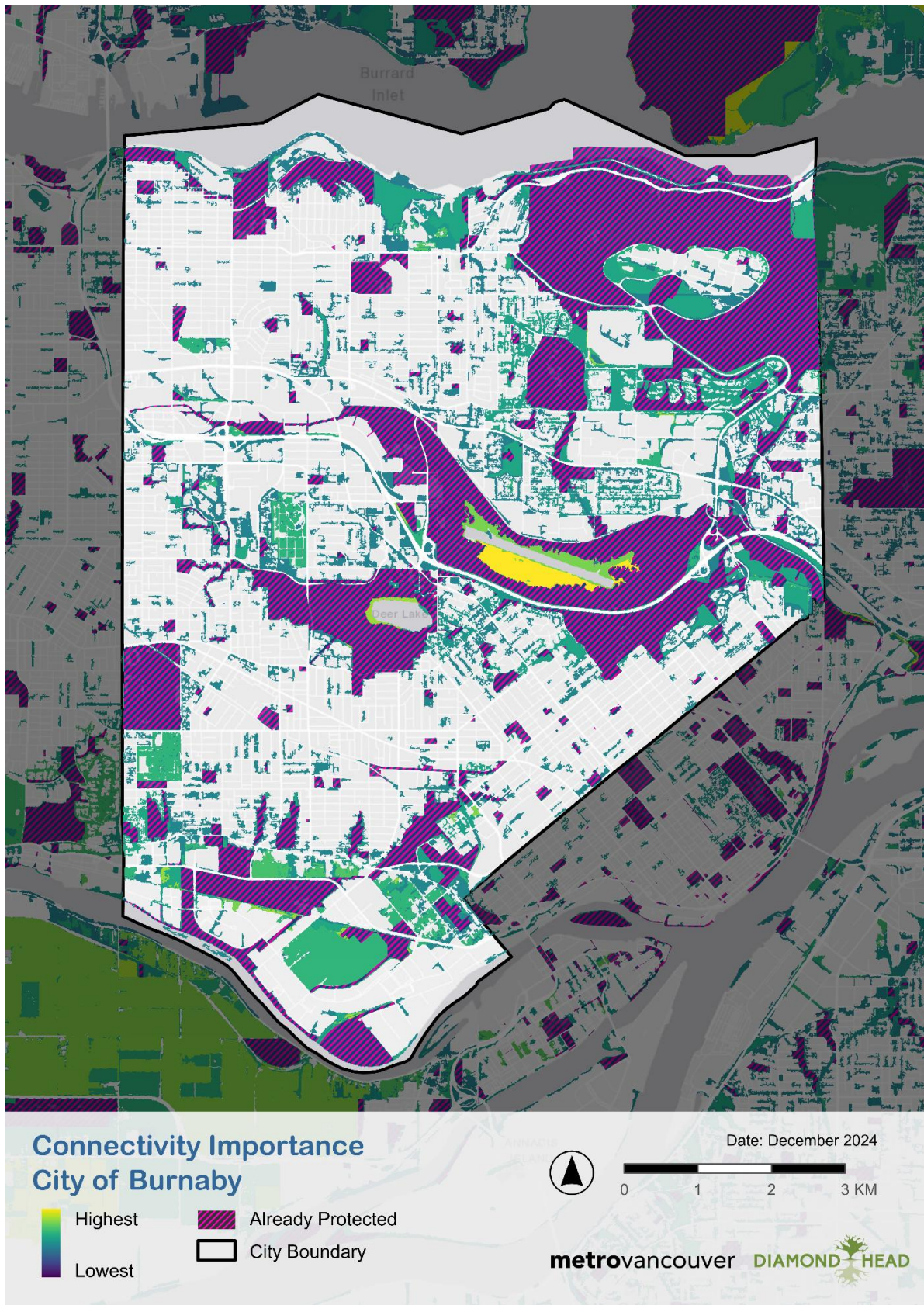


Figure 13 Connectivity Importance City of Burnaby.

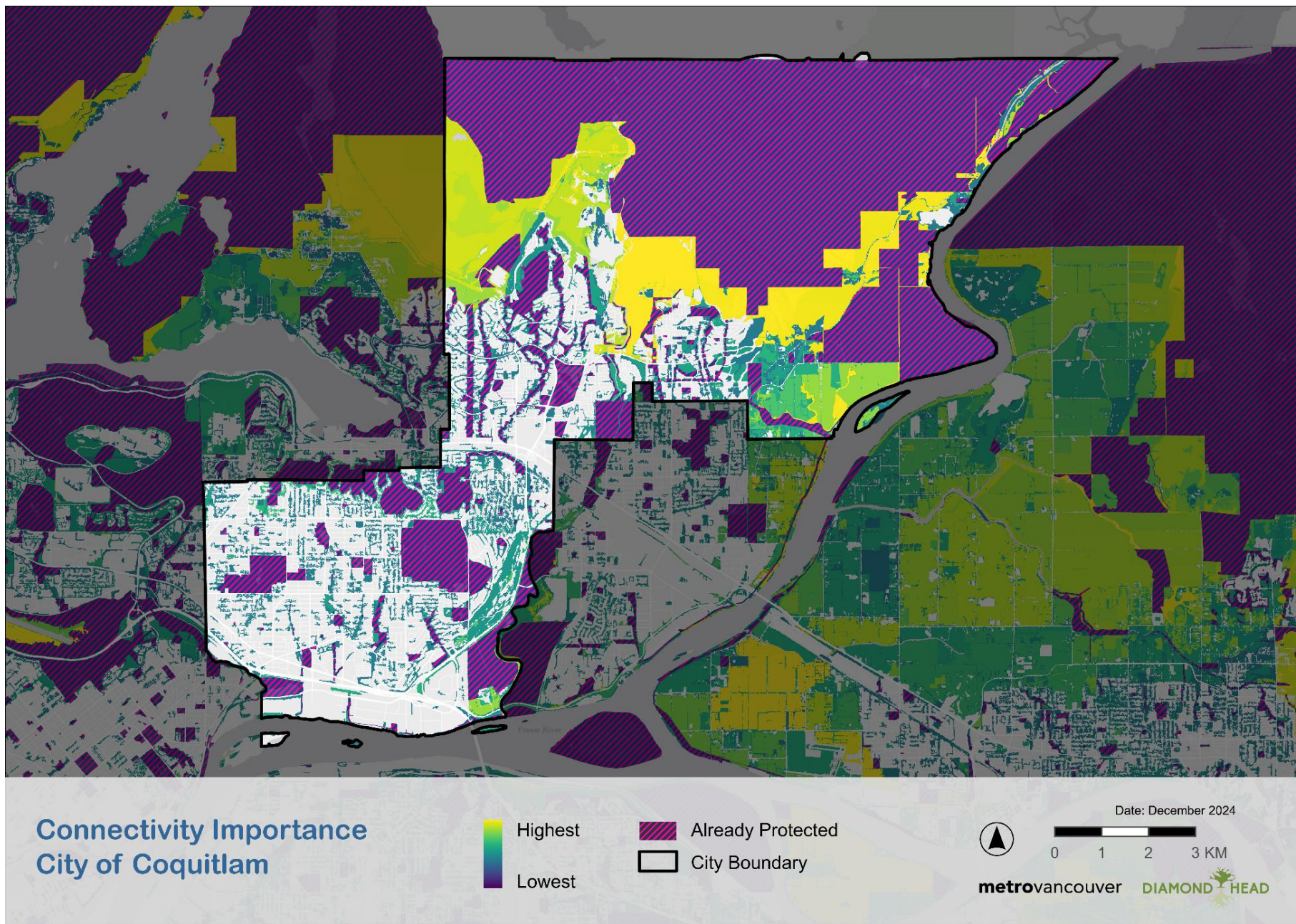
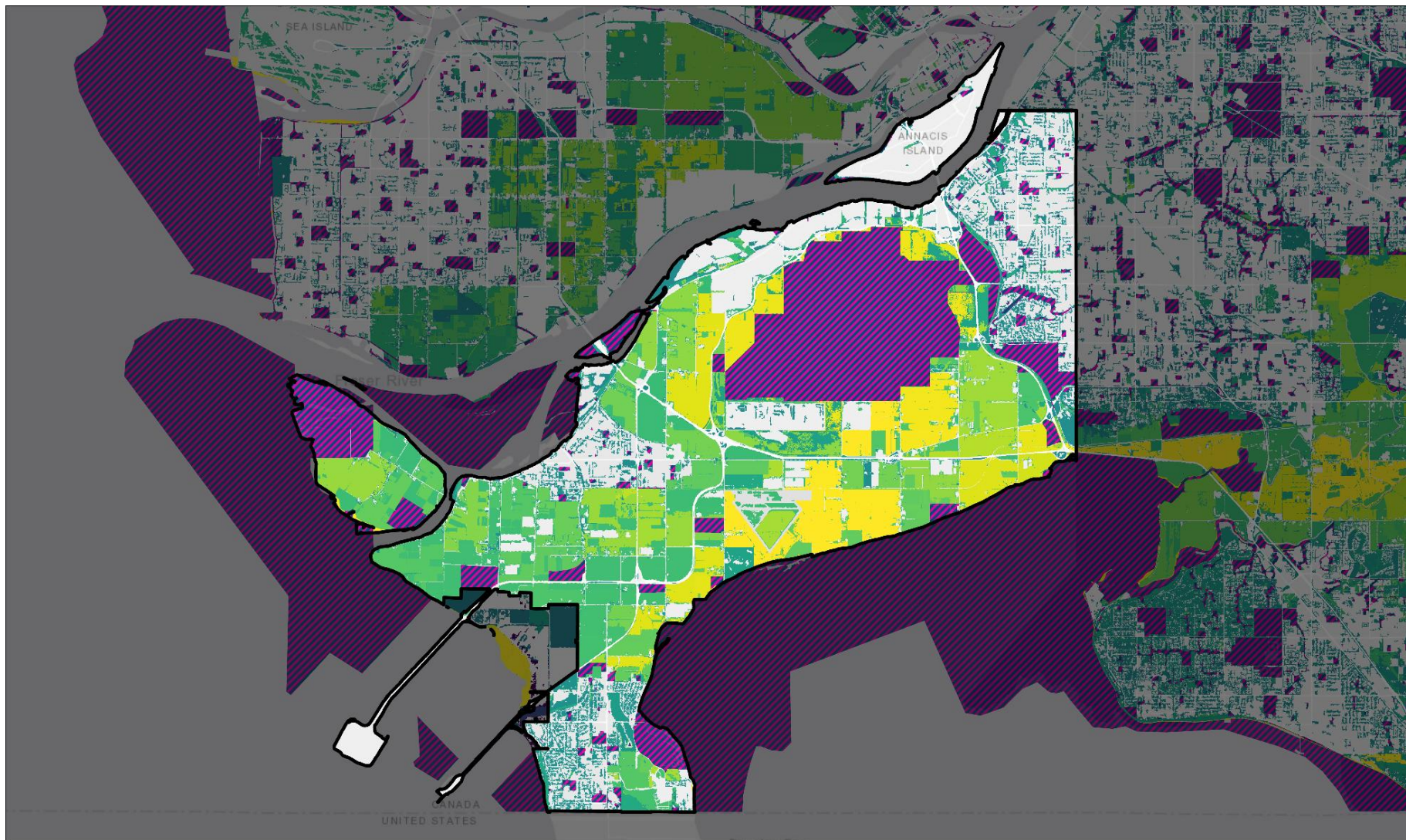





Figure 14 Connectivity Importance City of Coquitlam.



**Connectivity Importance
City of Delta**

 Highest
Lowest

 Already Protected
 City Boundary

Date: December 2024



metrovancouver 

Figure 15 Connectivity Importance City of Delta.

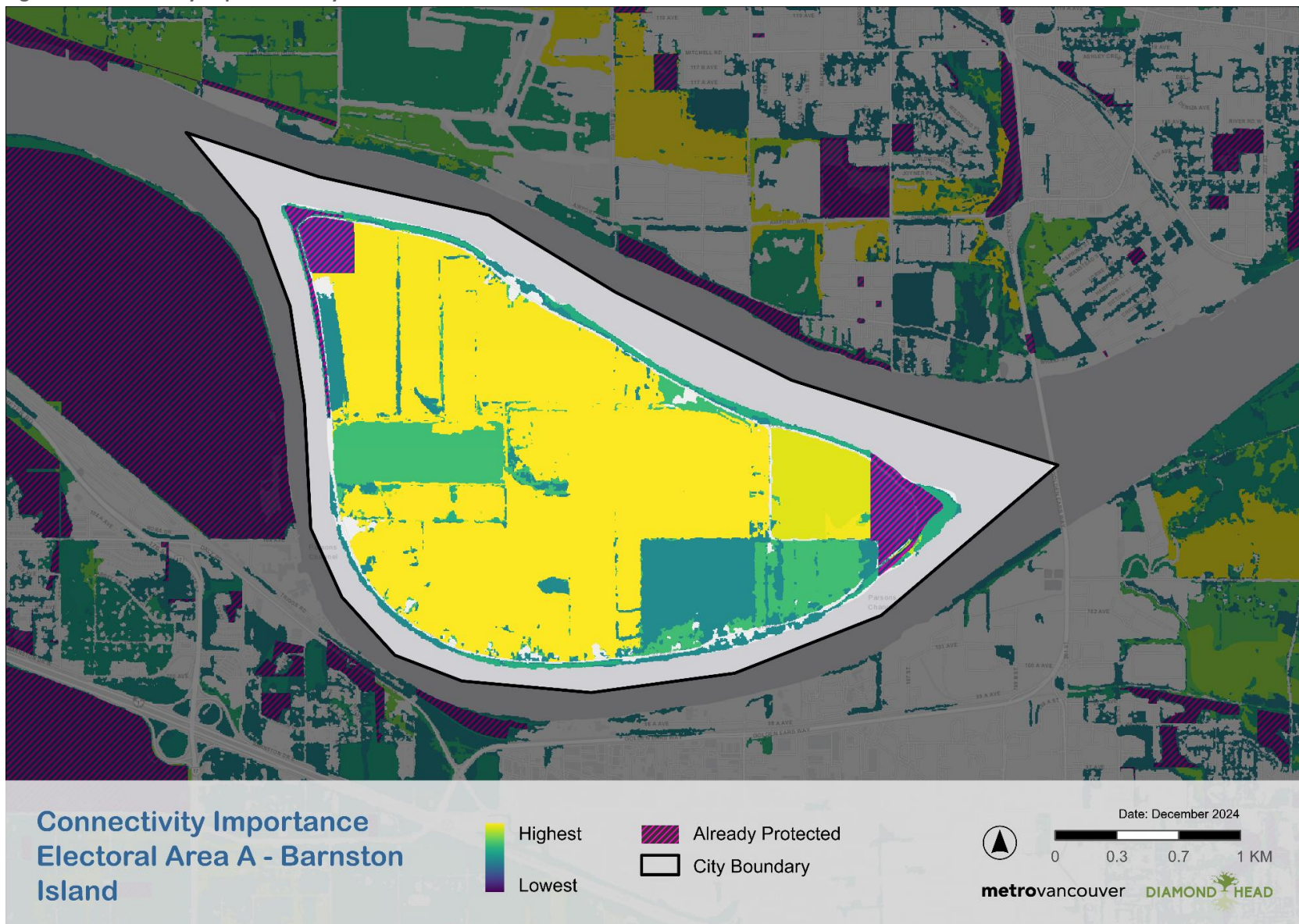


Figure 16 Connectivity Importance Electoral Area A – Barnston Island.

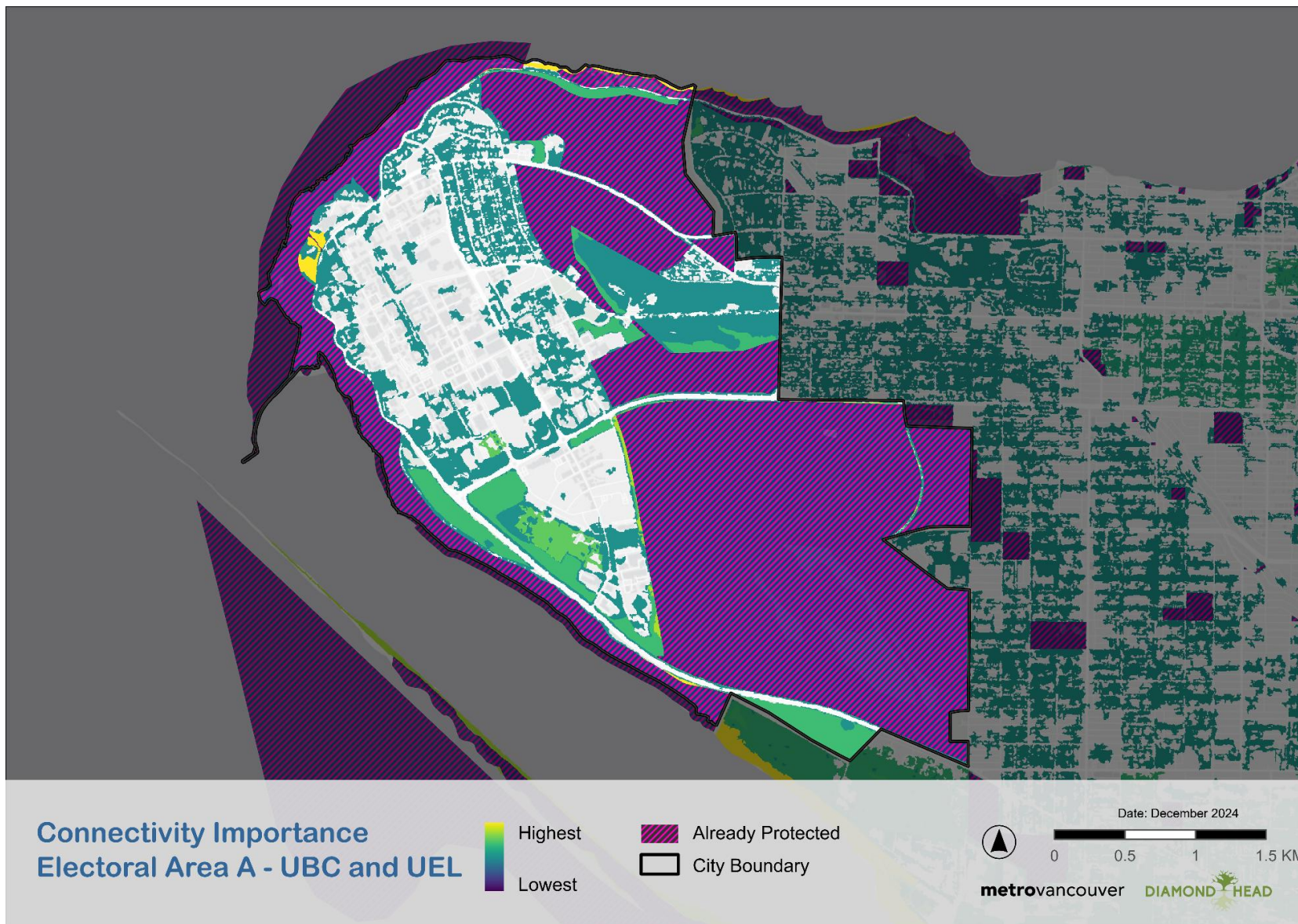


Figure 17 Connectivity Importance Electoral Area A – UBC and UEL.

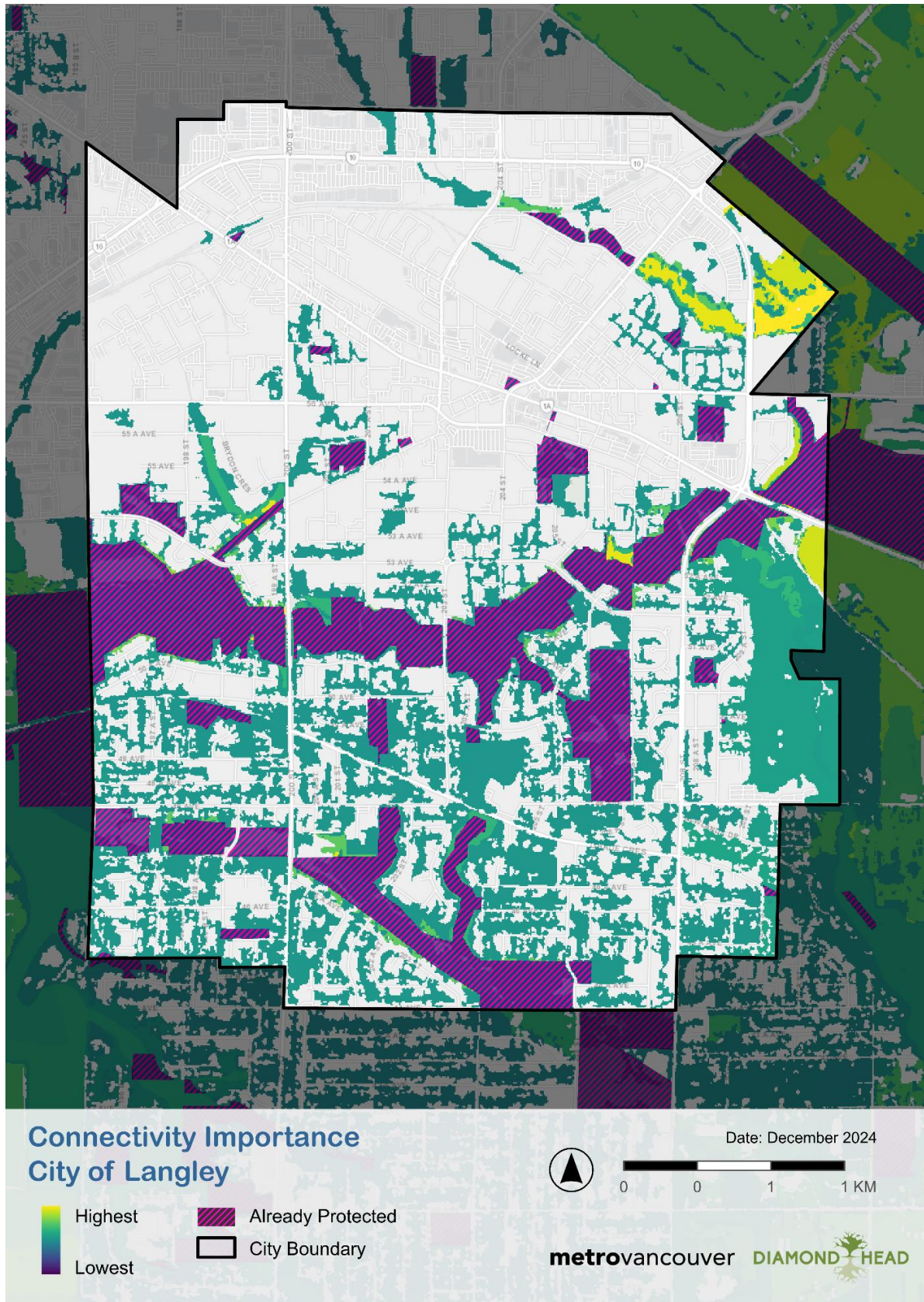
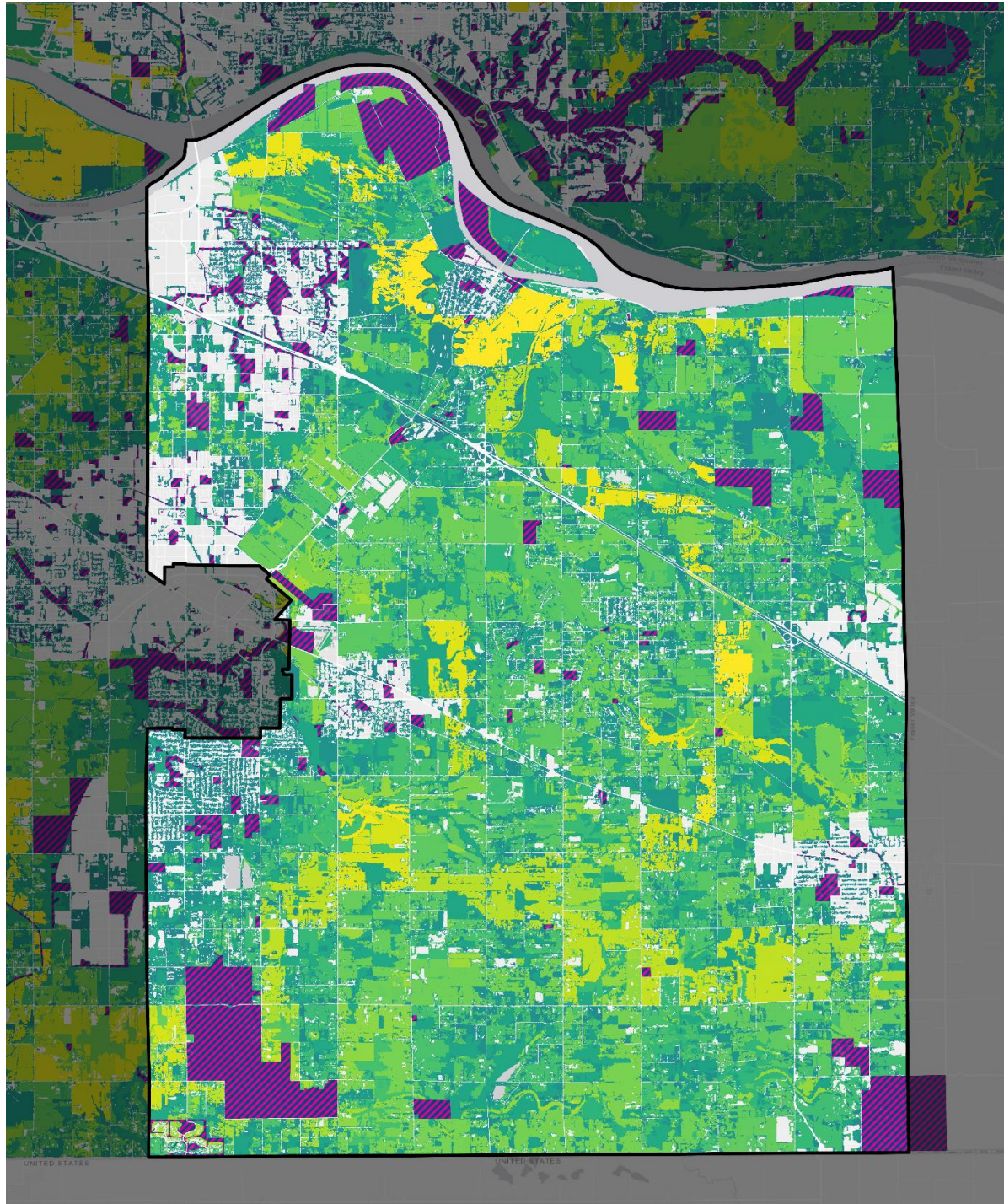


Figure 18 Connectivity Importance City of Langley.



Connectivity Importance Township of Langley

- Highest
- Lowest
- Already Protected
- City Boundary



Date: December 2024

0 1.5 3 4.5 KM



Figure 19 Connectivity Importance Township of Langley.

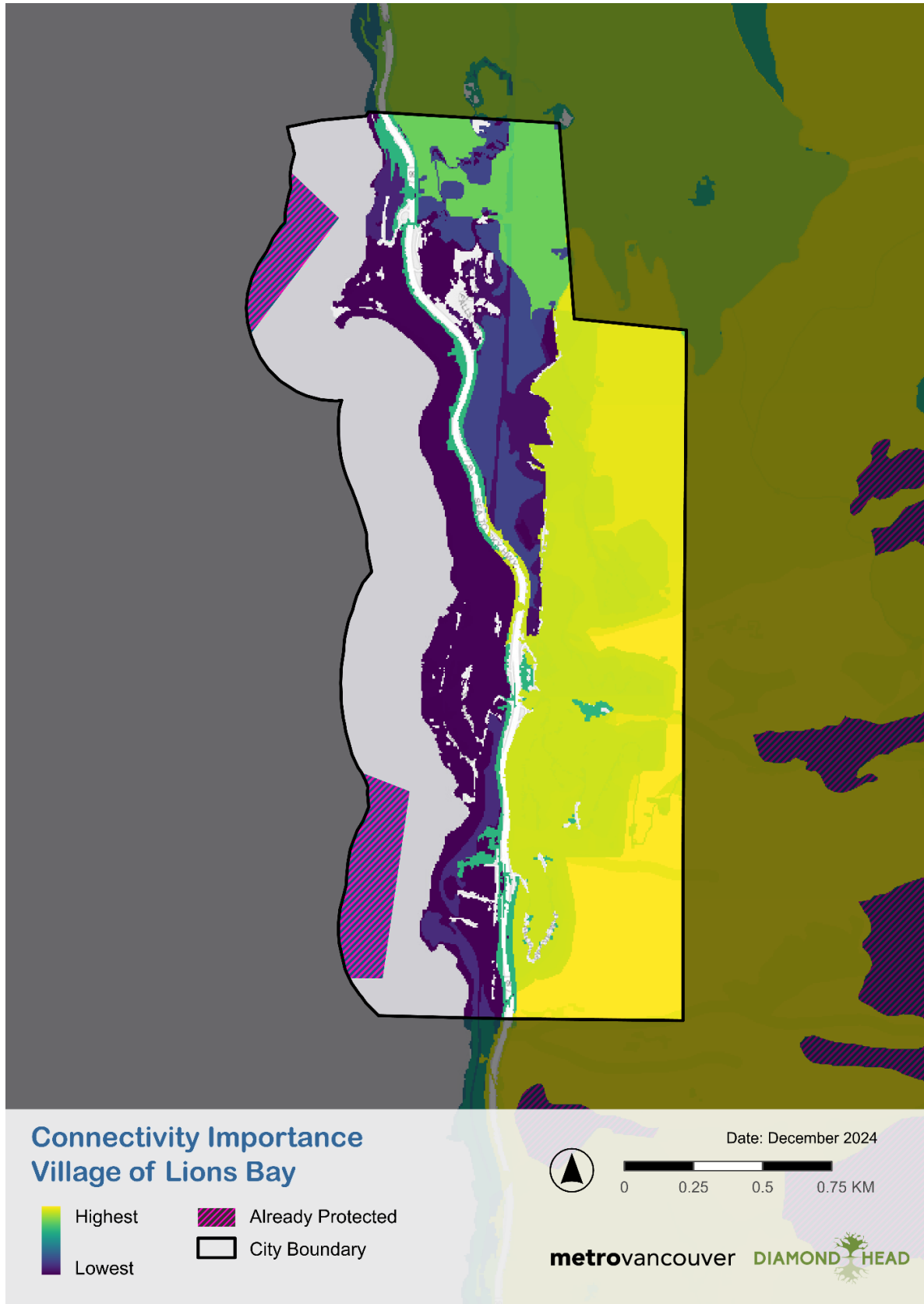


Figure 20 Connectivity Importance Village of Lions Bay.

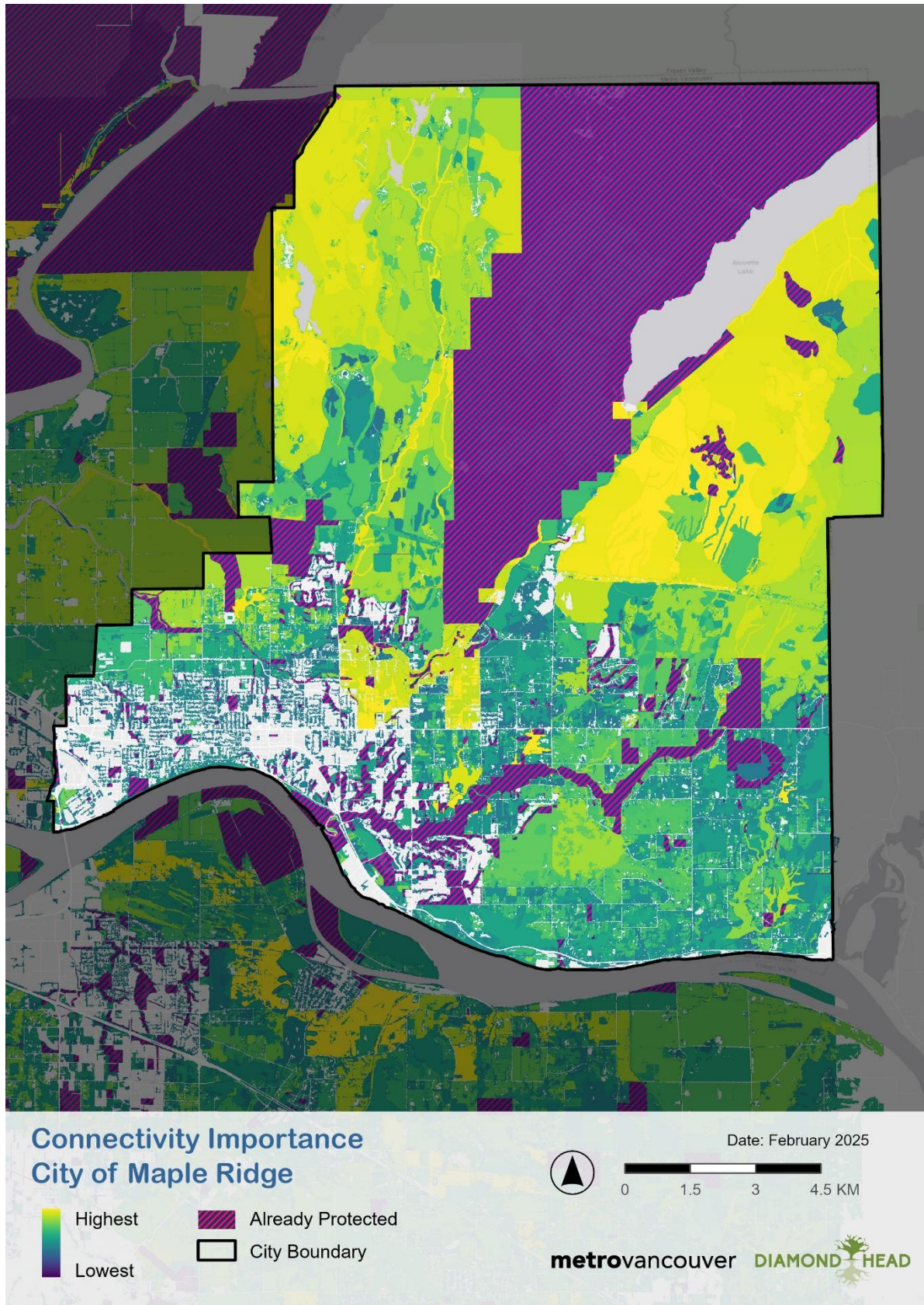


Figure 21 Connectivity Importance City of Maple Ridge.



Figure 22 Connectivity Importance City of New Westminister.

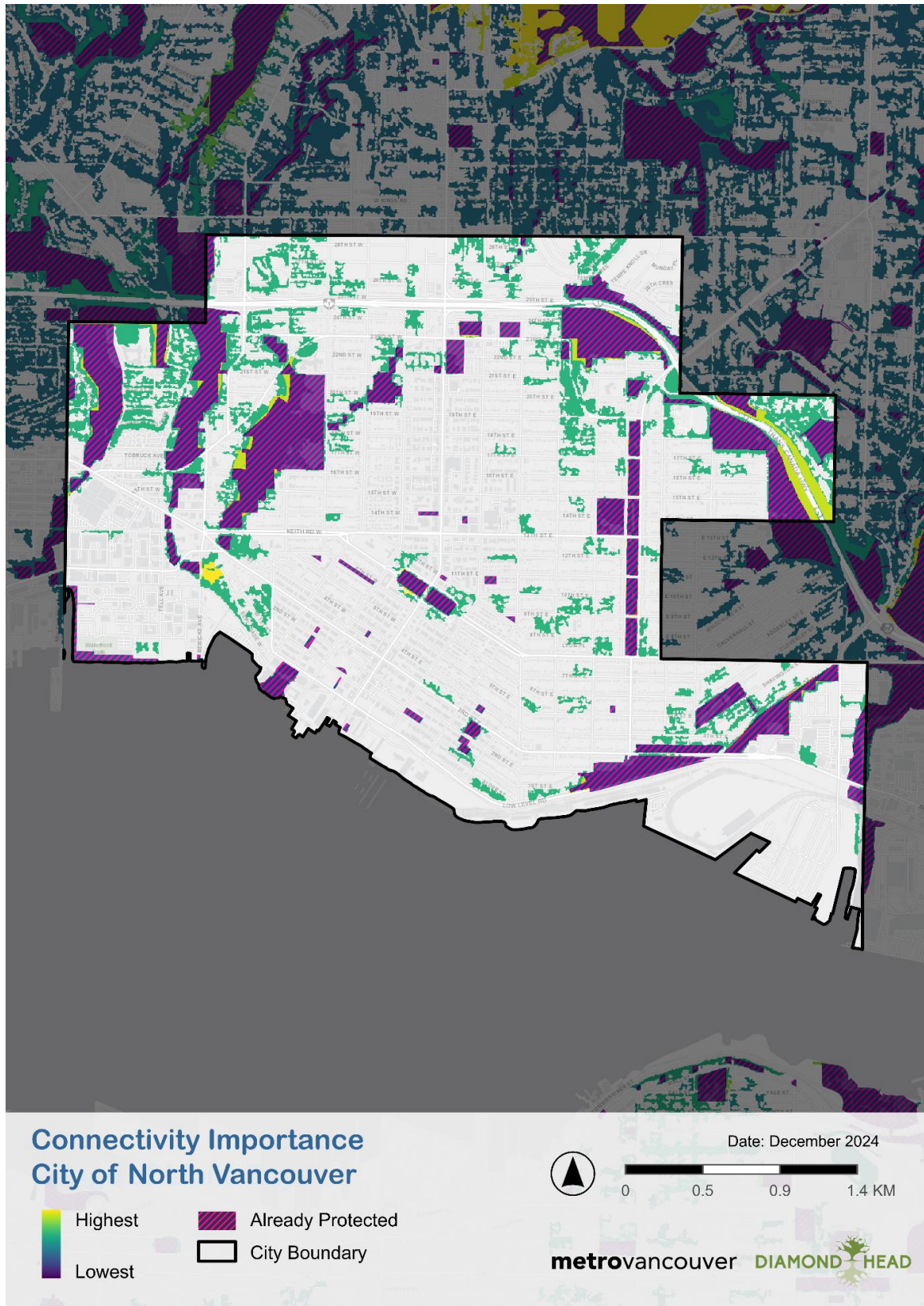


Figure 23 Connectivity Importance City of North Vancouver.

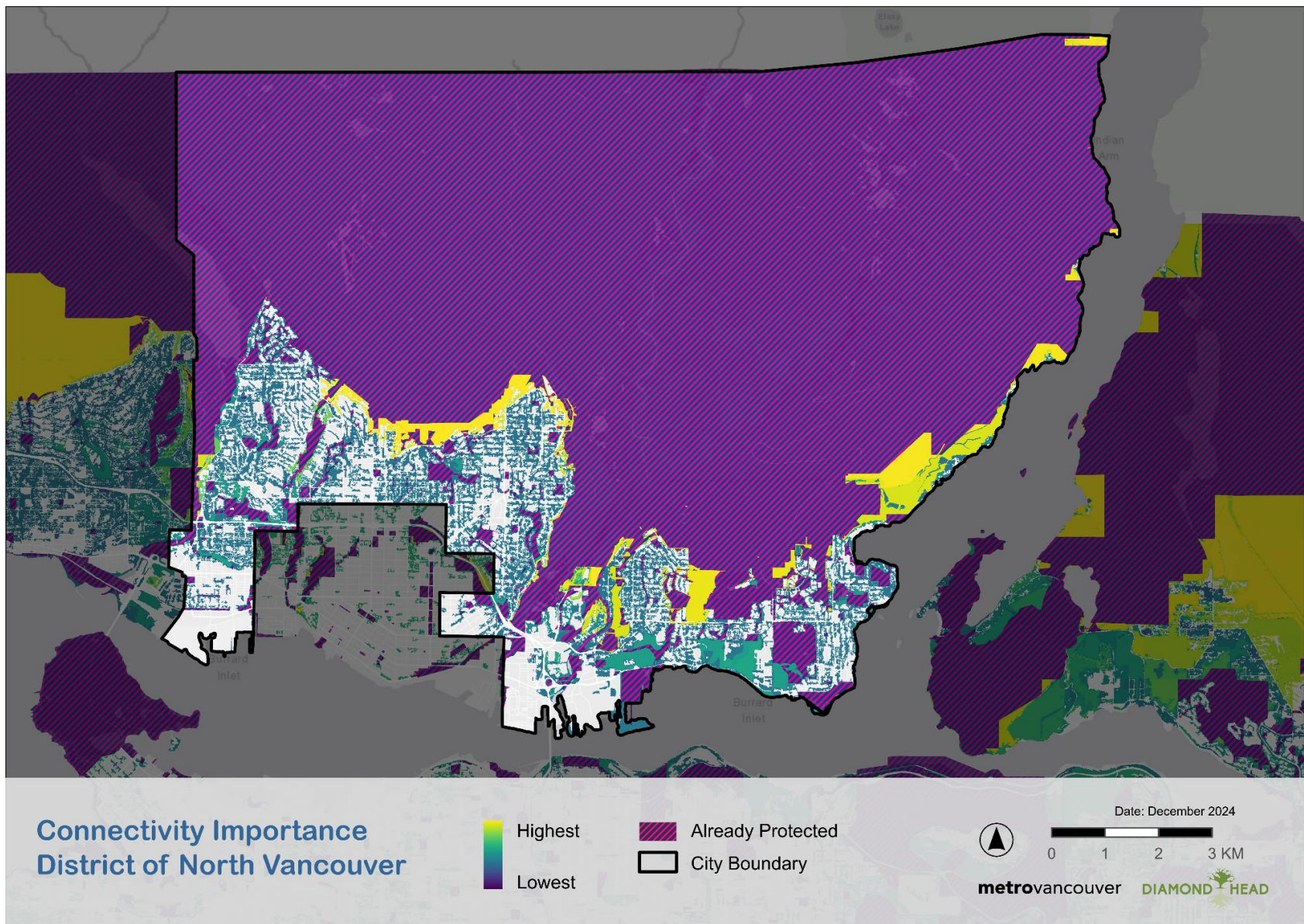


Figure 24 Connectivity Importance District of North Vancouver.

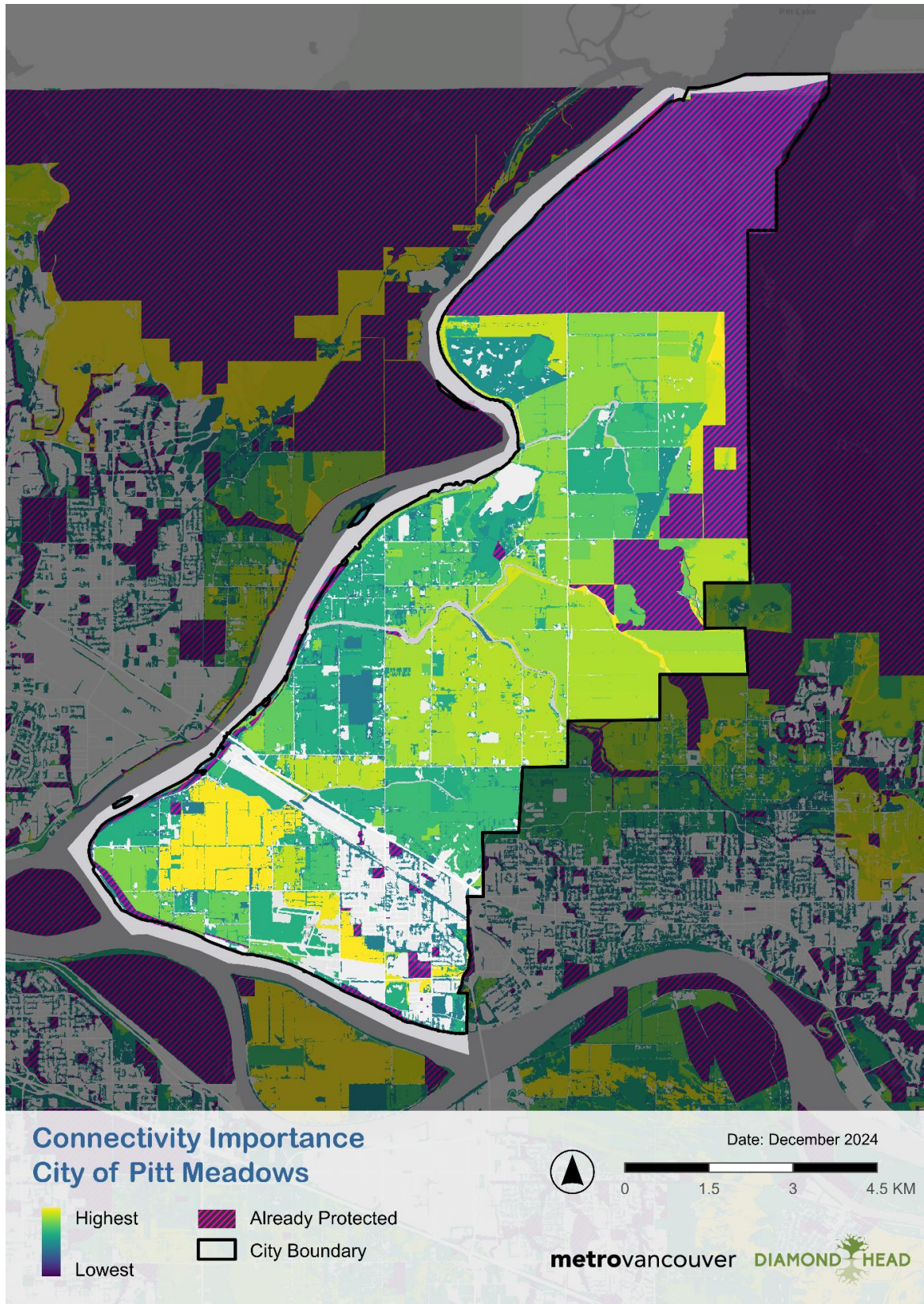


Figure 25 Connectivity Importance City of Pitt Meadows.

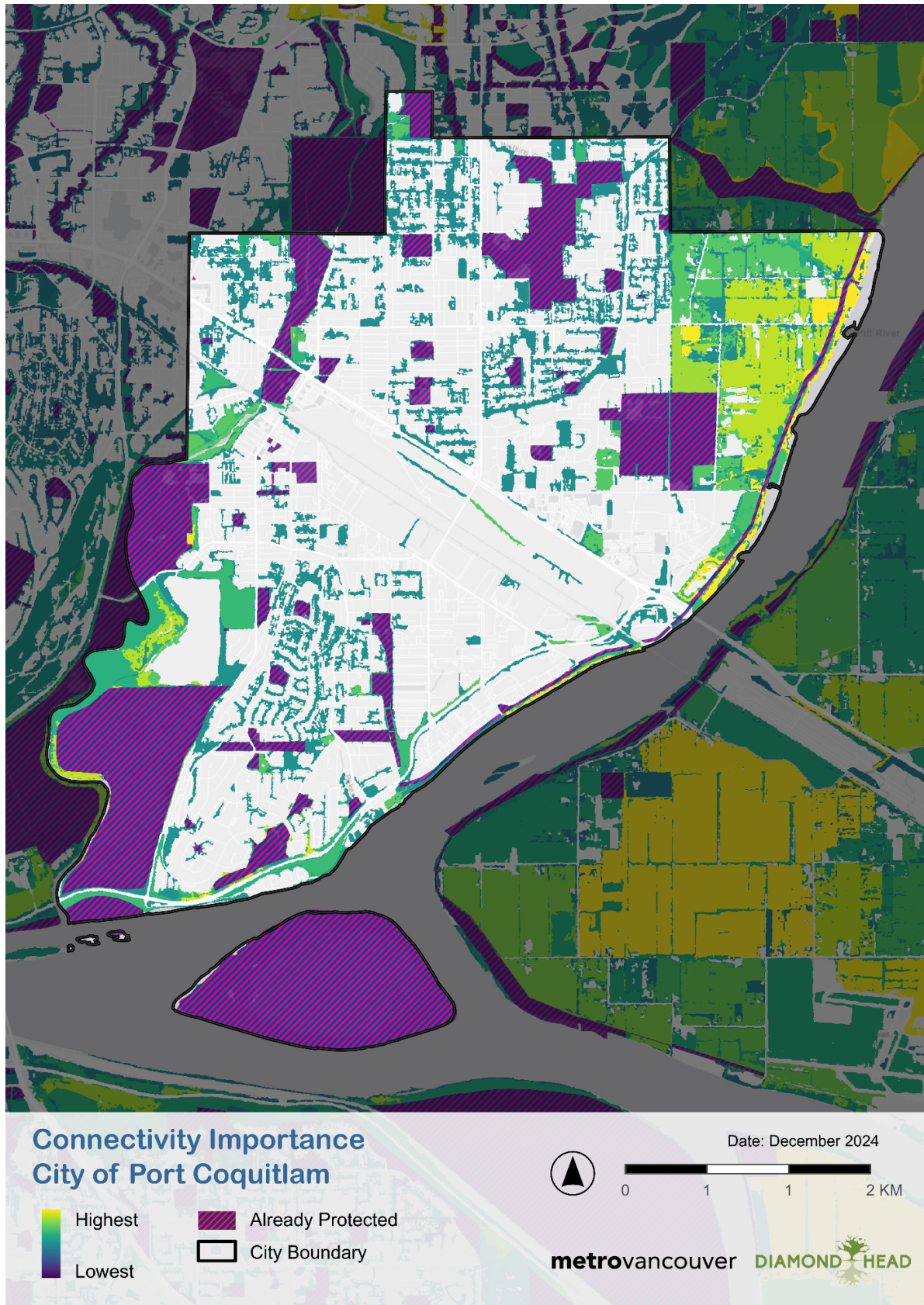


Figure 26 Connectivity Importance City of Port Coquitlam.

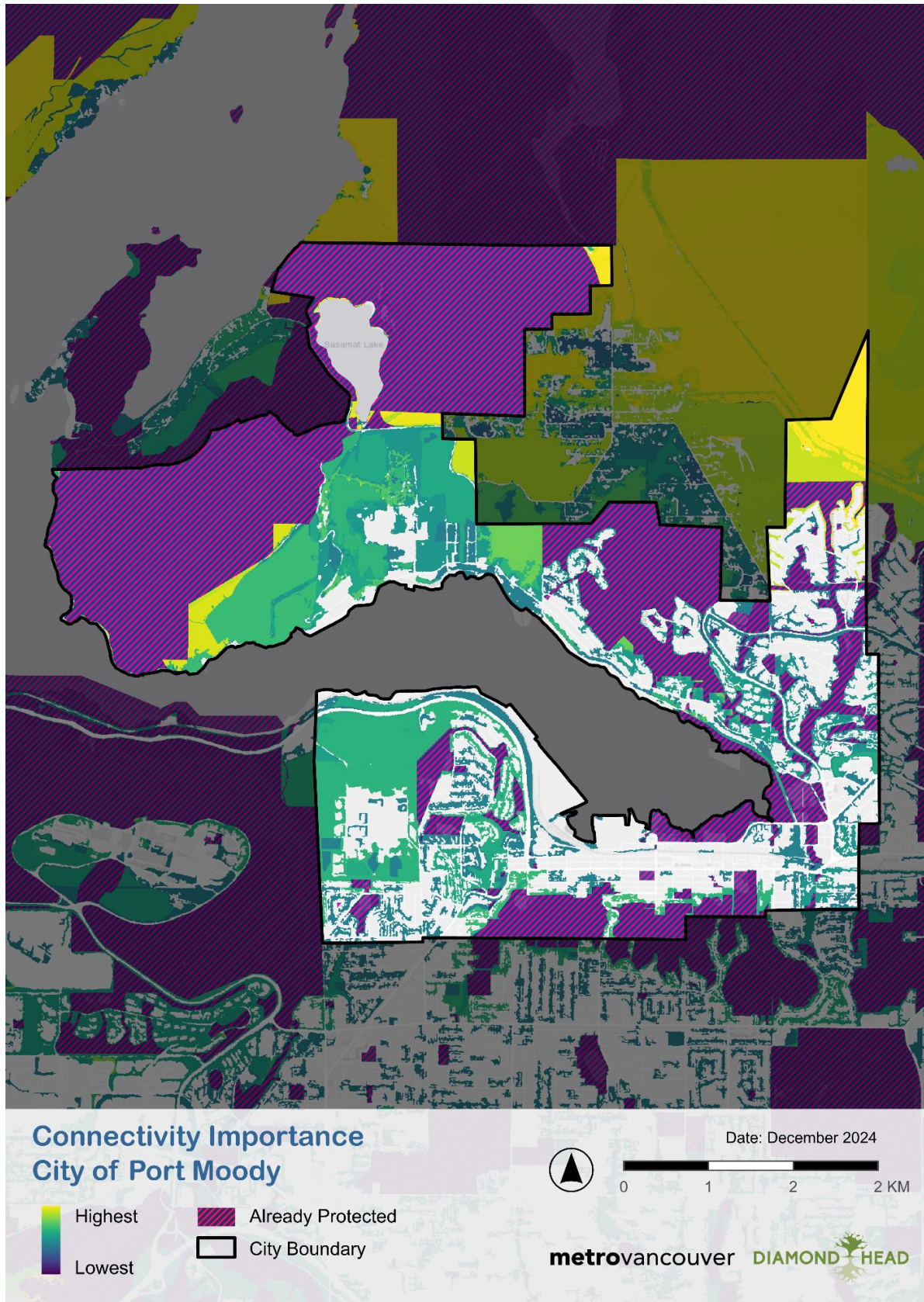


Figure 27 Connectivity Importance City of Port Moody.

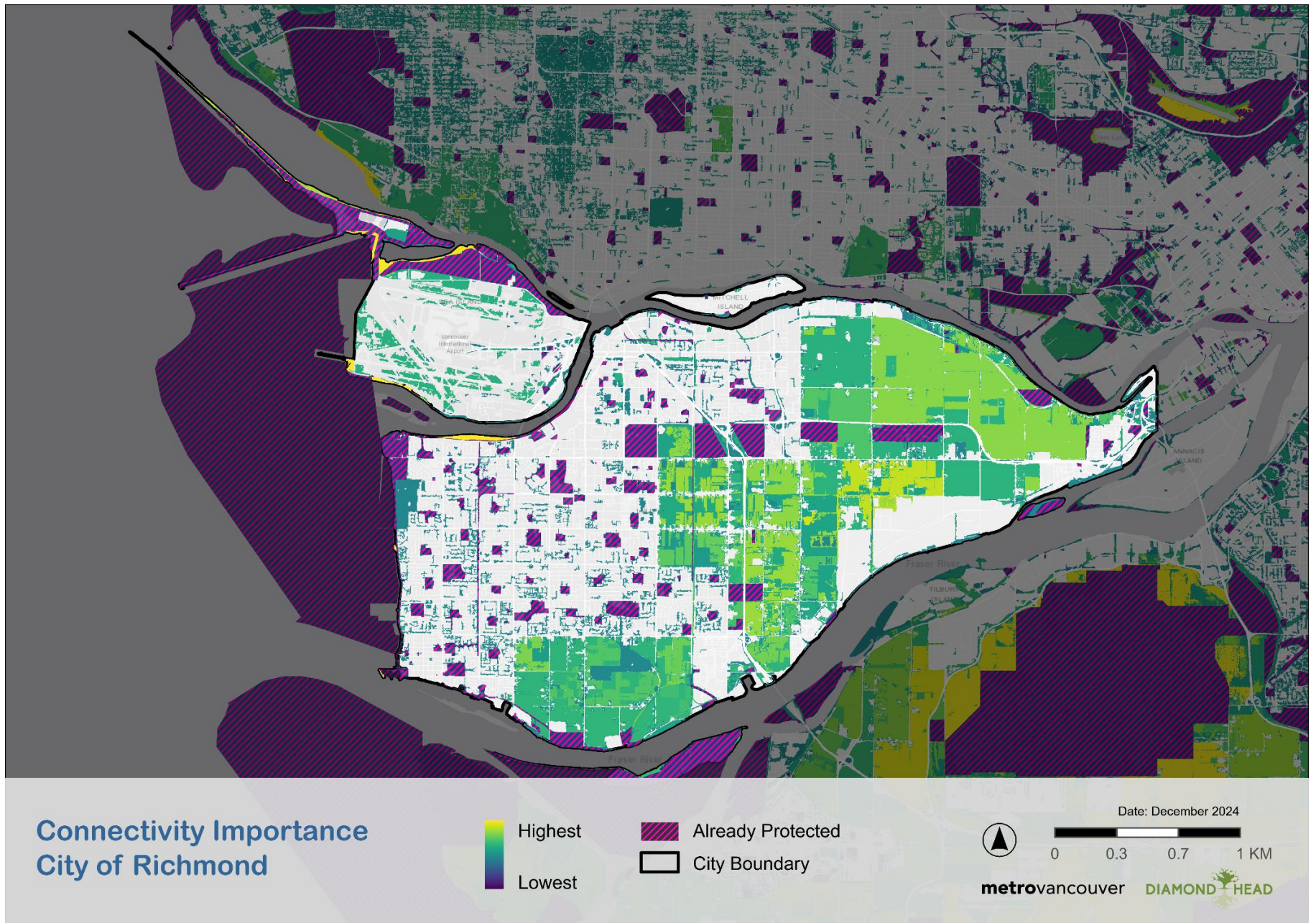


Figure 28 Connectivity Importance City of Richmond.

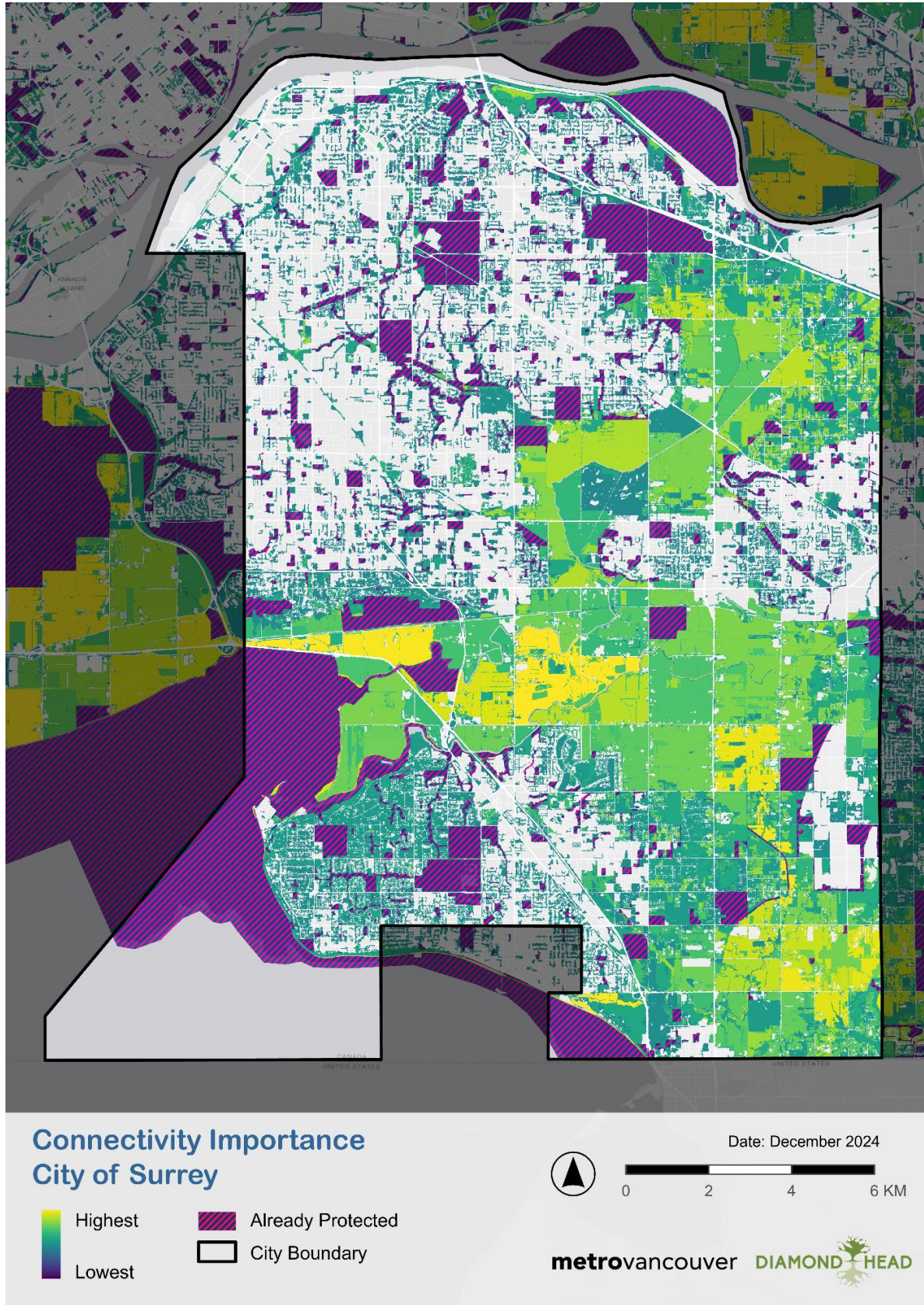


Figure 29 Connectivity Importance City of Surrey.

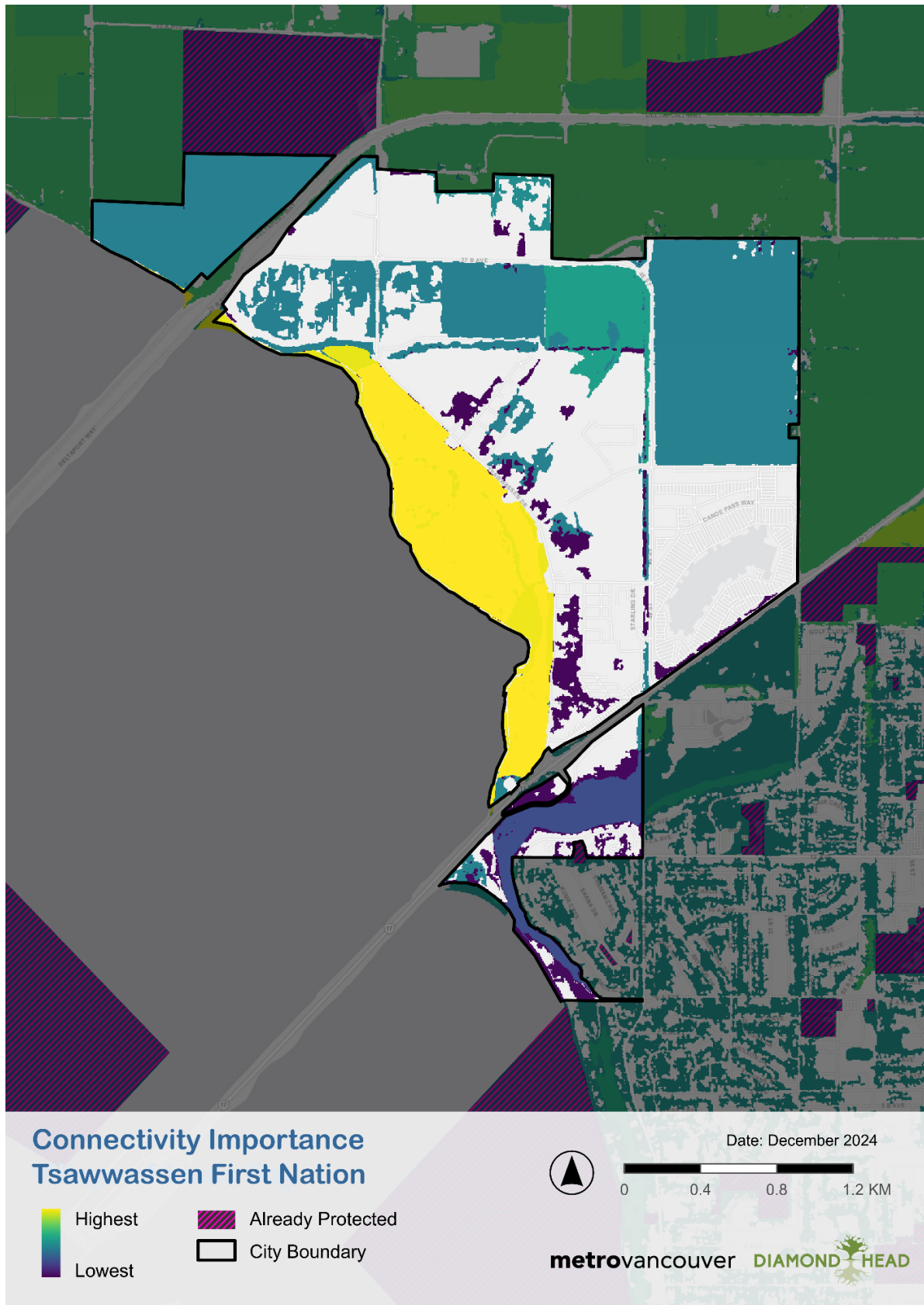


Figure 30 Connectivity Importance Tsawwassen First Nation.

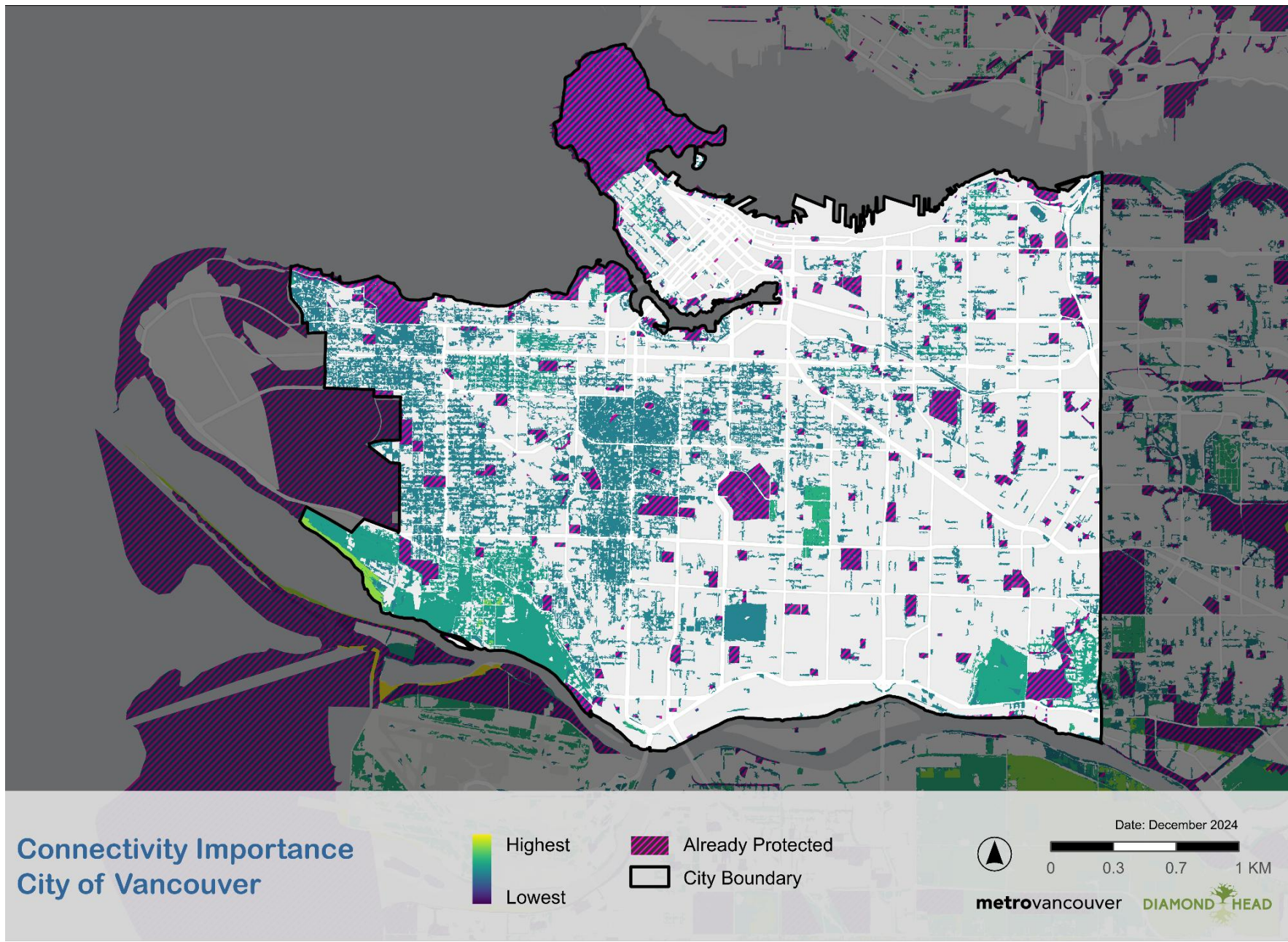
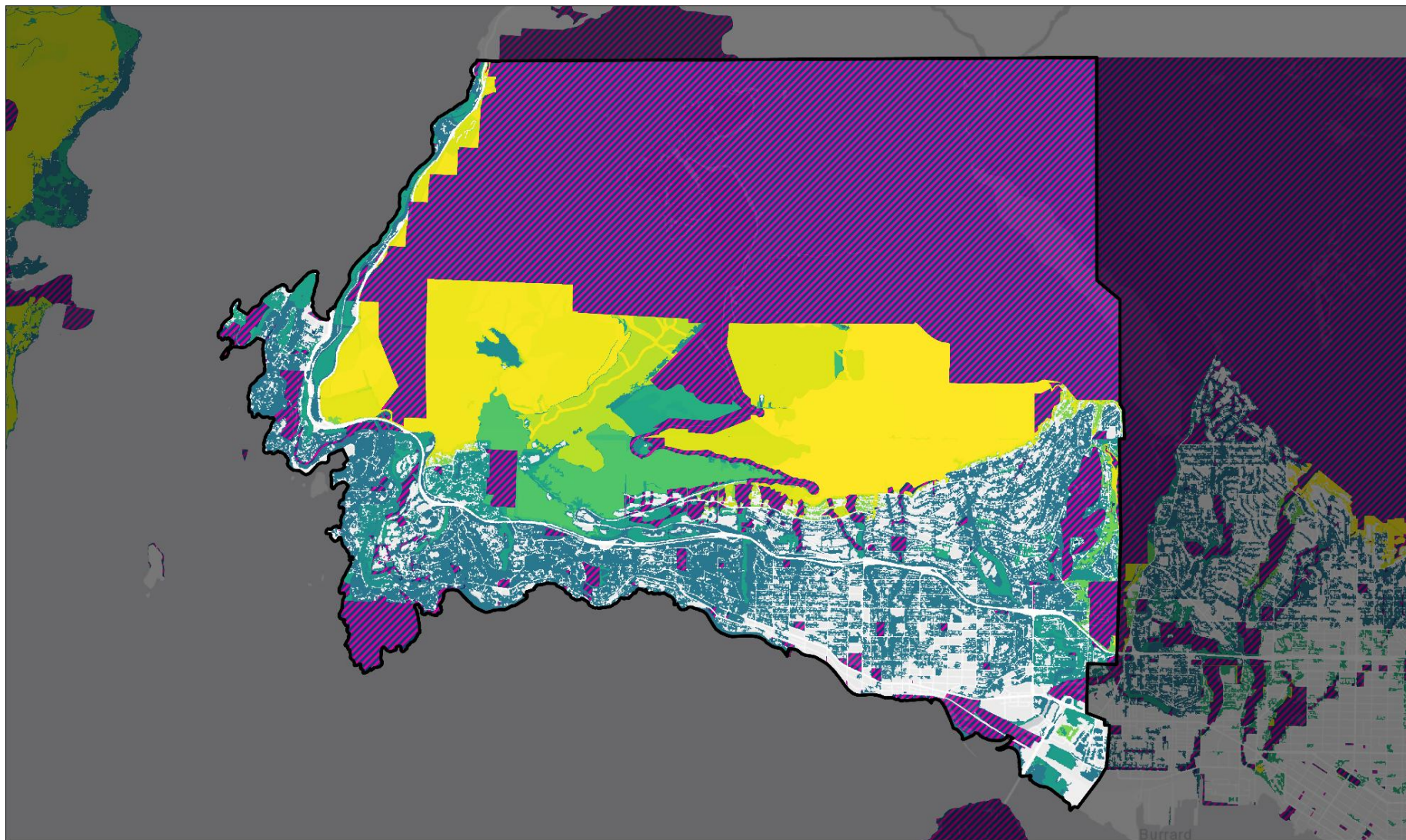





Figure 31 Connectivity Importance City of Vancouver.



Connectivity Importance District of West Vancouver

 Highest
Lowest

 Already Protected
 City Boundary

Date: December 2024



0 1 2 3 KM

metrovancouver **DIAMOND HEAD**

Figure 32 Connectivity Importance District of West Vancouver.

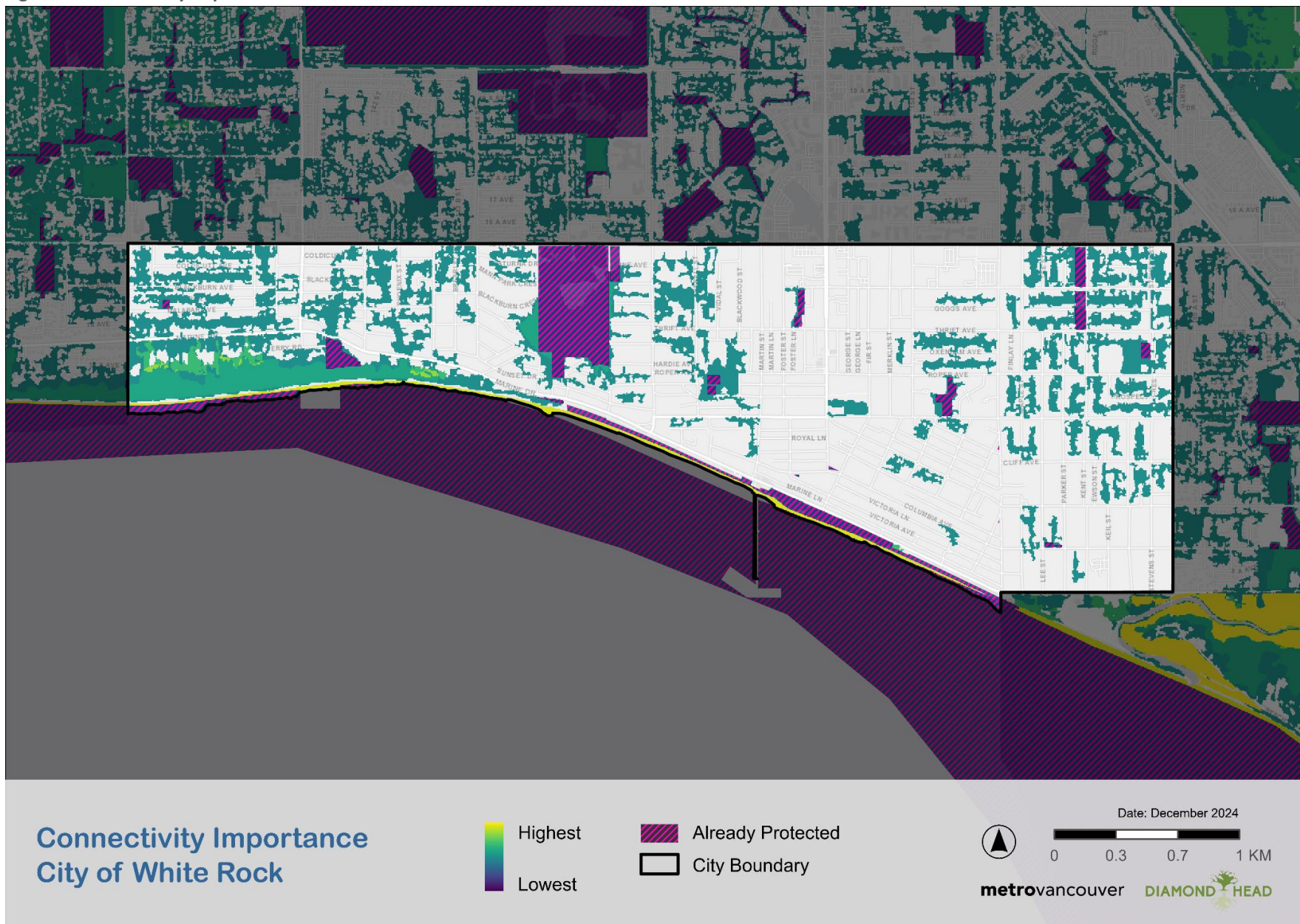


Figure 33 Connectivity Importance City of White Rock.

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