BEST MANAGEMENT PRACTICES FOR

Garlic Mustard

in the Metro Vancouver Region

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SERVICES AND SOLUTIONS FOR A LIVABLE REGION

ISCMV
INVASIVE SPECIES COUNCIL OF METRO VANCOUVER

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CREDIT: K. LI, CITY OF DELTA

Introduction

The impacts of invasive species on ecological, human, and economic health are of concern in the Metro Vancouver region. Successful control of invasive species requires concerted and targeted efforts by many players. This document - "**Best Management Practices for Garlic Mustard in the Metro Vancouver Region**" - is one of a series of species-specific guides developed for use by practitioners (e.g., local government staff, crews, project managers, contractors, consultants, developers, stewardship groups, and others who have a role in invasive species management) in the region. Together, these best practices provide a compendium of guidance that has been tested locally by many researchers and operational experts.

Garlic mustard[1] is one of the fastest spreading invasive plants in woodland and edge habitats in North America (King Country Noxious Weed Control Program, 2002). It was introduced to North America as a herb from Europe in the mid 1800s (King County Noxious Weed Control Program, 2010). When crushed, the aboveground parts of the plant smell strongly of garlic. It is edible and is sometimes used as a medicinal or culinary herb, where it can be substituted for garlic (Cavers, Heagy, & Kokron, 1979). Management efforts for this species focus on preventing seed production and dispersal, and can take many years.

Academic institutions, government, and non-government organizations continue to study this species in British Columbia. As researchers and practitioners learn more about the biology and control of garlic mustard, it is anticipated that the recommended best management practices will change. This document will be updated to reflect these changes as the information becomes available. Please check metrovancouver.org regularly to obtain the most recent version of these best management practices.

REGULATORY STATUS

Garlic mustard is classed as a noxious weed within all regions of the province under the *BC Weed Control Act*, Weed Control Regulation, Schedule A. The Act states that "an occupier must control noxious weeds growing or located on land and premises, and on any other property located on land and premises, occupied by that person".

1 Garlic mustard is the most widely used common name for ***Alliaria petiolata*** in North America, but it is also known elsewhere in the world by the common names: garlic root, hedge garlic and sauce alone **(Nuzzo, 2000)**.

Section 2 (1) (b) (iii) of the *Community Charter*, Spheres of Concurrent Jurisdiction – Environment and Wildlife Regulation, states that "municipalities may regulate, prohibit and impose requirements in relation to control and eradication of alien invasive species", which includes garlic mustard within the terrestrial vascular plants list.

IMPACTS

Indigenous Peoples have an intrinsic relationship with the natural world, built on reciprocity and stewardship. Many native plants and animals have cultural and spiritual significance for Indigenous Peoples, in addition to being important food and medicine sources. Indigenous communities in British Columbia have collectively called for invasive species prevention, management, and control due to their impact on infrastructure, the economy, human health, ecosystems, and cultural practices. Further collaboration with Indigenous Peoples will deepen our understanding about the impacts of invasive species, such as garlic mustard, on Indigenous ways of life and our shared environment.

Garlic mustard is a serious threat to natural areas, where it reduces biodiversity (Anderson, 2012). It grows during the early spring and in the fall when many native species are dormant, allowing it to dominate understory plant communities (Crosby, 2018). Monotypic stands of garlic mustard can cover hundreds of square metres, especially in forests (Cavers, Heagy, & Kokron, 1979).

Garlic mustard is allelopathic, which means it produces toxins that suppress the growth of nearby plants (Vaughn & Berhow, 1999). Several of these toxic chemicals (e.g., glycosides, phenolic acids, cyanide, and glucosinolates) have been found in leaf, stem, and root extracts of garlic mustard (Chen, Liao, Chen, Wei, & Peng, 2017). Some of these chemicals are toxic to soil microorganisms and the plant has long-term negative impacts on the growth of beneficial native mycorrhizal fungi that other plants and trees need to survive (Roche, et al., 2021), thereby reducing plant biodiversity and limiting food sources for wildlife. These phytotoxins can persist in the soil for years, even after garlic mustard has been removed, creating an opportunity for the introduction of other invasive plants and further displacement of native plants (Anderson, 2012).

Overwintered garlic mustard rosettes dominating a forest understory

CREDIT: CITY OF SURREY

Garlic mustard negatively impacts the life cycle of butterflies in some North American forest ecosystems (Garry Oak Ecosystem Recovery Team, 2010). Adults of several native butterfly species lay eggs on garlic mustard (in the absence of preferred native host plants), but the plant's phytotoxins inhibit or deter feeding (Renwick, Zhang, Haribal, Attygalle, & Lopez, 2001), causing many or all of the larvae die before completing development (Nuzzo, 2000).

Dairy cows that eat garlic mustard leaves will produce tainted milk (Cavers, Heagy, & Kokron, 1979). In Europe, garlic mustard is host to several fungi and viruses that can infect garden plants, especially commercially grown members of the same plant family (Brassicaceae), such as broccoli and turnip (Nuzzo, 2000).

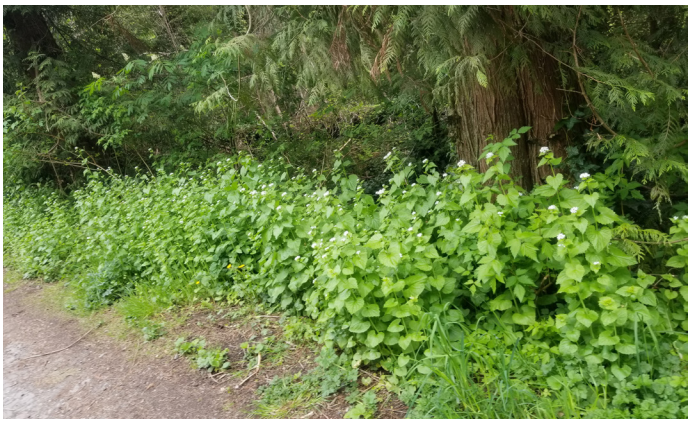
REPRODUCTION AND SPREAD

Garlic mustard reproduces by seeds that fall close to the parent plant (Cavers, Heagy, & Kokron, 1979). Seeds are primarily dispersed by anthropogenic methods (Nuzzo, 2000). For example, seeds can 'hitchhike' on pet and wildlife fur, human clothing, machinery, vehicles and in soil and water (Province of BC, 2021). Garlic mustard is often first detected along trails, roadsides or parking areas where it can quickly spread into forested areas (King Country Noxious Weed Control Program, 2002).

Seed production varies considerably by site, soil moisture, population density and year; maximum production is 7,900 seeds per plant per year, but on average is 136-295 seeds per year (Nuzzo, 2000). Garlic mustard can self-pollinate so only one plant is required for spread (Nuzzo, 2000). Seeds can germinate at any time during the year (Cavers, Heagy, & Kokron, 1979).

Cut plants are capable of re-sprouting from the root crown (Province of BC, 2021) or producing multiple flower heads from the top of the plant or any leaf axil (Brown, 2012). Flowers can form viable seed, and seeds can continue to ripen after being cut (King County Noxious Weed Control Program, 2010).

Europeans historically consumed garlic mustard as a herb in winter and early spring (Nuzzo, 2000). Garlic mustard seeds are still sold internationally.



Garlic mustard growing along the Capilano Pacific Trail

HABITAT AND DISTRIBUTION

Garlic mustard's distribution is positively associated with continued disturbance, which promotes seed production (Nuzzo, 2000). It is common in disturbed sites such as forest edges, fence lines, roadsides, trail sides, floodplains, and gardens but can quickly move into undisturbed habitats such as parks, forest understories and streambanks. The plants have a competitive advantage in high deer density areas as the animals avoid it (King County Noxious Weed Control Program, 2010).

Garlic mustard prefers damp, shaded soils although in areas where it is invasive, it can tolerate a wide range of moisture and soil conditions (Cavers, Heagy, & Kokron, 1979). It grows in a variety of light conditions, but plants are larger and produce more seeds in partial shade compared to full shade or full sun (Anderson, 2012).

In Eastern Canada, garlic mustard has devastated forest ecosystems (Anderson, 2012). While it is a newer invasive plant to BC, garlic mustard has been confirmed in the Great Victoria, Metro Vancouver, Fraser Valley, and Central and North Okanagan regions.

CLIMATE CHANGE ADAPTATION

Climate models predict that the Metro Vancouver region will experience warmer temperatures; a decrease in snowpack; longer dry spells in summer months; more precipitation in autumn, winter and spring; more intense extreme events; and an extended growing season. In the past, our region had an average of 252 days in the growing season. At lower elevations 45 days will be added to the growing season by the 2050s, and 56 days by the 2080s, resulting in nearly a year-round growing season of 357 days on average. In higher elevation ecosystems the growing season length will increase by 50% to 325 days by the 2080s (Metro Vancouver, 2016). These changes will stress many sensitive ecosystems, increasing their vulnerability to competition from invasive species.

Garlic mustard's ability to survive in a variety of conditions and habitats will likely influence its ability to adapt to future climate in several ways:

- **Extended growing season:** With a wide seasonal window of survival compared to many native plants, and the ability to germinate year-round and grow vigorously during near freezing temperatures in late fall and early spring (Cavers, Heagy, & Kokron, 1979), garlic mustard may be able to capitalize on a longer growing season.
- **Increased precipitation and flooding:** Garlic mustard has been observed growing on wet riverbanks that flood for up to four months annually (Cavers, Heagy, & Kokron, 1979), suggesting that it tolerates fluctuating water conditions. Garlic mustard seeds have a thick impermeable outer layer with grooves that allow them to float (Cavers, Heagy, & Kokron, 1979), making them easily dispersible in floodwaters (Nuzzo, 2000). Increased germination of garlic mustard is observed in spring after heavy rainstorms (Cavers, Heagy, & Kokron, 1979).
- **Drought tolerance:** Although garlic mustard is associated with moist forests and floodplains, in the United States, it is increasingly invading drier habitats (Nuzzo, 2000).
- **Fewer frost days:** Germination rates are higher when garlic mustard seeds have not been exposed to below freezing temperatures (King County Noxious Weed Control Program, 2010).

With these kinds of competitive advantages, garlic mustard is more adaptable than native species in a variety of ecosystems, suggesting that it will be able to withstand, and possibly thrive, with changing climate conditions.

Identification

Unless otherwise noted, the following identification information was collected from the Province of BC (2021), King County Noxious Weed Control Program (2010) and Cavers, Heagy & Kokron (1979).

Lifecycle: Biennial to winter annual[2] herb; low-lying clusters of leaves (rosettes) form in the first year (usually in the spring) and those that survive through the winter produce flowering stems in the second year and then die.

Stem: Thin, hairy, flowering stems grow in the second year, usually a single unbranched stem or a few branches; 5-150 centimetres tall.

Leaves: Dark green with few hairs; first-year (rosette) leaves are kidney- to heart-shaped with scalloped edges that grow close to the ground. Second-year leaves are more triangular-shaped with toothed edges and an alternate arrangement on the stem, becoming smaller towards the top of the stem.

Flowers: Clusters of white, 4-petaled flowers growing at the top of the main stem and branches. Flowers from February to May in Metro Vancouver, and is one of the first blooming plants that grows in forest understories. If cut or damaged, stems can produce flowers later in the year.

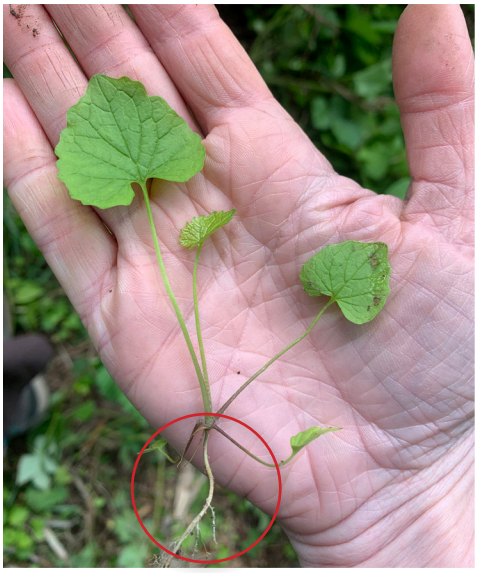
Fruits: Long, narrow and upright seed pods (siliques) 2.5-6 centimetres long. From May through the rest of the summer, dark, mature seed pods split open and release 10-20 small, brownish-black seeds. Seeds can germinate anytime of the year and are viable for as long as 10 years, although germination rates decrease every year.

Roots: Thin, white taproot with a distinct 'S' shape at the top of the root.

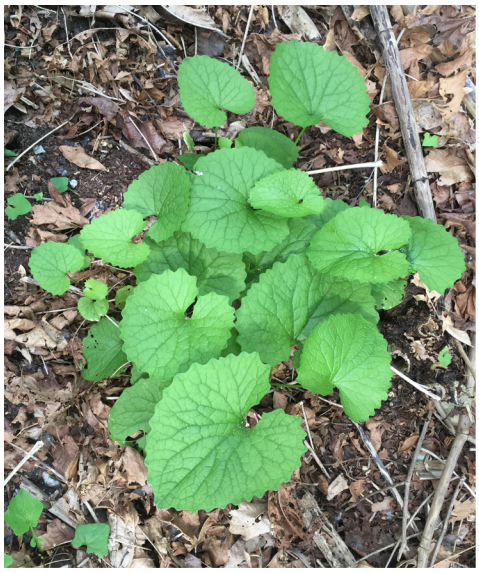
Other characteristics: Plants emit a distinct garlic odour when crushed, especially young plants.

2 A winter annual germinates in fall or winter, lives through the winter, flowers in spring and dies after setting seed.

The following photos show garlic mustard plant parts.



Seedling – note the S-shape at the top of the taproot
CREDIT: ISCMV



First-year leaves
CREDIT: ISCMV

First-year rosette
CREDIT: ISCMV

Flowers and immature seed pods
CREDIT: ISCMV

Inside of a seed pod with mature seeds
CREDIT: LESLIE J. MEHRHOFF, UNIVERSITY OF CONNECTICUT, BUGWOOD.ORG

Second-year leaves
CREDIT: F. STEELE

SIMILAR SPECIES

Garlic mustard, especially in the absence of mature flowers, can be easily mistaken for many non-native and weedy species that grow in similar habitats. Garlic mustard can be distinguished from these species by the characteristic **garlic odour** (Cavers, Heagy, & Kokron, 1979) and the **'S' shaped taproot** (Garry Oak Ecosystem Recovery Team, 2010). Also, most of the similar species have hairy leaves but garlic mustard **leaves are smooth** with very few hairs.

NATIVE SPECIES

During the rosette stage (first year), garlic mustard can be easily confused with the following native plant:

- **Wild violets (*Viola* species)** – Leaves grow on long, slender, hairy stalks and are often cupped; purple flowers with 5 petals, the lower petal larger with a spur at the base (Anderson, 2012).

During the flowering stage (second year), garlic mustard can be easily confused with the following native plants:

- **Fringecup (*Tellima grandiflora*)** – Leaves hairy, lobed and sharply toothed (King County Noxious Weed Control Program, 2010); flowers grow in terminal spikes along one side of the stem and petals are white to reddish and divided into 5-7 lobes at the ends (Klinkenberg, 2021).
- **Piggy-back plant (*Tolmiea menziesii*)** – Plant is entirely hairy; basal leaves have long stalks and there are few leaves on the stems; flowers grow in terminal spikes and usually have 4 brownish-purple petals, 8-12 mm long and thread-like (Klinkenberg, 2021).
- **Stinging nettle (*Urtica dioica*)** – Perennial plant 1-3 metres tall with lanceolate to egg-shaped coarsely-toothed leaves that grow on opposite sides of the stem (Klinkenberg, 2021). Small greenish-white flowers clusters hang from the leaf axils (Klinkenberg, 2021). Covering the leaves and stems, there are numerous thin hairs that can **pierce the skin and cause a stinging sensation**. Stinging nettle is common at moist sites such as woodlands, streamsides, ditches, and waste areas throughout the Metro Vancouver region.

Viola odunca
CREDIT: BREWBOOKS, FLICKR

Fringecup
CREDIT: LEONORA (ELLIE) ENKING, FLICKR

Piggy-back plant
CREDIT: NZ_WILLOWHERB, FLICKR

Stinging nettle
CREDIT: ISCMV

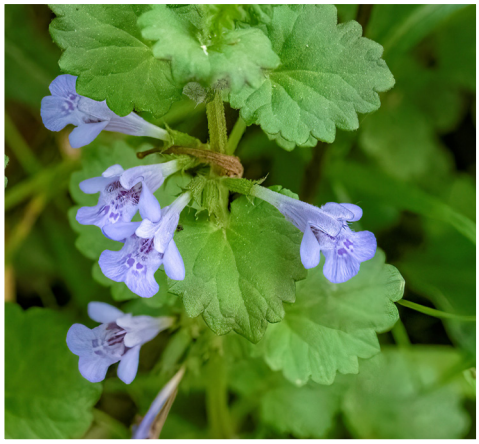
NON NATIVE SPECIES

During the rosette stage (first year), garlic mustard can be easily confused with the following non-native plants:

- **Ground ivy (*Glechoma hederacea*)** – Grounds ivy smells like mint when crushed. Leaves are hairy on the surface and grow along runners, not rosettes. Leaf stems are attached to the middle of the leaf; purple-blue, funnel-shaped flowers grow in clusters (Anderson, 2012).
- **Purple dead-nettle (*Lamium purpureum*)** – An annual plant 10-40 centimetres tall with square stems that grow from a short taproot (Klinkenberg, 2021). Leaves are opposite, round to egg-shaped, hairy, and 1-5 cm long. Several pink-purple, small, tubular-shaped flowers grow from the leaf axils. The upper leaves and stem of flowering plants are also purple tinged, and look less like garlic mustard at this mature stage. Purple dead-nettle is common in the Metro Vancouver region in lawns, fields, gardens, roadsides, trails, and waste sites, often covering large areas.

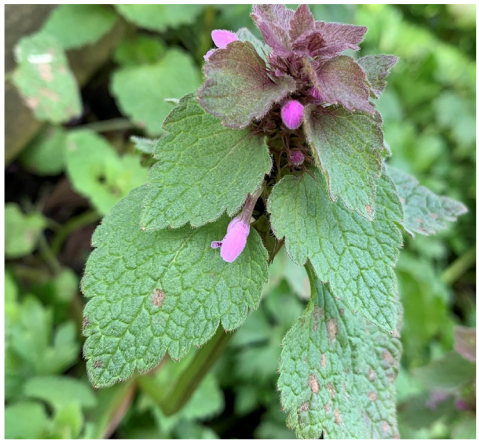
Ground ivy leaves

CREDIT: BRUCE ACKLEY, THE OHIO STATE UNIVERSITY, BUGWOOD.ORG



Ground ivy flowers

CREDIT: STEVE GUTTMAN NYC, FLICKR



Purple dead-nettle

CREDIT: ISCMV

During the flowering stage (second year), garlic mustard can be easily confused with the following non-native plants:

- **Nipplewort (*Lapsana communis*)** – From a distance, mature nipplewort plants resemble garlic mustard, but nipplewort flowers are yellow and leaves have lobes extending along the leaf stem below the main leaf (King County Noxious Weed Control Program, 2010).
- **Money plant (*Lunaria annua*)** – Leaves are thicker and hairier than garlic mustard (King County Noxious Weed Control Program, 2010). Money plant flowers are usually pink to purple, but a white flowering variety looks similar to garlic mustard with larger flowers (King County Noxious Weed Control Program, 2010). Seed pods are round and flattened and look like coins.
- **Bitter winter cress (*Barbarea vulgaris*)** – Basal leaves have long stalks, multiple leaflets and 1-2 pairs of lateral lobes (Klinkenberg, 2021). Flowers are in terminal clusters and have bright yellow petals (Klinkenberg, 2021). This plant has short, erect and numerous seed pods with smaller seeds than garlic mustard (Cavers, Heagy, & Kokron, 1979).

Nipplewort

CREDIT: FOREST AND KIM STARR, FLICKR

Nipplewort leaves

CREDIT: BRENDA DOBBS, FLICKR

Money plant

CREDIT: ISCMV

Bitter winter cress

CREDIT: STEVE GUTTMAN NYC, FLICKR

Tracking

The provincial government maintains the Invasive Alien Plant Program (IAPP) application (BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development 2017), which houses information about invasive plant surveys, treatments, and monitoring. Many agencies, including local governments, have their own internal invasive species inventory and mapping protocols that are used by staff, contractors, and, in some cases, the public. For example, the City of North Vancouver has its own system called AlienMap. Agencies in British Columbia that do not enter data into IAPP are encouraged to check it regularly because it contains public reports and data from other agencies and it is important to consider as much data as possible when making management decisions. The Map Display module of IAPP is publicly accessible.

When carrying out a garlic mustard inventory it is useful to record the following information as it will later inform treatment plans:

- Size and density of infestation;
- Location in relation to the 10-metre Pesticide-Free Zone adjacent to water courses;
- Location in relation to other water sources, such as wells; and
- The suspected source of infestation and potential for spread.

Since garlic mustard is easiest to detect when it is flowering, conduct surveys in April and May (King County Noxious Weed Control Program, 2010). It is more difficult, but useful, to conduct a garlic mustard inventory in late winter to early spring to detect it in areas where it may be obscured by deciduous foliage at other times of the year (King County Noxious Weed Control Program, 2010).

Reporting

Please report garlic mustard occurrences to:

- The Provincial Report Invasive Species program (via smart phone app www.gov.bc.ca/invasive-species).
- The Invasive Species Council of Metro Vancouver: 604-880-8358 or www.iscmv.ca.
- The municipality where the garlic mustard was found.
- The landowner directly – If the landowner is unknown, the Invasive Species Council of Metro Vancouver can provide support to identify the appropriate authority.

Reports submitted through these channels are reviewed by invasive species specialists who coordinate follow-up activities when necessary with the appropriate local authorities. However, some people may be hesitant to report infestations as their presence may affect property values.

Prevention and Control Strategies

Effective invasive plant management may include a variety of control techniques ranging from prevention, chemical, manual, mechanical, biological, and/or cultural methods.

Populations of garlic mustard may fluctuate from year to year – they may seemingly disappear one year and then become prolific the next year (Cavers, Heagy, & Kokron, 1979). Perceived control in any given year may not be accurate (King County Noxious Weed Control Program, 2010) and management efforts should be evaluated over multiple seasons.

Control of isolated plants and small patches should be prioritized to prevent spread (King County Noxious Weed Control Program, 2010). For larger or fragmented infestations, start on the outside and move towards the centre (King County Noxious Weed Control Program, 2010) (Anderson, 2012). Garlic mustard seeds spread rapidly along trails in the region, so control along transportation corridors should be a priority.

Garlic mustard will take many years to eradicate and management efforts should focus on preventing seed production and exhausting the seed bank (Nuzzo, 2000) (Garry Oak Ecosystem Recovery Team, 2010). **It is recommended to establish a multi-year management plan before initiating control activities, as many of the methods outlined below, if completed only once, will increase garlic mustard densities** (Anderson, 2012). It is also important to target both stages of plants - rosettes and flowering plants (Anderson, 2012) - which may require the use of multiple methods.

STRATEGY COLOUR LEGEND

GREEN: RECOMMENDED

ORANGE: CAUTION

RED: NOT RECOMMENDED OR NOT AVAILABLE

PREVENTION: IMPERATIVE

Prevention is the most economical and effective way to reduce the spread of garlic mustard over the long term.

When working in or adjacent to garlic mustard, it is best to inspect and remove plants, plant parts, and seeds from personal gear, clothing, pets, vehicles, and equipment and ensure soil, gravel, and other fill materials are not contaminated with garlic mustard before leaving an infested area. Plants, plant parts, and seeds should be tarped or bagged before transport to an appropriate disposal site (see Disposal section). If possible, do not move soil or mulch from infested areas (King County Noxious Weed Control Program, 2010) and avoid disturbing soil in areas with ripe garlic mustard seeds, as this will encourage seed spread.

When selecting plants for a site, do not purchase, propagate, trade or transport this plant. The Invasive Species Council of BC's 'Grow Me Instead' Program or Metro Vancouver's Grow Green website provide recommendations for non-invasive, drought-tolerant plants, and garden design ideas. All materials (e.g., topsoil, gravel, mulch, compost, wood chips, plant stock) should be weed-free. Garlic mustard could be unintentionally introduced via these materials and sites where they are used should be monitored carefully for any growth (Crosby, 2018).

Healthy green spaces are more resistant to invasion by invasive plants, so it is also important to maintain or establish healthy plant communities.

MANUAL/MECHANICAL: RECOMMENDED

Soil disturbance is common during manual and mechanical control and may increase seed germination and release (PNW - GMWG, 2017). After manual control, it is best to pack down the soil to minimize seed germination (King County Noxious Weed Control Program, 2010) (Nuzzo, 2000). Consider applying mulch to the site after manual/mechanical control options (see Cultural control methods section).

Management of garlic mustard is suitable for volunteers (King County Noxious Weed Control Program, 2010); however, the work should be closely supervised to ensure that efforts are timed appropriately and prevention methods are followed.

- **Hand pulling flowering stems** is recommended for individual second-year or older plants or small infestations when the soil is loose or wet to allow for complete root extraction (King County Noxious Weed Control Program, 2010). The plants should be pulled after they begin flowering but before the seed pods mature, typically from April to June (King County Noxious Weed Control Program, 2010). They can be pulled prior to flowering, but the plants are less conspicuous at that time and easier to miss. It is best to grab the plant low down at the root crown, easing the taproot out of the ground and removing as many roots as possible (PNW - GMWG, 2017). Roots can easily snap off at the soil level, especially in gravel and at sites where the garlic mustard is growing with other plants (Edmonds, 2022). A weeding/soil knife (with a serrated edge and sharp pointed tip) may be useful to loosen the soil around the base of plants (PNW - GMWG, 2017).

  After pulling plants, search the site for remaining rosettes. **Since first-year rosettes tend to snap off at the root and re-sprout, they should be dug out (see Digging bullet) and not hand pulled** (Province of BC, 2002). This method is more difficult when plants are immature or stunted (Brown, 2012) or if the soil is hard. If plants do not release easily, digging may be required.

  Flowers can form viable seeds and seeds can ripen even after plants are pulled, so plants should be bagged and removed offsite (see Disposal section). This method may need to be repeated often from the time the plants are flowering until seeds are produced. Some land managers suggest this method should be undertaken weekly, which makes it very labour intensive on a landscape scale (Brown, 2012).

- **Digging** is recommended for first-year rosettes and also effective on small infestations of flowering plants (King County Noxious Weed Control Program, 2010). As much of the roots should be removed as possible and soil disturbance should be minimized. Digging should take place through the winter and early spring when the soil is moist and prior to seed production. Since flowers can form viable seeds and seeds can ripen even after plants are pulled, flowering plants should be bagged and removed offsite (see Disposal section).

- **Repeated cutting of flowering stems** (second year or older) with hand pruners or garden shears **as close to the ground as possible** will reduce the number of seeds produced and reduce soil disturbance (King County Noxious Weed Control Program, 2010). Cutting is most effective when the plants are in full bloom, as earlier in the flowering process, cut plants may still have sufficient resources to produce additional flowering stems (Nuzzo, 2000). Depending on the timing, it may be necessary to cut up to 3 times per growing season (Garry Oak Ecosystem Recovery Team, 2010). Since flowers can form viable seeds and seeds can ripen even after plants are pulled, flowering plants should be bagged and removed offsite (see Disposal section). Cutting first-year rosettes is not recommended as this encourages growth (King County Noxious Weed Control Program, 2010).

This method reduces soil disturbance compared to pulling and digging methods (Anderson, 2012). Brown (2012) experienced good suppression with cutting, then raking and mulching in a trial in 2011 on southern Vancouver Island (see Cultural control methods section for more information on mulching). Follow-up surveys are needed to confirm the current status of these trial sites.

- **Repeated mowing or grading after blooming but before seed production** throughout the growing season can provide short term suppression along roadsides and other sites with full sun (ISCBC & Ministry of Transportation & Infrastructure, 2019) (Nuzzo, 2000). After mowing, plants will re-sprout and flower again within the same season, and therefore mowing needs to be repeated regularly throughout the growing season (King County Noxious Weed Control Program, 2010). Any flowering plant parts must be removed from the site to prevent seed production, which may be challenging for large infestations (King County Noxious Weed Control Program, 2010). Even if conducted before seed production, mowing will disturb soil encouraging seed germination (Nuzzo, 2000). Since seeds can easily stick to gear, all equipment should be thoroughly cleaned to reduce risk of spread between sites. Mowing after seeds are present (as early as May through the summer) is not recommended because it can trigger rapid germination and growth (PNW - GMWG, 2017).
- **Burning** opportunities are limited and often not appropriate in urban areas due to fire risk, municipal bylaws and other required permits. Trials of prescribed burning of garlic mustard infestations have yielded inconsistent results (Nuzzo, 2000). This method could be successful for large infestations if followed by up to five years of consecutive burns or other forms of manual control (Garry Oak Ecosystem Recovery Team, 2010) (Brown, 2012), but it is not recommended in urban settings. Burning may reduce leaf litter on the ground, further encouraging garlic mustard growth, especially in deciduous forests (Anderson, 2012). This method also encourages germination of seeds in the soil and can increase growth of other invasive plants.

REMOVAL TIMING

Timing of removal should be carefully considered based on the control methods used. Second-year plants should be managed after the plants have flowered but before seeds are produced (King County Noxious Weed Control Program, 2010). Garlic mustard can flower at different times (Anderson, 2012), especially after they have been treated, so planned management activities may need to be adjusted for the plant's current stage. Depending on the site, treatment may only be possible during a short time period, and may require flexibility of crew scheduling to get the timing right.

Control is possible on rosettes during the first year, into late fall and until flower production beings in the spring of the following year (Nuzzo, 2000). Late fall is the best timing for first-year rosette control because many native plants are dormant, reducing the risk of damage to off-target plants (Nuzzo, 2000).

APPLYING MANUAL/MECHANICAL CONTROL METHODS IN RIPARIAN AREAS

Garlic mustard often grows in large contiguous patches right up to the edge of water courses. Consider the impact of control techniques and the resulting bare soil on the adjacent aquatic environment. Schedule removal works during a period of least risk to fish species, outside of the fish window. Adhere to Provincial and Federal riparian regulations. It is recommended to consult with a qualified environmental professional when working around water bodies.

CHEMICAL: RECOMMENDED

When alternative methods to prevent or control invasive plants are unsuccessful, professionals often turn to herbicides. Several combinations of control techniques were trialed in 2011 by Brown (2012) on southern Vancouver Island: glyphosate-based herbicide application, EcoClear (acetic horticulture vinegar) application, herbicide application and mulch, manual control, burning, and various combinations of techniques. A combination of cutting, raking and mulch reduced the area of garlic mustard plants by 87% after one season of treatment. Glyphosate-based herbicide application alone and glyphosate application plus mulch resulted in an 85% and 84% reduction, respectively. Other techniques were not as successful.

Chemical control can be used at isolated sites, or on a landscape scale (Brown, 2012). It may be the most cost-effective option for management of large infestations (King County Noxious Weed Control Program, 2010) (Brown, 2012). Chemical control is also appropriate for rights-of-way if pulling or digging are not feasible (King County Noxious Weed Control Program, 2010).

This method should be used with caution for the following reasons (Crosby, 2018):

1. Weather conditions greatly influence treatment efficacy;
2. Garlic mustard often grows in riparian areas where pesticide use is restricted; and
3. Since garlic mustard growth is closely associated with other plants, chemical control can easily damage non-target species (Province of BC, 2002).

With the exception of substances listed on Schedule 2 of the BC Integrated Pest Management Regulation, the use of herbicides is highly regulated in British Columbia.

Site characteristics must be considered with herbicide prescribed, based on site goals and objectives and in accordance with legal requirements. This summary of BC's *Integrated Pest Management Act* provides an overview of the provincial legislation.

PESTICIDE LICENCE AND CERTIFICATION

A valid pesticide licence is required to:

- offer a service to apply most pesticides;
- apply most pesticides on public land including local government lands[3]; and
- apply pesticides to landscaped areas on private land, including outside office buildings and other facilities.

Pesticides (e.g., herbicides, insecticides, fungicides) are regulated by the Federal and Provincial governments, and municipal governments often have pesticide bylaws.

- Health Canada evaluates and approves chemical pest control products as per the *Pest Control Products Act*.
- The BC *Integrated Pest Management Act* sets out the requirements for the use and sale of pesticides in British Columbia. This Act is administered by the Ministry of Environment and Climate Change Strategy.
- Several municipalities have adopted bylaws that prohibit the use of certain pesticides.

Everyone who uses pesticides must be familiar with all relevant laws.

3 on up to 50 ha/year by a single organization. Organizations looking to treat over 50 hectares of land per year are also required to submit a Pest Management Plan and obtain a Pesticide Use Notice confirmation.

ONLY companies or practitioners with a valid Pesticide Licence and staff who are certified applicators (or working under a certified applicator) may apply herbicide on invasive plants located on public lands in British Columbia. Applicators must be either the land manager/owner or have permission from the land manager/owner prior to herbicide application.

On private property, the owner may obtain a Residential Applicators Certificate (for Domestic class products only) or use a qualified company. Residents do not require a Residential Applicator Certificate for certain uses of domestic class glyphosate including treatment of plants that are poisonous for people to touch, invasive plants and noxious weeds listed in legislation, and weeds growing through cracks in hard surfaces such as asphalt or concrete. Refer to the 'Pesticides & Pest Management' and 'Home Pesticide Use' webpages listed in the Additional Resources Section for more information.

Questions? Contact the BC Integrated Pest Management Program: Telephone: 250-387-9537

Email: bc.ipm@gov.bc.ca

Pesticide applicator certificates can be obtained under the category 'Industrial Vegetation Management' to manage weeds on industrial land, roads, power lines, railways, and pipeline rights-of-way for control of noxious weeds on private or public land. Assistant applicator training is also available and the online course and exam are free.

It is best practice for personnel supervising or monitoring pesticide contracts to also maintain a pesticide applicator licence so they are familiar with certification requirements.

For more information on how to obtain a licence and the requirements when working under the provincial *Integrated Pest Management Act* and Regulation, please review the Noxious Weed & Vegetation Management section on this webpage: gov.bc.ca/PestManagement.

HERBICIDE LABELS

Individual herbicide labels must always be reviewed thoroughly prior to use to ensure precautions, application rates, and all use directions, specific site and application directions are strictly followed. Under the federal Pest Control Products Act and the BC Integrated Pest Management Regulation, **persons are legally required to use pesticides (including herbicides) only for the use described on the label and in accordance with the instructions on that label**. Failure to follow label directions could cause damage to the environment, create poor control results, or pose a danger to health. Contravention of laws and regulations may lead to cancellation or suspension of a licence or certification, requirement to obtain a qualified monitor to assess work, additional reporting requirements, a stop work order, or prohibition from acquiring authorization in the future. A conviction of an offence under legislation may also carry a fine or imprisonment.

Herbicide labels include information on both the front and back. The front typically includes trade or product name, formulation, class, purpose, registration number, and precautionary symbols. Instructions on how to use the pesticide and what to do in order to protect the health and safety of both the applicator and public are provided on the back (BC Ministry of Environment, 2011).

Labels are also available from the Pest Management Regulatory Agency's online pesticide label search or mobile application as a separate document. These label documents may include booklets or material safety data sheets (MSDS) that provide additional information about a pesticide product. Restrictions on site conditions, soil types, and proximity to water may be listed. If the herbicide label is more restrictive than Provincial legislation, the label must be followed.

HERBICIDE OPTIONS

The following herbicides can be used on garlic mustard. Information is from King Country Noxious Weed Control Program (2010) and Brown (2012), unless otherwise noted.

ACTIVE INGREDIENT (EXAMPLE BRAND NAMES)+	APPLICATION	PERSISTENCE	GROWTH STAGE++	TYPE+++	COMMENT
Glyphosate (many products) §	foliar application	non-residual*	actively growing	non-selective	Apply in early spring or late fall to minimize damage to other plants and trees with roots within or adjacent to the treatment area
2,4-D (amine formulation)	foliar application	short residual	actively growing	selective, no effect on most grasses	2,4-D products not currently permitted on BC Ministry of Transportation and Infrastructure jurisdiction
Triclopyr (e.g., GarlonTM)	foliar application	residual	actively growing	selective, no effect on grasses	Apply in early spring, will minimize damage to surrounding grasses and may prevent seed maturation (PNW - GMWG, 2017)
Metsulfuron (e.g., Escort™)	foliar application	residual	actively growing	selective, no effect on grasses	Apply in spring or fall

+ The mention of a specific product or brand name of pesticide in this document is not, and should not be construed as, an endorsement or recommendation for the use of that product.

++ Active growing periods vary from year to year depending on weather and other factors. There may be more than one active growing period for a plant in a year.

+++ Herbicides that control all vegetation are non-selective, while those that control certain types of vegetation (e.g., only grasses or only broadleaf plants) are termed selective.

§ Glyphosate can impact trees with roots within or adjacent to the treatment area.

* Non-residual herbicides are active only on growing plant tissue and have little or no persistence in the soil, whereas residual herbicides persist in the soil, remaining effective over an extended period.

APPLYING PESTICIDE IN RIPARIAN AREAS

Provincial legislation prohibits the use of herbicides within 10 metres of natural water courses and 30 metres of domestic or agricultural water sources on public lands. On private lands, herbicide labels need to be followed (which means for glyphosate products treatment can happen up to the water's edge) and other restrictions may apply (e.g. industrial sites, forestry sites, golf courses, etc.). On public lands, glyphosate is the only active ingredient that can be applied within the 10 metre Pesticide-Free Zone (PFZ)[4] in British Columbia in accordance with the Integrated *Pest Management Act* and Regulation and all public land Pesticide Management Plans (PMPs). A plant must be either a listed Noxious Weed (under the *Weed Control Act*) or appear in *the Forest and Range Practices Act* Invasive Plants Regulation to be treated within the 10 metre PFZ. **Garlic mustard is listed and therefore glyphosate can be applied on garlic mustard up to 1 metre away from the high water mark (HWM)** [5]. The 30 metre no-treatment zone around a water supply intake or well used for domestic or agricultural purposes may be reduced if the licencee or PMP holder is "reasonably satisfied" that a smaller no-treatment zone is sufficient to ensure that pesticide will not enter the intake or well.

When managing garlic mustard with herbicide in riparian areas:

- Observe and mark all PFZs before treatments.
- The high water mark (HWM) should be determined by careful evaluation by the applicator.
- Distances in PFZs should be measured as horizontal distance.
- Herbicides restricted in a PFZ must not enter these zones by leaching (lateral mobility) through soil or by drift of spray mist or droplets.
- Consider if treatments can be conducted when water levels are low (e.g. summer months) to reduce risk.
- Note that efficacy may be dependent on site conditions, including moisture in the soil.

4 The Pesticide-Free Zone (PFZ) is an area of land that must not be treated with pesticide and must be protected from pesticide moving into it, under the *Integrated Pest Management Act* and Regulation.

5 The High Water Mark (HWM) is defined as the visible high water mark of any lake, stream, wetland or other body of water where the presence and action of the water are so common and usual and so long continued in all ordinary years as to mark upon the soil of the bed of the lake, river stream, or other body of water a character distinct from that of the banks, both in vegetation and in the nature of the soil itself. Typical features may include, a natural line or "mark" impressed on the bank or shore, indicated by erosion, shelving, changes in soil characteristics, destruction of terrestrial vegetation, or other distinctive physical characteristics. The area below the high water mark includes the active floodplain (BC Ministry of Environment, 2011).

APPLICATION METHODS

Foliar application can be undertaken by hand sprayer or backpack sprayer. Herbicide works best if applied in early spring on all garlic mustard plants and/or in fall for any first-year rosettes that are still green (PNW - GMWG, 2017). The entire plant should be sprayed, including flowering stems and immature seed pods, as unsprayed seed pods may continue to produce viable seeds (PNW - GMWG, 2017). Spraying plants that have hardened, mature seed pods will be ineffective to prevent seed production and dispersal (PNW - GMWG, 2017). Rosettes can also be sprayed in winter, but only after winter dormancy ends and re-sprouting is observed (PNW - GMWG, 2017). If only one treatment will occur during the season, it should be completed in early spring (early April to late May) (PNW - GMWG, 2017). Treatments may need to be repeated for multiple years if there is an existing seed bank (Anderson, 2012).

Spring herbicide application followed by hand pulling can be effective (PNW - GMWG, 2017). Any plants that were missed, or re-grew after spraying, can be pulled, but pulling may need to be repeated multiple times (PNW - GMWG, 2017).

CULTURAL: CAUTION

- **Mulching** with at least twelve centimetres of a mulch material (e.g., wood chips, leaves) can be used after manual and chemical control methods to suppress new growth and seed germination (Brown, 2012) (PNW - GMWG, 2017). Hemlock mulch has been found to be particularly successful (PNW - GMWG, 2017). The perimeter of the site must be monitored for re-growth (King County Noxious Weed Control Program, 2010) as the mulch will become thinner at the edges due to sloughing (Brown, 2012). This control method is not practical for sites greater than 20 square metres (Brown, 2012) and is not likely to be successful if used on its own.
- **Grazing** animals tend to avoid garlic mustard, so targeted grazing is generally not a viable management option for this invasive plant species.

BIOLOGICAL: NOT AVAILABLE

There are no biological control agents currently available in BC for garlic mustard. In Europe, a root-mining insect (*Ceutorhynchus scrobicollis*) is an effective biocontrol for garlic mustard, and is currently undergoing testing in the USA (King County Noxious Weed Control Program, 2010). The Provincial biocontrol program is not currently studying this potential biocontrol agent.

CREDIT: ISCMV

CONTROL SUMMARY

The following table provides a summary and comparison of control methods for garlic mustard.

CONTROL STRATEGY	TECHNIQUES	APPLICABLE SITE TYPE	PROS	CONS
Manual	**Hand pulling flowering stems** (second-year or older plants)	Individual flowering plants (not rosettes) when the soil is loose or wet	Selective and low risk to environment, can be managed by volunteers, non-chemical	Disturbs soil, labour intensive, pulled stems can still produce viable seeds so must be removed from the site
	Digging	First-year rosettes and small sites of flowering plants	Selective and low risk to environment, can be managed by volunteers, non-chemical	Disturbs soil, labour intensive, dug stems can still produce viable seeds so must be removed from the site
	Repeated cutting of flowering stems	Flowering plants	Selective and low risk to environment, minimal soil disturbance, can be managed by volunteers, non-chemical	Labour intensive, may need to be repeated within the same season, cut stems can still produce viable seeds so must be removed from the site
Chemical	**Foliar application**	All site sizes	Cost effective treatment method for plants that cannot be managed other ways, less labour intensive, best for treating large areas	Unintended environmental/health impacts; high public concern; requires trained staff, specialty equipment and herbicide products; weather dependent; cannot treat within PFZ
Mechanical	**Repeated mowing or grading**	Roadsides and other sites with full sun	Less labour intensive, non-chemical	Requires trained staff and specialty equipment, non-selective, needs to be repeated multiple times a season, must deal with biomass
Cultural	**Mulching**	Sites less than 20 square metres	Non-chemical, can supplement other control methods	Not an effective method on its own, challenging to implement around existing vegetation, access constraints, costly, not practical on a landscape scale
Manual	**Burning**	Large infestations		Not a suitable management option in urban settings
Cultural	**Grazing**	None		Not a viable management option for this species
Biological	**No biological control agents are currently available for distribution in British Columbia**			

CONTROL SUMMARY COLOUR LEGEND

GREEN: RECOMMENDED

ORANGE: CAUTION

RED: NOT RECOMMENDED OR NOT AVAILABLE

Disposal

ON SITE DISPOSAL

Since garlic mustard plants will continue to grow, flower and produce seeds even after removal or treatment, plants should not be left or composted onsite (PNW - GMWG, 2017) (King County Noxious Weed Control Program, 2010).

OFF SITE DISPOSAL

All plant parts should be tarped or placed in sturdy plastic or yard waste bags immediately after treatment (Anderson, 2012) and before transporting to an appropriate disposal or compost facility. In the Metro Vancouver region, several facilities accept garlic mustard plants and/or infested soil. Please consult this disposal facility list for current details.

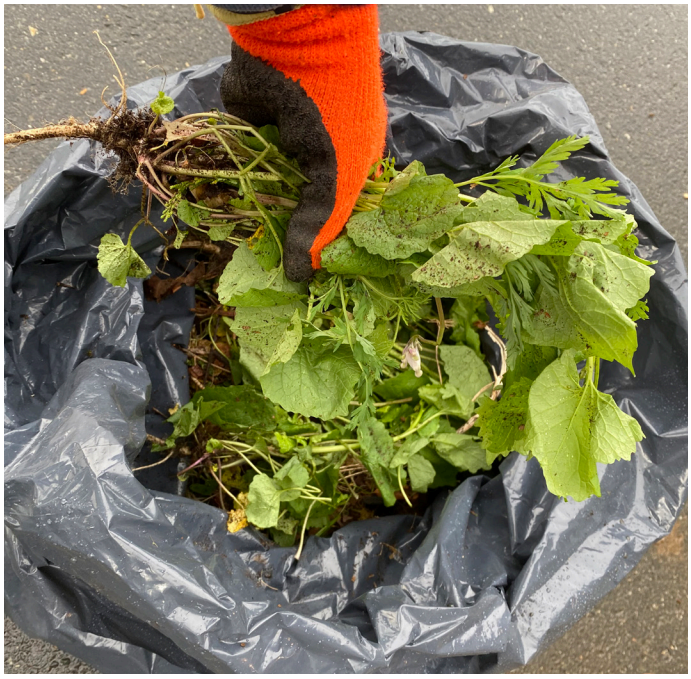
PLEASE CONTACT ALL FACILITIES BEFOREHAND TO CONFIRM THEY CAN PROPERLY HANDLE THE MATERIAL.

CLEANING AND DISINFECTION[6]

Before leaving a site, all visible plant parts and soil from vehicles, equipment, and gear should be removed and rinsed if possible. When back at a works yard or wash station, vehicles should be cleaned and disinfected using the following steps:

- Wash with 180 °F (82°C) water at 6 gpm, 2000 psi*, with a contact time of ≥ 10 seconds on all surfaces to remove dirt and organic matter such as vegetation parts or seeds. Pay special attention to undercarriages, chassis, wheel-wells, radiators, grills, tracks, buckets, chip-boxes, blades, and flail-mowing chains.
- Use compressed air to remove vegetation from grills and radiators.
- Sweep/vacuum interior of vehicles paying special attention to floor mats, pedals, and seats.
- Steam clean poor access areas (e.g., inside trailer tubes) – 200 psi @ 300 °F (149°C).
- Fully rinse detergent residue from equipment before leaving the facility.

* Appropriate self-serve and mobile hot power-wash companies in the Metro Vancouver area include: Omega Power Washing, Eco Klean Truck Wash, RG Truck Wash, Ravens Mobile Pressure Washing, Hydrotech Powerwashing, Platinum Pressure Washing Inc, and Alblaster Pressure Washing. Wash stations should be monitored regularly for garlic mustard growth.



After hand pulling at a City of Surrey park, garlic mustard plants are collected in a garbage bag.

CREDIT: CITY OF SURREY

6 Adapted from Metro Vancouver 2017 Water Services Equipment Cleaning Procedures and Inspection Protocols.

Follow-up Monitoring

Whatever control method is used, follow-up monitoring and maintenance treatments are components of an integrated management plan or approach. Nuzzo (2000) recommends monitoring twice annually: once for rosettes in late fall or early spring, then again in early to mid-spring for flowering adults. While monitoring sites, it is best to search adjacent potential habitats, such as parking lot edges, trails, roadsides and streamsides (Nuzzo, 2000). **Sites should be monitored regularly for at least 10 years after the last plant is observed (King County Noxious Weed Control Program, 2010).** Monitoring crews should be trained in identification of all life stages – flowering plants are easy to detect, but rosettes are less noticeable (Nuzzo, 2000).

CREDIT: CITY OF SURREY

Restoration

After control activities, evaluate if site restoration is required or if the site will regenerate naturally (Anderson, 2012). Factors to consider are the level of disturbance at the site, the risk of re-invasion by other species in the area, and the existing native vegetation (Anderson, 2012). Usually sites will need to be restored with competing native plants or reseeded (King County Noxious Weed Control Program, 2010) (PNW - GMWG, 2017). It is best to wait until the seed bank at the site has been significantly depleted (Anderson, 2012). If garlic mustard has formed monocultures, erosion may be an issue after management and the site may require stabilization measures (King County Noxious Weed Control Program, 2010).

Examples of common competitive native species prescribed in Metro Vancouver sites are summarized in the table below based on site moisture.

WET SITES	MOIST SITES	DRY SITES
SHRUBS		
Salmonberry	Salmonberry	Thimbleberry
Hardhack	Willow	Nootka rose
Willow	Red osier dogwood	Red flowering currant
Red osier dogwood	Red elderberry	Snowberry
Pacific ninebark	Vine maple	Tall Oregon grape
	Indian plum	Oceanspray
TREES		
Western red cedar	Western red cedar	Douglas-fir
Red alder	Red alder	Red alder

Replacement species should be chosen based on the ecology of the site by a qualified environmental professional. Local biologists, environmental professionals, agronomists, agrologists, native and domestic forage specialists, seed companies, and plant nurseries are all good sources for localized recommendations for regional native species and regionally adapted domestic species, based on site usage. Native grass seed mixes are also available. There are several science-based resources available to guide restoration efforts, such as the South Coast Conservation Program's Diversity by Design restoration planning toolkit.

Revegetation of the site to a domestic or cultured non-native plant species composition may be considered in some circumstances. Often domestic species establish faster and grow more prolifically, which aids in resisting garlic mustard re-invasion.

Garlic mustard sites are often found in areas with existing or potential wildlife populations (e.g., deer, beaver, muskrat, vole, etc.) that can damage restoration plantings. Therefore, any revegetation plan must consider potential impacts from wildlife and utilize appropriate mitigation measures to protect the restoration and existing native plantings (e.g., tree wrapping, exclusion caging/fencing, vole guards, etc.).

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Additional Resources

For more information please refer to the following resources.

- BC Ministry of Forests, Lands, and Natural Resource Operations, Invasive Alien Plant Program (IAPP). www.gov.bc.ca/invasive-species
- Grow Green Guide. www.growgreenguide.ca
- Grow Me Instead. http://bcinvasives.ca/resources/programs/plant-wise/
- King County Noxious Weed Control Program, 2010. *Best Management Practices: Garlic Mustard.* https://www.nwcb.wa.gov/images/weeds/Garlic-Mustard-Control_King.pdf
- Pacific Northwest Garlic Mustard Working Group https://4countycwma.org/aresources/past-events/garlic-mustard-working-group/
- Pesticides and Pest Management. Province of British Columbia https://www2.gov.bc.ca/gov/content/environment/pesticides-pest-management
- Province of BC, 2021. *Garlic Mustard. Invasive Species Alert! Garlic Mustard.* https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/invasive-species/alerts/garlic_mustard_alert.pdf

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