Royal Botanical Gardens' Hemlock Woolly Adelgid (*Adelges tsugae*) Management Strategy

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Document Description:

This document summarizes information, strategies, and cost options for managing the impacts of the new invasive insect Hemlock Woolly Adelgid (*Adelges tsugae*) as it pertains to the properties of Royal Botanical Gardens. This insect was first discovered on the South Shore of Cootes Paradise in the late winter of 2023 along Caleb's Walk Trail in West Hamilton. Funding assistance to complete this document was provided by the Ontario Invasive Species Centre through the Invasive Species Action Fund, as well as by donors to Royal Botanical Gardens.

Executive Summary

Eastern Hemlock (*Tsuga canadensis*) is the only species of hemlock native to eastern Canada and a prominent tree in the cool damp forests of the "Cottage Country" region of Ontario - Algonquin Park, Muskoka, and Parry Sound. This species is often nicknamed the 'redwood of the east, with a potential maximum age of 1,000 years and reaching 150 feet in height. It is a beloved forest giant across eastern North America with a rich connection to the Indigenous community. Its dense foliage casts cooling shadows on the forest floor, creating diversity in microhabitats within a forest community. At Royal Botanical Gardens (RBG), a predominantly Carolinian species type forest, Eastern Hemlock is limited to the shaded, cool, north facing slopes of ravines. Overall, it is estimated that about 1,200 Eastern Hemlock trees of all age classes are found across the property located within approximately thirteen principal forest stands covering 16 hectares. There are also 102 hemlocks of various species, planted within RBG's cultivated garden areas, with most growing at RBG's Rock Garden. These areas include three sites on the south side of Cootes Paradise Nature Sanctuary, three sites on the north side, three locations in Hendrie Valley, and one location along the perimeter slope of the Rock Garden. While all sites have ecological implications, two of the locations have additional liabilities with nature trail systems passing through them (Westdale Ravine and Hickory Valley). The largest Eastern Hemlock on RBG property has a diameter of 91.1cm (DBH) and stands alone in the interior forest on the north side of Cootes Paradise.

The completion of this management strategy for Hemlock Woolly Adelgid (HWA) is part of RBG's response to the infestation first identified in 2023 and summarizes the scale of the issue, along with the financial and ecological implications. HWA is an invasive insect that attacks and kills hemlock trees (within 10 years). The predominant mechanism of long-distance spread is through bird movement and human activities involving the transport of plant material. RBG is currently one of 12 Ontario locations (and growing) where HWA has been found and, as a result, is at the forefront of Ontario's HWA infestation. It is recognized that the actions, and inactions, in managing HWA at RBG have near-term impacts throughout the province. This plan outlines potential short and long-term onsite integrated management strategies to slow the decline of hemlock stands and slow the spread of HWA to other locations in Ontario. Providing time for broader management actions to be prepared by other stakeholders and land managers in Ontario, including a plan to release biocontrol agents in the province is critical. RBG acknowledges the importance of maintaining biodiversity, but the long-term persistence of Eastern Hemlock at RBG is in question based on climate modelling scenarios by Natural Resources Canada.

Communication and collaboration are essential in sustaining the ecological integrity of Eastern Hemlock's unique ecosystems in Ontario. This document presents detailed management and control options for HWA available in Ontario at the end of 2024, and its informed management approaches are taken by leading agencies from the United States, Nova Scotia, and the Ontario Invasive Species Centre's up-to-date management guide. Recommendations are presented in response to the current infestation on RBG lands. RBG's strategy and associated actions will be updated as new information emerges. Response prior to completion of this strategy, includes 16 trees injected with TreeAzin along Caleb's Walk Trail, and the installation of CFIA regulatory signage at all trailheads near hemlock stands.

Management practices presently available in Ontario are HWA control using pesticides and silviculture techniques. These are temporary, short-term solutions that may help slow the spread and reduce the impacts of HWA but are not viable long-term solutions as the pest persists. Various approaches and/or levels of management exist under each of these options. Biocontrol, which is not currently approved for use in Ontario, is the only promising long-term management option for Hemlock Woolly Adelgid (HWA).

Management Recommendations

Based on review of options in this report, an integrated management approach is recommended. Actions are as follows:

Short-term

- Complete a detailed inventory of Eastern Hemlock and the status of HWA across the property.
- Trees will receive an initial treatment with a pesticide, as they become infested with HWA, to slow the invasion front. The recommended pesticide is TreeAzin, the only non-neonicotinoid option currently available.
- Develop a site-specific restoration plan which includes a list of native plants reflective of a changing climate.
- Build partnerships with stakeholders involved in the monitoring and management of HWA.

Long-term

- Undertake restoration at hemlock sites impacted by HWA.
- Pesticide treatments may be completed biennially based on funding and regional status of the HWA infestation. Ongoing treatment will be based on criteria outlined in this strategy. For example, primary focus will be on trees located along nature trails followed by trees with a designated status (ex. Biological Legacy Trees aka. Heritage Trees or critical habitat tied to a Species-at-Risk), and tree stands vital to maintaining cool creek temperatures.
- As the only long-term option currently available is adelgid control through natural predation, RBG's goal is to actively seek a partnership with the appropriate research agency to collaborate on experimental biocontrol work.

Budget Estimate: $125,000 in contractor costs plus RBG staff time for initial treatment of all hemlock in as they become infested with Hemlock Woolly Adelgid (using TreeAzin).

Short-term: Initial treatment with TreeAzin at the current invasion front is expected to cost approximately $35,000, plus staff time, for all known infested trees which is close to 300 hemlocks throughout the South Shore Forest of Cootes Paradise Nature Sanctuary and approximately 40 trees on the North Shore Forest by RBG's Arboretum. This estimate is based on the cost of TreeAzin in 2024. Staff time will be required to complete inventory and monitoring for HWA for RBG properties beyond the South Shore of Cootes Paradise. Additional costs will incur as new HWA infestations are found. Staff time to monitor the success of treatments and communicate our management strategy with stakeholders is also required.

Long-term: For treatments to remain effective, biannual injections are required. Should treatments continue, RBG will stagger treatments to divide costs between years and treat trees using prioritization criteria outlined in this report. Restoration costs will ensue as trees succumb to HWA and costs (staff time, plant materials and fencing) will vary based on the number of invasive plants that colonize the site and size of area required for planting. The costs of establishing biocontrol are currently unknown as this management strategy is at the very early stages of research and implementation in Canada.

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Introduction and Background

Hemlock Woolly Adelgid

Distribution and Abundance

Hemlock Woolly Adelgid (HWA) is a destructive, aphid-like, invasive insect that attacks and kills hemlock trees in eastern North America. Native to Japan, HWA was first reported in Eastern North America in the 1950s in Richmond, Virginia (Souto et al. 1996). It attacks hemlocks causing death within 4-10 years (Preisser et al. 2014). The predominant mechanism of spread is via bird movement and anthropogenic activities involving the movement of plant material. It is plausible that localized spread may also be linked to the movement of animals. By the end of 2024, on the east coast of North America, the insect can be found from Georgia to Maine, through southwestern Nova Scotia, and sporadically through southern Ontario in 9 different regions, RBG's Cootes Paradise Nature Sanctuary being a site associated with the Hamilton region (Figure 1 & **Error! Reference source not found.**).

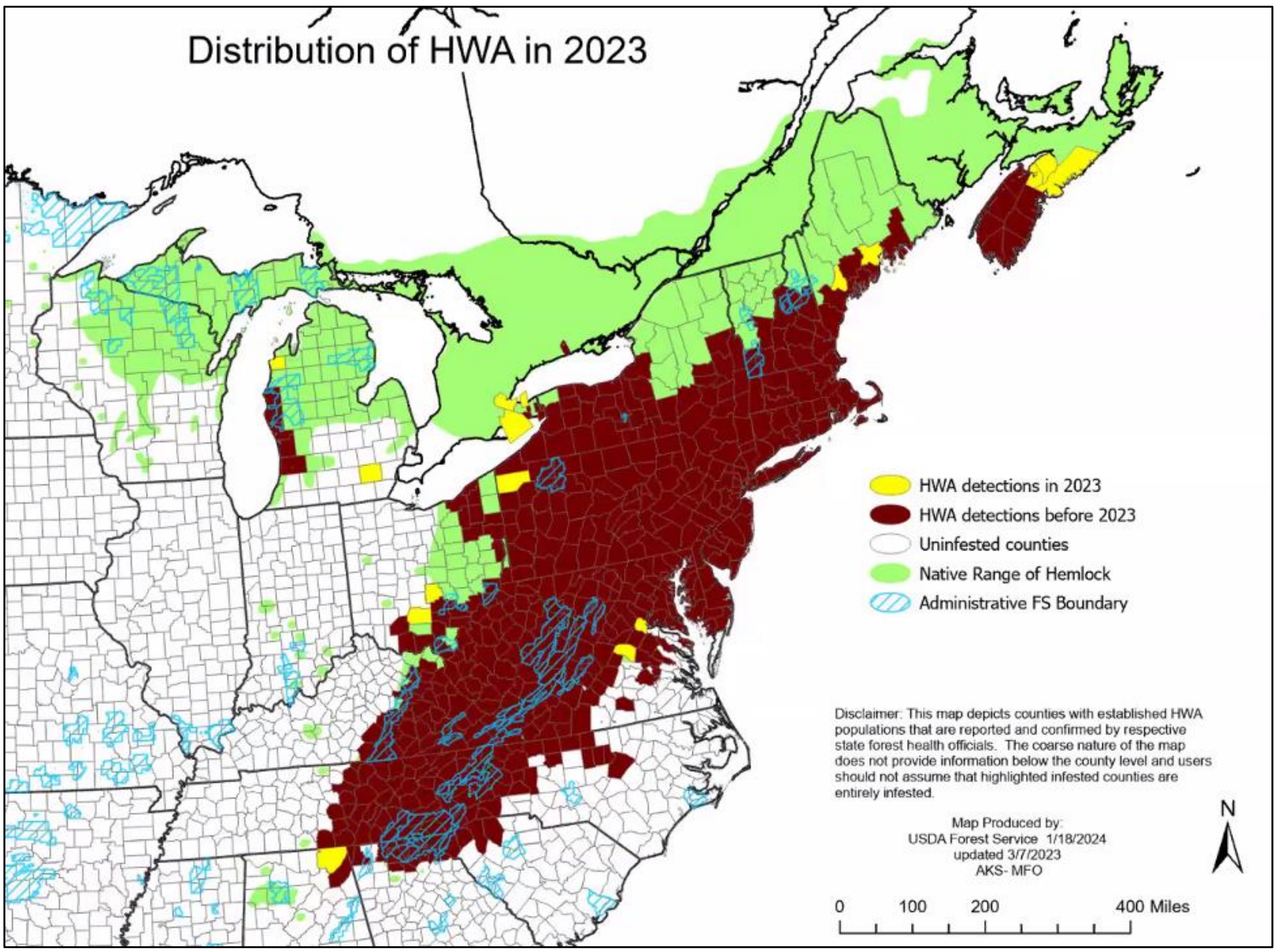

Figure 1. Time period of HWA establishment across Eastern North America (source: USDA Forest Service, 2024)

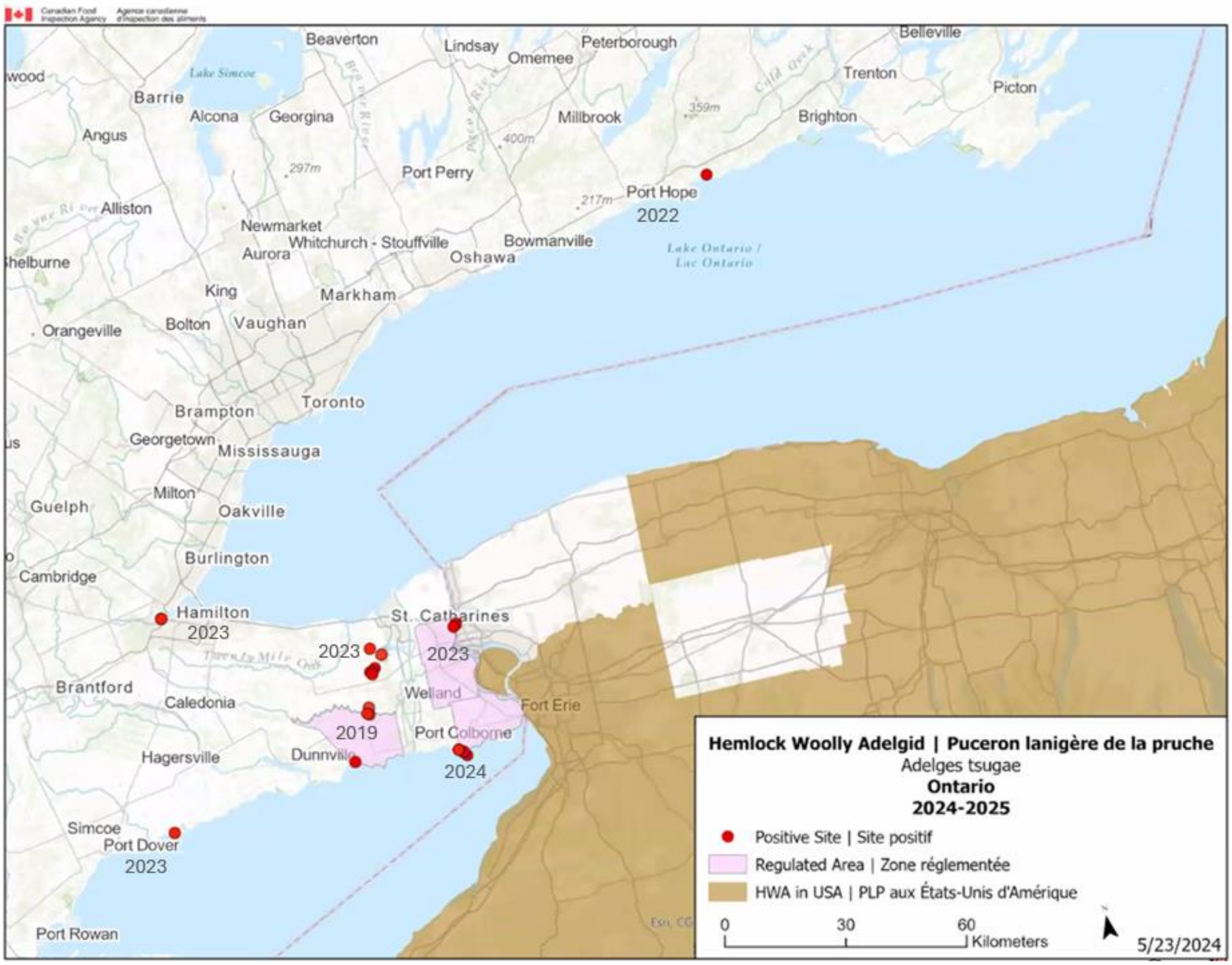

Figure 2. Distribution of HWA in Ontario (source: Canadian Food Inspection Agency, dates by RBG).

HWA was first detected in Ontario in 2013 in Niagara Falls, at the Niagara Glen. It was successfully eradicated, but despite valiant efforts, the spread of HWA has continued throughout the province. HWA was first detected on RBG property in March 2023 in a stand of Eastern Hemlock trees on the South Shore of Cootes Paradise Nature Sanctuary in the Westdale Creek ravine at Caleb's Walk trail. Upon detection, RBG notified the Canadian Food Inspection Agency (CFIA) who confirmed the infestation and issued a prohibition of movement of all hemlock trees (and any plant parts) located within the Cootes Paradise Nature Sanctuary, including both the North and South Shore properties. The infestation spans multiple properties including the City of Hamilton, McMaster University, and various private landowners. Some trees are severely infested hemlock decline is evident. Several trees have already died from the impact of HWA. Recent (2024) visual surveys from RBG have confirmed the infestation has expanded to three different hemlock stands within the Cootes Paradise nature sanctuary (Figure 3). RBG conducted formal visual surveys on the South Shore and found another site 800 metres from the original site. The third site was discovered in November (2024) while staff made an impromptu check for HWA with binoculars at a hemlock stand along Hickory Valley Trail. During the visual inspection, heavily HWA-infested branches were observed. This detection was the first to be found across the marsh on the North Shore of Cootes Paradise. Formal surveys for the rest of RBG's nature sanctuaries are scheduled for 2025.

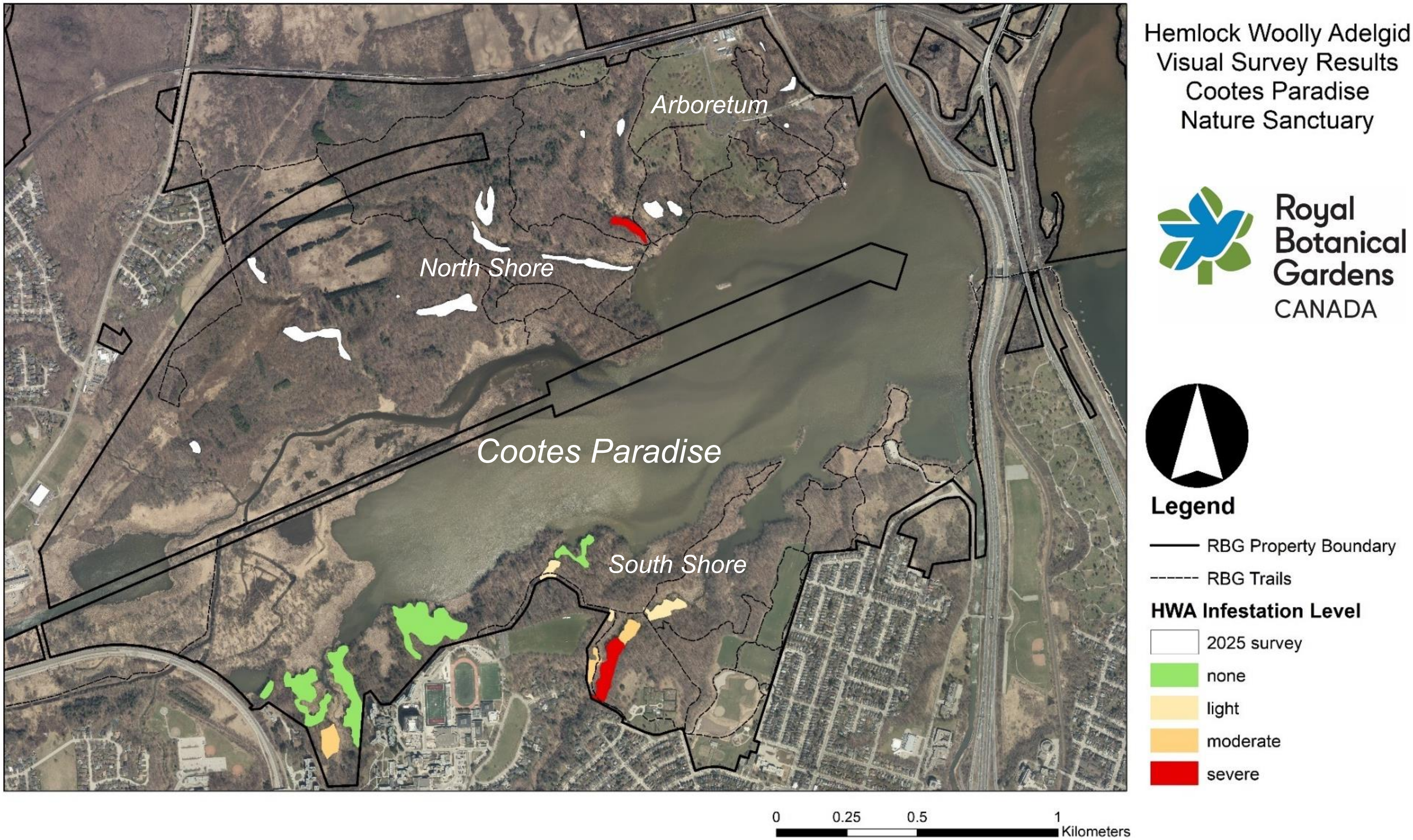

Figure 3. Map of HWA distribution and severity of infestation in hemlock stands throughout Cootes Paradise Nature Sanctuary visually surveyed by RBG in 2024. White polygons represent hemlock stands that have not yet been visually assessed for HWA and are scheduled to be surveyed in 2025.

HWA is expected to spread throughout Ontario, resulting in decline and eventual mortality of Eastern Hemlock. RBG is at the leading edge of invasion to the region and thus, it is critical that RBG develops a thorough and robust plan to manage HWA, whilst acknowledging our responsibility for ecological stewardship for our forest assets and for the rest of Ontario. This document presents all options available to RBG in response to HWA and provides specific recommendations and rational for moving forward.

Description

HWA is easily identified through its woolly appearance, both adults and egg sacs have a cotton ball-like appearance (Figure 4). Adults are very small and often look like flakes of black pepper, measuring less than 2mm long. Their defining feature is its cotton ball-like egg sac, which is laid on the underside of hemlock branches, with each egg sac containing up to 200 eggs. Upon hatching, the first instar nymphs (aka “crawlers”) begin feeding on the hemlock needles. The “crawler” stage is the timeframe of greatest risk of HWA spread across the landscape.

HWA feeds on hemlock trees by inserting a piercing feeding apparatus into the base of hemlock needles and feeds on the nutrients stored in the xylem (Havill et al. 2014). In the process, HWA not only starves the tree of its nutrients, but is also believed to restrict water movement through the tree (Havill et al. 2014). HWA prefers to feed on new needles, which leads to progressive needle loss – which is often first observed in the lower and central portions of tree crowns. This causes the eventual death of the tree sometime between four and ten years after the pest begins feeding. Unfortunately, trees lack any natural defense against HWA (Havill et al. 2014) and once HWA begins its attack, trees do not recover and eventually perish. Certain ecological factors can prolong a tree’s fateful battle, such as reliable and stable moisture availability (Havill et al. 2014).

Figure 4. HWA on hemlock needles. Photos from right to left: HWA crawlers feeding at base of needles; woolly egg secs (May); woolly egg sacs (March).

HWA shares many biological characteristics with its relatives in the Aldelgidae family, both Aphididae (true aphids) and Phylloxeridae (phylloxerans). One of the most complex characteristics of HWA is its life cycle, featuring both sexual and asexual generations. However, in eastern North America, only asexual reproduction occurs.

HWA was first identified as a unique species in the early 1920s from infestations on Western Hemlock (*Tsuga heterophylla*) in the Pacific Northwest (Annand, 1924). The adelgid is genetically diverse through its native range, and different genetic lineages are closely associated with specific regions and host plants. The HWA present in the Pacific Northwest is genetically different from the HWA population in Asia. The invasive population in Eastern North America is genetically related to the HWA population found in Asia, which originated from low-elevation populations infesting *Tsuga sieboldii* (Southern Japanese Hemlock) in Japan (Havill et al. 2006). HWA was first reported in eastern North America in the 1950s in Richmond, Virginia (Souto et al. 1996). Initially, it was assumed that HWA was only a pest to ornamental specimens, however by the 1980s, the adelgid began its attack on native hemlocks in forested ecosystems (Preisser et al. 2014). Presently, on the east coast of North America, HWA can be found from Georgia to Maine, through southwestern Nova Scotia, and sporadically through the southern Ontario. It has been estimated that the current extent of the HWA-infestation is "more than 10,000km^2 across North America" (Ellison et al. 2018).

Life Cycle and Mechanisms of Spread

In North America, there are two generations and three forms of HWA. The two generations that that occur on hemlock trees are sistens and progrediens, all of which are female and reproduce asexually. The second generation of HWA can produce two forms: progredient adults (wingless and remain on hemlock) or sexuparae (which have wings and migrate to spruce trees). At this time, sexuparae do not survive on native spruce or spruce trees from their native range that have been ornamentally planted in North America. Therefore, the sexuparae form of HWA is not important to the infestation of HWA in North America.

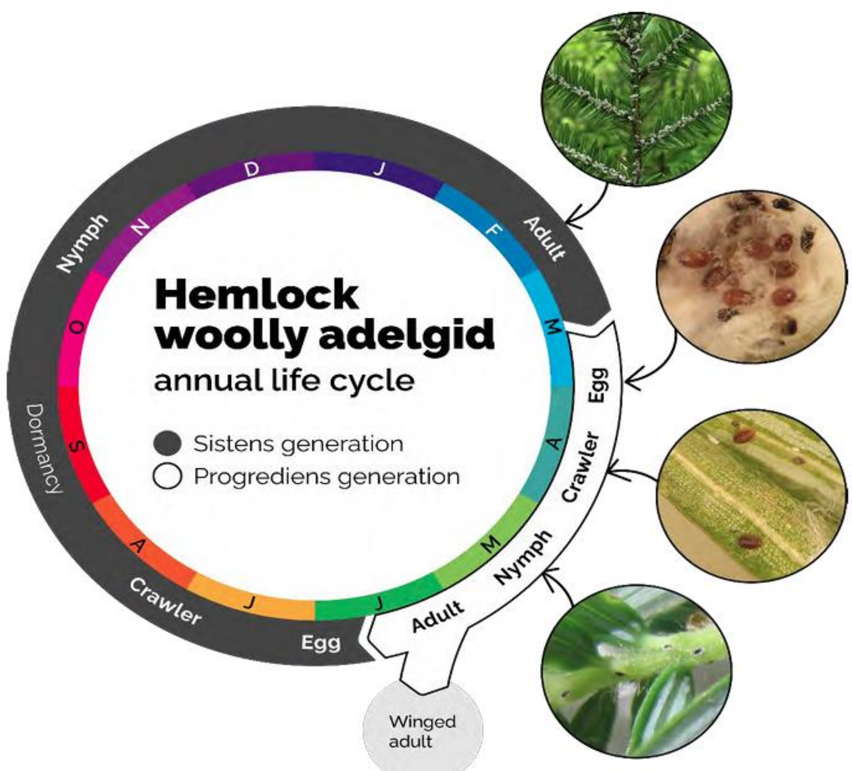

Figure 5. The life cycle of HWA by season in Eastern Canada (Parker et al. 2023).

The sistens and progrediens are easily split based on their presence on hemlocks. Sistens, often referred to as the “overwintering generation”, are present from June until the following March. The progrediens, or the “spring generation”, are observed on hemlocks from March until June. As seen in Figure 5, HWA has six developmental stages: eggs, four nymphal stages (including crawlers), and adults (Cheah et al. 2004; Parker et al. 2023). The most concerning stage of the HWA lifecycle occurs during the crawler stage, which is when the crawlers can attach themselves to humans or wildlife and travel great distances.

Natural spread of HWA during the crawler stage via rain, wind, or mammals is considered localized (under or equal to 30km/year), however there are a few cases of natural dispersal occurring over much larger distances (Emilson et al. 2018). Bird migration and movement is a major dispersal mechanism, as HWA and crawlers can attach to birds, which allows for much larger range dispersal to un-infested areas (McClure 1990, Russo et al. 2016).

Factors Impacting HWA Population Levels

The cold temperatures in North America are known to suppress populations and restrict the range expansion of various forest pests (Bleiker and Smith 2019; Lesk et al., 2017; Regniere et al., 2008; Cuddington et al. 2018). However, a changing climate and warmer winter temperatures may remove this control from forest pest populations. Studies have shown that HWA populations experience increased and significant mortality at winter temperatures below -25°C (Skinner et al. 2003), and a recent study based in Ontario noted that a single night cold spell of a temperature just below -20°C impacted the survival of HWA (MacQuarrie et al. 2024). Although high mortality rates were observed during the study, levels did not reach the required 90% mortality to maintain static population levels (Paradis et al. 2007). However, cold event mortality combined with biological control or insecticide use would decrease HWA population levels (MacQuarrie et al. 2019).

Eastern Hemlock

Eastern Hemlock (*Tsuga canadensis*) is the only hemlock tree native to eastern Canada and a prominent tree in the cool damp forests of the “Cottage Country” region of Ontario - Algonquin Park, Muskoka, and Parry Sound. This species is often nicknamed the ‘redwood of the east’, with a potential maximum age of 1,000 years and reaching 150ft in height, it is a beloved forest giant across eastern North America with a rich of connection to Indigenous Peoples. Hemlocks are known to be excellent at carbon sequestration and temperature regulation. At RBG, the Eastern Hemlock is predominantly limited to the shaded, cool, north facing slopes of ravines (Figure 6).

Figure 6. Eastern Hemlock at Caleb's Walk, Royal Botanical Gardens, 2023, and site of the original discovery.

Range and Distribution

Eastern Hemlock's native range extends from Nova Scotia to Minnesota and Missouri, and south to Georgia and Alabama. It is the only hemlock native to eastern Canada. Climate Change is expected to dramatically shift its range north, and potentially out of southern Ontario (Natural Resources Canada, 2023).

In Ontario, Eastern Hemlocks can be found growing throughout Southern Ontario, with smaller populations in Algoma across to Northwestern Ontario, near the Ontario-Minnesota border. In a forest community it is often found growing near Yellow Birch and Sugar Maple on cool, moist soils near water.

Preliminary information on the distribution of Eastern Hemlock throughout RBG's nature sanctuaries prior to the detection of HWA was held within RBG's Ecological Land Classification (ELC) surveys and mapping database. ELC polygons with Eastern Hemlock present in the canopy or sub-canopy layers were mapped based on their abundance to determine where hemlocks are distributed. Hemlock stands were then mapped more precisely using a combination of aerial image interpretation and ground-truthing to map distinct hemlock stands within RBG's nature sanctuaries (Figure 8).

In 1972, Eastern Hemlocks were inventoried as 1,581 trees within the property (RBG Bulletin 1972). Overall, it is estimated that currently 1,213 Eastern Hemlock trees of all ages are found in thirteen principal areas, a decline in number from 1972. Current areas include approximately four sites on the south side of Cootes Paradise, four sites on the north side with individual trees scattered throughout the property, three locations in Hendrie Valley and one site at Burlington Heights by the Rock Garden. Hemlocks are suspected at Rock Chapel; however, their location and presence have not been confirmed. Each site may have several stands of hemlock forest, and most sites are associated with a specific ravine corridor on the property. The hemlock stands on the South Shore have been surveyed, and the number of trees is accurate, however, the rest of the property remains to be surveyed therefore the number of trees is an educated estimate. These stands will be surveyed in 2025. The largest Eastern Hemlock tree on RBG property has a diameter of 91.1cm (DBH) and interestingly stands alone (away from other hemlocks), in the interior forest on the North Shore of Cootes Paradise.

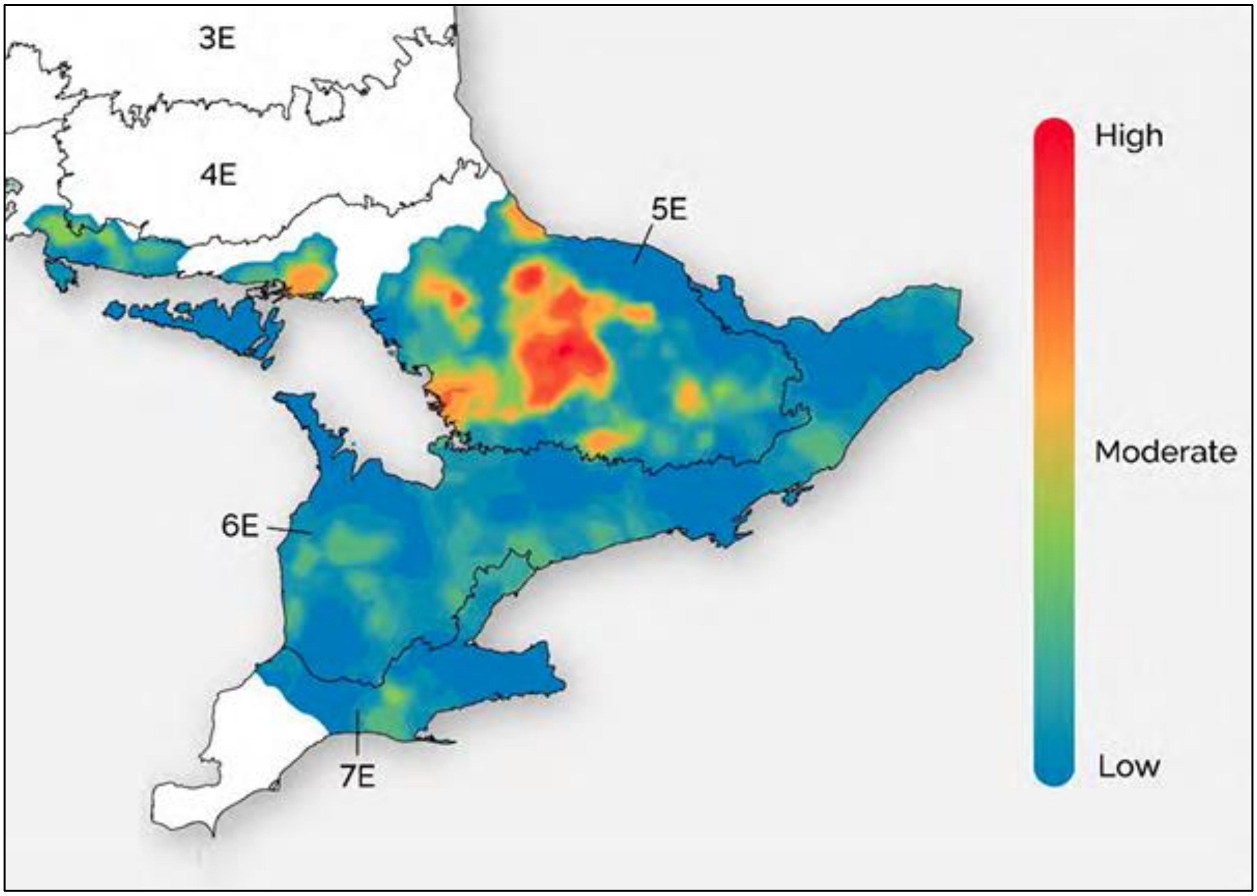

Figure 7. Relative abundance of Eastern Hemlock in Ontario by ecoregion (Parker et al. 2023). White portion of the map is outside the natural range of Eastern Hemlock.

Table 1. Summary of hemlock stands across RBG properties.

Locations	Approximate Number of Sites	Approximate Area (ha)	Estimated Number of Trees	Trees >75cm DBH* Present?
South Shore	4	9.7	717	Yes
North Shore	4	5	300	Yes
Hendrie Valley	3	1.2	65	Yes
Escarpment	1	n/a	10	n/a
Burlington Heights	1	0.4	15	n/a
Gardens	n/a	n/a	106	n/a
Totals	**13**	**16.3**	**1,213**	**Yes**

**DBH = diameter at breast height*

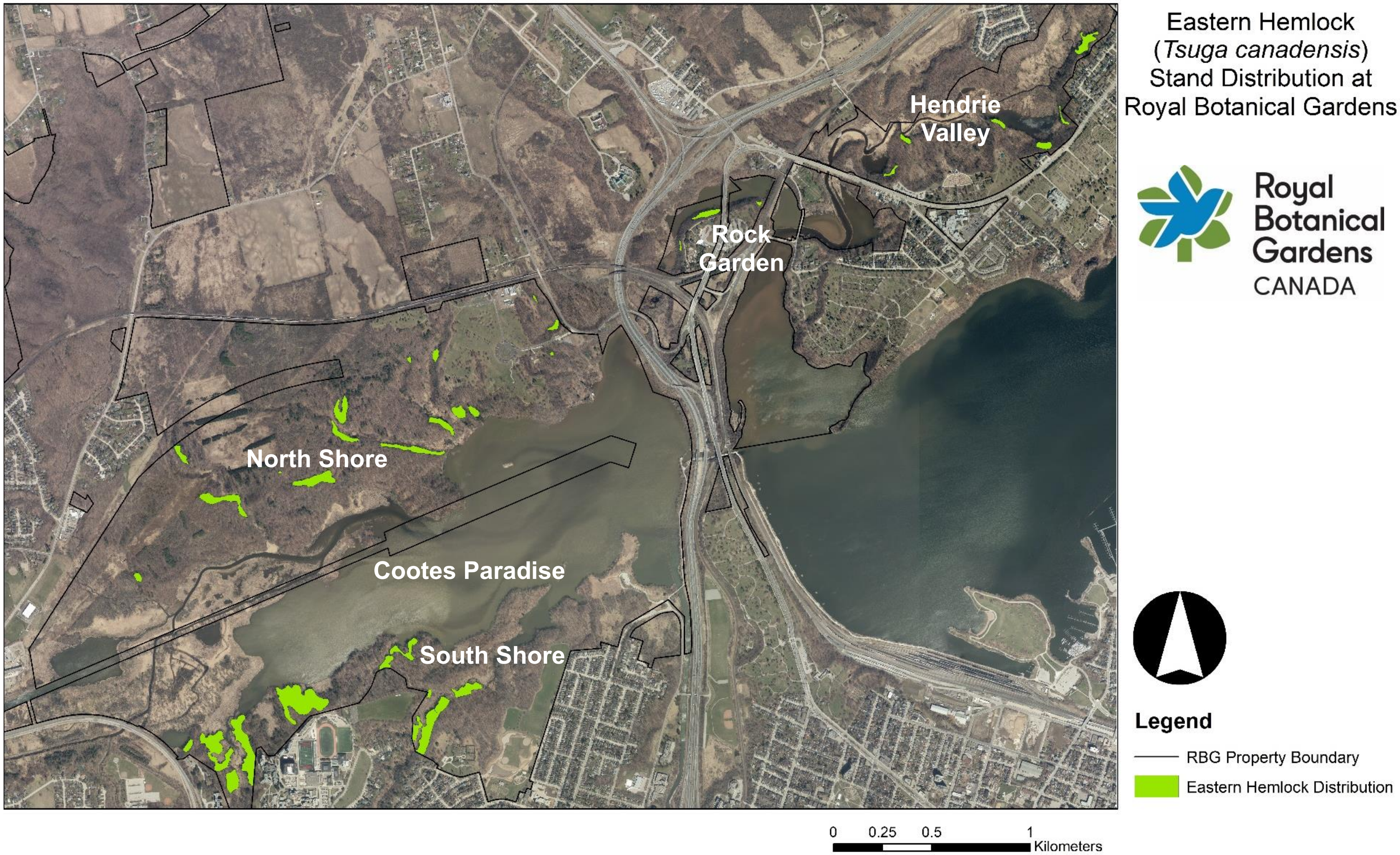

Figure 8. Map of the stand distribution of Eastern Hemlock throughout RBG's nature sanctuaries. Note that Rock Chapel Nature Sanctuary is not shown on map.

Figure 9. Map of planted Eastern Hemlock (highlighted blue) by RBG Garden Area from all plant records.

At RBG, there are 102 individual hemlocks of various species, planted throughout the cultivated gardens. The locations of these accessioned plants are Rock Garden, Laking Garden, Hendrie Park, Main Centre, Arboretum, (Figure 9) and Teaching Garden. RBG's Horticulture Department will be responsible for monitoring their specimens for HWA, and treating, if necessary.

While all hemlock sites have ecological implications, two of the locations have additional liabilities with nature trail systems passing through them (Westdale and Hickory Valley).

Identification

Eastern Hemlocks are extremely shade tolerant and are considered the most shade tolerant tree species in North America (United States Department of Agriculture). Generally, a slow growing tree, Eastern Hemlock can remain in the understory between 25 and 400 years (United States Department of Agriculture).

Growing nearly 30 meters tall, Eastern Hemlocks have a broadly conic crown with branch tips that droop at the ends. The trunk of the tree is wide at the base and tapers at the top, with deeply furrowed bark. Needles grow singly (not clustered), and are 1-2cm long, flat, evergreen with shiny green hue on top and pale underneath. Eastern Hemlock cones are small, ranging from 12mm to 20mm in length.

Eastern Hemlocks reach sexual maturity around 15 years of age, and bear both female and male flowers. Male flowers are present from April until early June in light yellow clusters at the axis of needles from the previous year. Bud scales then surround the male flowers to form a tiny male "conelet". Female flowers are shorter and develop on the terminals of the preceding years' branchlets, developing into conelets, which are then pollinated by the wind (Adirondacks Forever Wild, 2023). Following pollination, conelets exhibit a drooping position, and the light green cones slowly turn into brown cones. The fertilization process occurs over the course of around 6 weeks. These pollinated cones remain soft and flexible until the release of the seeds in the late fall and early winter.

Figure 10. Eastern Hemlock reproductive parts. From left to right: fertile male conelet; male conelet post-fertile period; developing fertile female conelet; previous year opened female conelet.

Role in the Forest Community

The dense foliage of Eastern Hemlocks cast cooling shadows on the forest floor, creating diversity in microhabitats within a forest community. It is a vital shade tolerant 'foundation' species (a species that defines the forest structure) that help stabilize streambanks (Ford and Vose 2007) and maintains cool temperatures in headwater streams that are home to trout along with a wide variety of diverse aquatic invertebrates (Orwig and Foster 2000), and diverse assemblage of salamanders (Havill et al. 2014). Ross et al. 2003 found that streams near hemlock forests were three times as likely to contain Brown Trout and Brook Trout than streams in hardwood forests.

Certain bird species like Blue-headed Vireo, Acadian Flycatcher, Blackburnian Warbler, and Black-throated Green Warbler (and up to 90 others) are hemlock obligates, and only occur in forests with hemlocks (Havill et al. 2014; Hemlock Restoration Initiative).

During the winter months, hemlock's dense foliage and grove-like structure of stands create a haven for deer to escape the snow, as well as protection for birds. Hemlock foliage is also an important food source in eastern forests, especially during the winter when deciduous trees are dormant and lack leaves.

Eastern Hemlocks' dense canopy intercepts precipitation, which prevents sedimentation, thereby reducing erosion (Hemlock Restoration Initiative). Many of RBG's hemlock stands line slopes alongside trails. Upon the death of these trees, many dead standing hemlocks will need to be removed to ensure trail user safety. Removing all dead hemlocks in a stand increases the likelihood of erosion on the slopes, which will be cause for slope stabilization projects and plantings.

Significance in Indigenous Culture

Eastern Hemlocks are respected trees in Indigenous communities, and are still used in traditional methods today, as the tree provides material for building and medicine. Medicinally, Eastern Hemlock was used to treat various ailments including colds, coughs, fever, skin conditions, pain, rheumatism, arthritis, and scurvy (Adirondacks Forever Wild, 2023). Hemlock bark was often boiled to make a paste to promote wound healing (University of Vermont, 2022). Tea made from the needles of hemlocks were also important in the diets of Indigenous Peoples, as the tea has a high level of vitamin C (Nesom, 2012). The cambium of hemlocks was often used as a base for breads and soups and often mixed with dried fruit and animal fats for pemmican (United States Department of Agriculture). Dead hemlock logs also host reishi mushrooms, which is one of the most important medicinal mushrooms for Indigenous Peoples (O'Driscoll, 2024).

The Eastern Hemlock is also featured prominently in Indigenous Peoples' storytelling and ceremonies. Themes of the stories often involve Eastern Hemlock representing refuge, warmth, and new hope. The Seneca story "Okteondo and his Uncle" (Andrew Johnny-John) features hemlock boughs to keep characters warm at night, used for both sleeping on and shelter.

Carbon Sequestration

The mechanisms and physiology behind a species' decline and eventual degradation have a direct influence on the carbon cycle, and HWA infestations rapidly impact the carbon cycle (Nuckolls et al. 2008). The Eastern Hemlock is a key component in the carbon dynamics in forested ecosystems due to several characteristics: long-lived trees (lifespan up to 1,000 years), potential growth height of more than 150ft, a DBH of greater than 6 feet, greatest producer of leaf litter than any other species of similar DBH, and a volume of 1,000 cubic feet (Ward et al. 2004, Thompson 2000, Finzi et al. 1998). These features enable hemlocks to store considerable amounts of carbon not only in their biomass and leaf litter, but also in soil for longer periods of time when compared to co-occurring species (Finizi et al. 1998).

When large hemlock mortality occurs, large logs on the forest floor are created, which slows decomposition due to their small surface area to volume ratio (Zell et al. 2009), as well as a higher heartwood to sapwood ratios (Herrmann and Bauhus 2008), allowing the logs to hold carbon longer than other species. Another reason for slower decomposition post-mortality, is the high lignin percentage (Meillilo et al. 1989) and high tannic acid that then decreases soil pH, thus slowing decomposition and continuing carbon storage for extended periods (White 1991).

To confirm the characteristics of hemlocks and their importance in carbon storage, a 1998 study in Connecticut confirmed that Eastern Hemlock had the greatest carbon storage capacity in the soil and forest floor (10.8 ± 0.6kg C/m^2) in Eastern North American mixed forests, followed by Red Oak, Red Maple, American Beech, and White Ash (Finzi et al. 1998).

Hemlocks not only act as houses for carbon storage but also play a critical role in sequestering carbon from the atmosphere (Krebs 2014). Comparing sequestration ability between deciduous forests and hemlock stands, it has been shown that the evergreen nature of hemlocks allows for continuous and higher carbon sequestration rates in the early spring and late fall than deciduous forests (Hadley and Schedlbauer 2002, and 2008).

As unsustainable levels of anthropogenic carbon emissions continue to increase atmospheric CO_2 concentrations, it is critical that effective ecological carbon sinks that are known to absorb atmospheric carbon should be protected. Therefore, the protection of Eastern Hemlock is a critical step in maintaining an ecosystem's ability to hold carbon during the climate crisis to reduce atmospheric CO_2 levels.

Habitat for Species-at-Risk

With any work that occurs at RBG, impacts to at-risk species must be considered. RBG's nature sanctuaries span between a coastal marsh and the Niagara Escarpment within the Carolinian Forest Zone, and because of this unique array of habitat, RBG is home to over 50 different Species-at-Risk (SAR) (Theysmeyer, 2022).

The Acadian Flycatcher, a SAR listed as Endangered nationally and provincially, nest in mature deciduous forest ravines that are dominated by oak-hickory forests near streams often shaded by Eastern Hemlock (Curry 2006; Allen et al. 2020). The Acadian Flycatcher was last detected at RBG in 2015 but has not been found during the breeding season since. However, RBG's properties remain critical habitat for this species and RBG has been working toward creating and maintaining suitable habitat for Acadian Flycatchers by removing invasive shrubs and trees from the forest understory.

Few-flowered Club-rush (*Trichophorum planifolium*) is also listed as an Endangered plant nationally and provincially. The only remaining club-rush populations in Canada exist on RBG property. It is an herbaceous perennial sedge that grows in dense tufts and most of the known plants at RBG occur in the open understory of mature oak forest on well-drained soil and within 20 meters of a watercourse or wetland edge (Iwanycki et al., 2010). While oak canopy is the main associate for Few-flowered Club-rush, it is documented, through Ecological Land Classification, that some plants exist within Dry-Fresh Hemlock-White Pine Mixed Forest Ecosite. There are three main concerns that must be addressed regarding SAR and the management of HWA: non-target pesticide exposure, trampling SAR plants during treatment, and maintaining quality habitat for SAR.

 

Figure 11. Hemlock-associated SAR at RBG. Left: Acadian Flycatcher in nest on the branches of an Eastern Hemlock tree. Photo by Andrew Weizel. Right: Few-flowered Club-rush clump in flower.

Stakeholders

Currently, Cootes Paradise is the only known HWA infestation area in Hamilton. RBG, the City of Hamilton, McMaster University, and private landowners are the land stewards responding to the HWA infestation. Nearby to the west, Hamilton Conservation Authority is the steward of thousands of hemlocks in the Dundas Valley Conservation Area. The Hamilton Naturalists' Club is also responding to a separate HWA infestation on their property outside of Hamilton. It is predicted that the number of landowners in Hamilton with HWA will expand in the coming years.

Since the discovery of multiple new HWA infestations in Ontario, there has been various levels of communication between stakeholders ranging from the local to the federal level. They are outlined in Table 2. Communication with various organizations and networking with HWA specialists is critical to RBG's effective rapid response to this invasive forest pest.

Table 2. Stakeholders in RBG's HWA infestation and treatment options. Additional stakeholders will become involved as research opportunities arise.

Federal	Provincial	Municipal/Local
Canadian Food Inspection Agency (CFIA) Canadian Forest Service (CFS) Natural Resources Canada (NRC)	Ontario Ministry of Natural Resources and Forestry (MNRF) Ontario Woodlot Association Invasive Species Centre (ISC)	City of Hamilton Hamilton Naturalists' Club Hamilton Conservation Authority McMaster University Ward 1 Residents in Hamilton

Ecological Corridors in Hamilton and Burlington

The four agencies who form most of the local stakeholders in RBG's HWA infestation are also partners within the Cootes to Escarpment EcoPark System. The Cootes to Escarpment EcoPark System is a collaboration among nine government and not-for-profit agencies that collectively protect nearly 2,200 hectares of open space and nature sanctuary between Cootes Paradise Marsh, Hamilton Harbour and the Niagara Escarpment. Partner agencies manage their lands individually but collaborate on areas of mutual interest, one area of mutual interest that has been highlighted in recent projects are ecological corridors. While the benefits of ecological corridors far outweigh the disadvantages, it is important to recognize that the connected lands can act as a pathway for the spread of invasive species. Figure 12 is adapted from Southern Ontario Nature Coalition's document "Near-urban Nature Network: A Solution to Climate Change and Biodiversity Loss" and depicts how EcoPark partner lands connect to each other and important regional ecosystems.

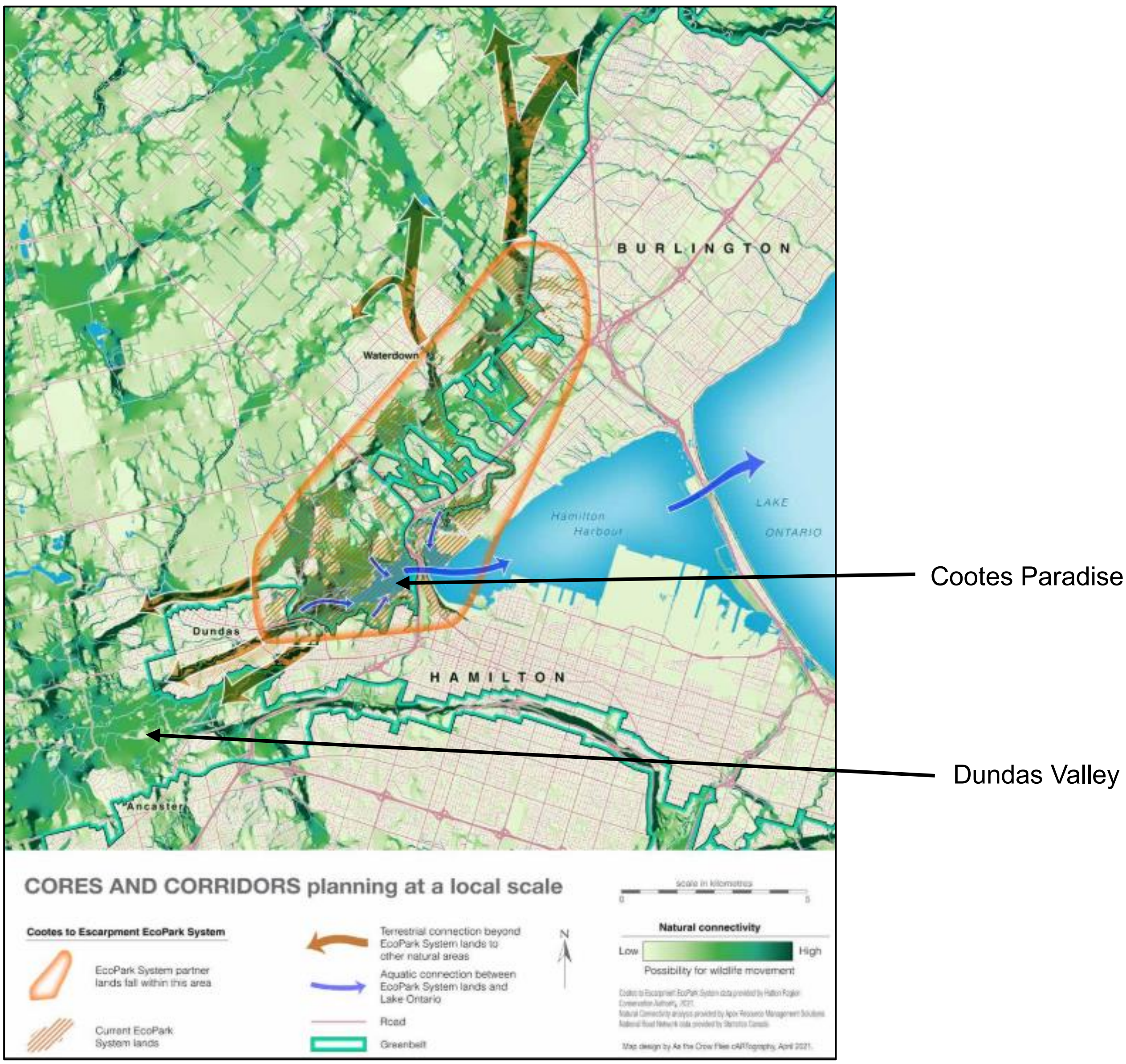

Figure 12. Cores and Corridors connected to the Cootes to Escarpment EcoPark System. Note thick arrows highlight the ecological corridors between Cootes Paradise and the Dundas Valley.

At a landscape level, partner properties are connected via ecological corridors where hemlocks play a vital role in maintaining the integrity of these connections. For example, the lower left area of Figure 12 highlights corridor connections from Cootes Paradise to the Dundas Valley (photo Figure 13) which has a significant amount of hemlock forest. The Dundas Valley contains 222 hectares of hemlock-dominated ecosystems which comprise approximately 10% of the area (Hamilton Conservation Authority, Ecological Land Classification Data). This is significantly more compared to RBG's 16 hectares. In between, along the Ancaster Creek corridor, McMaster University stewards a property known as Mac Forest, which also contains a significant stand of old growth hemlock forest. HWA will have significant and irreversible impacts on this corridor ecosystem that feeds water into Cootes Paradise Marsh. Slowing the spread of HWA throughout the ecological corridor will limit impacts on water quality and watershed sustainability.

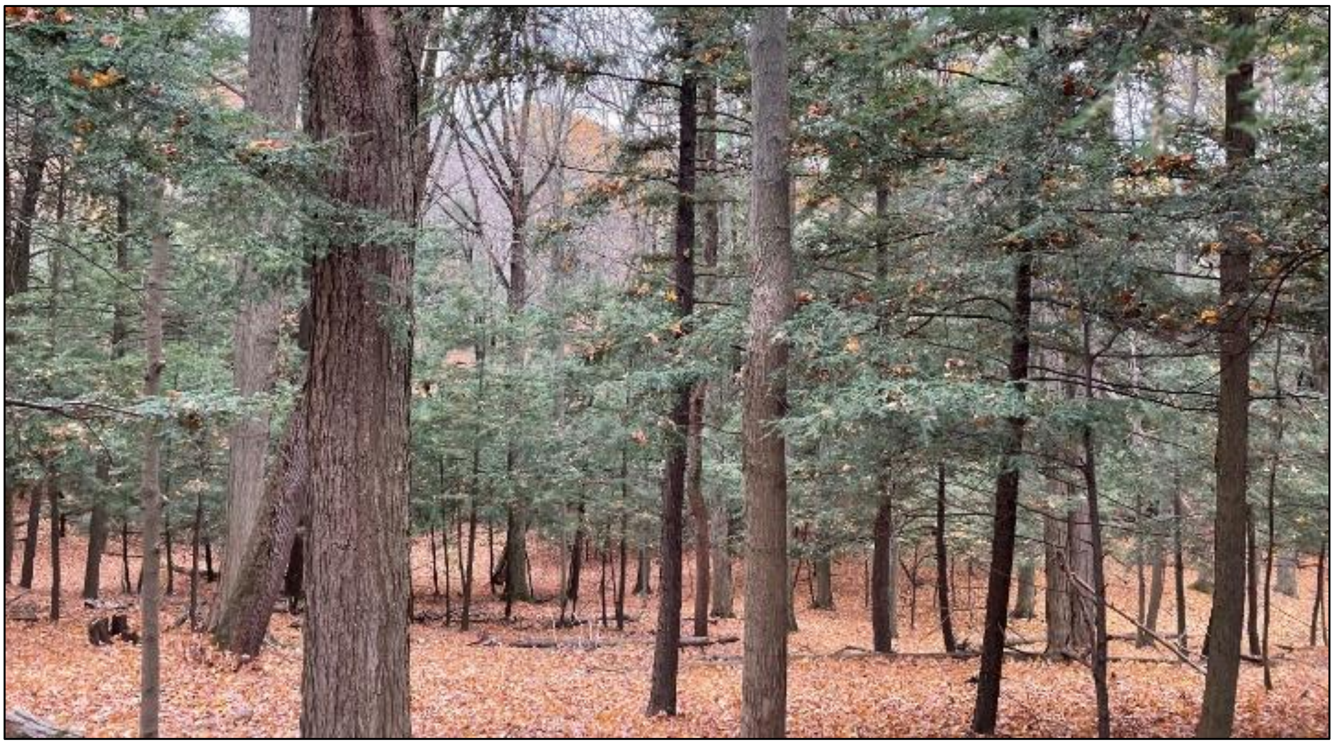

Figure 13. Eastern Hemlock Forest, Dundas Valley Conservation Area.

Climate Change and the Future of Eastern Hemlock in Southern Ontario

Overall, the changing climate is expected to largely eliminate the core range of Eastern Hemlock from Southern Ontario during the coming 50 years. Natural Resources Canada has completed distribution maps (Figure 15) based on four IPCC climate change scenarios (Figure 14) for many species, including Eastern Hemlock. For all scenarios, the core range is no longer in southern Ontario, and for the most extreme scenario, RCP 8.5, hemlock is eliminated from Southern Ontario.

Despite the potential of this species struggling in the face of climate change in the future, maintaining landscape biodiversity is a critical component in sustaining ecosystem integrity. Decisions on whether to act or not must be thoroughly scrutinized and carefully considered.

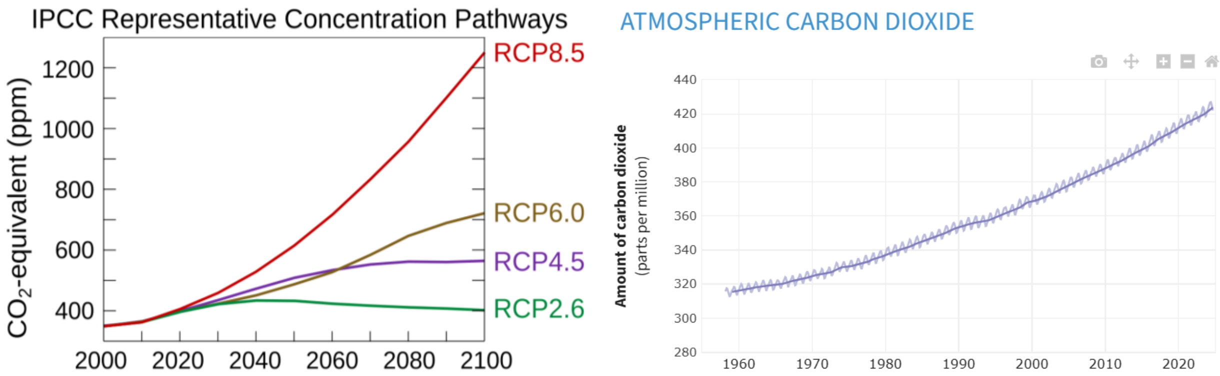

Figure 14. Intergovernmental Panel on Climate Change (IPCC) Climate Models and associated CO2 concentrations (left) and monthly mean carbon dioxide measured at Mauna Loa Observatory 1958-2024 (right).

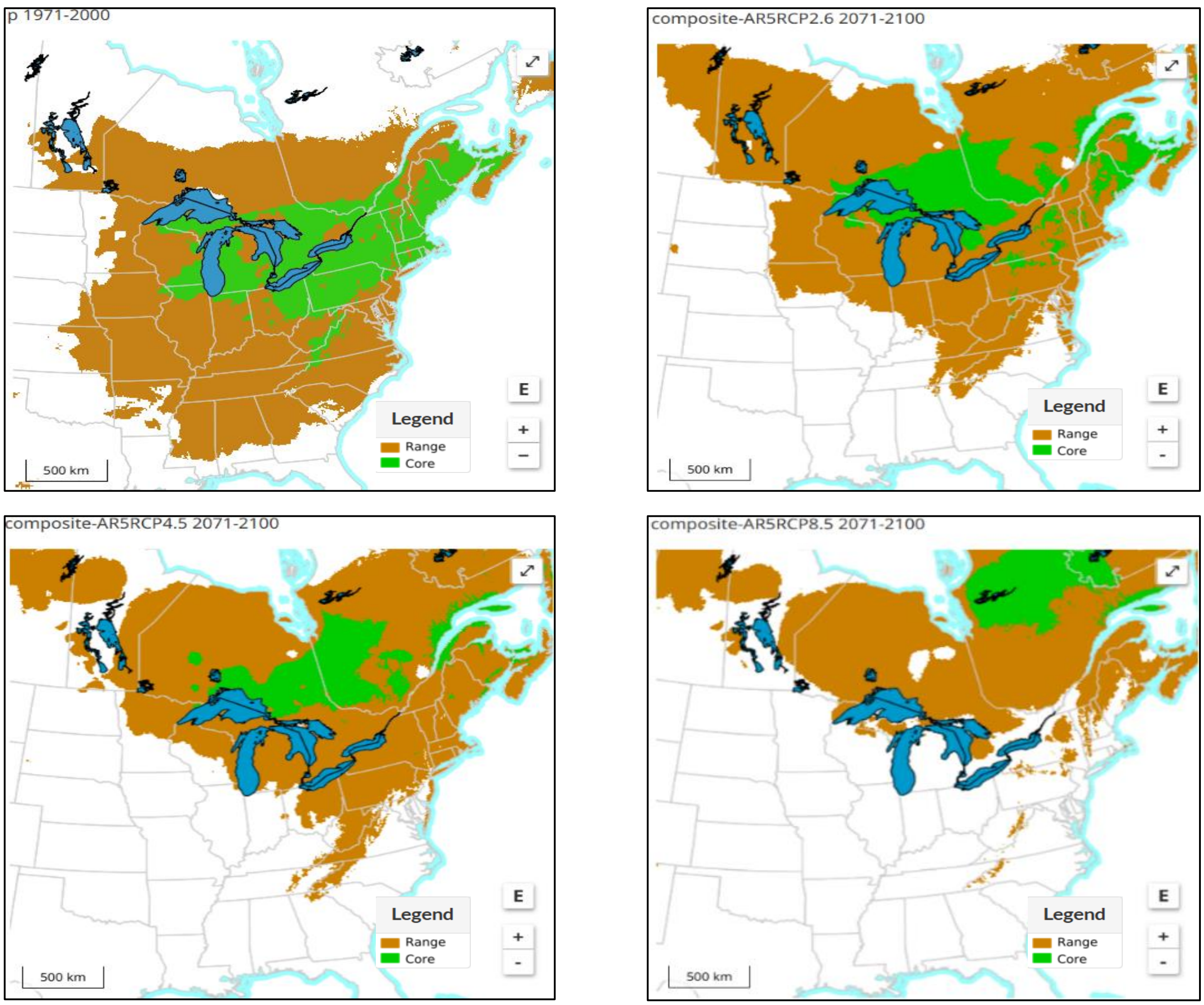

Figure 15. Current climate (1971-200) and Climate Change Models 2071-2100 for Eastern Hemlock (Tsuga canadensis). Distribution Maps Current (top left), AR5RCP 2.6 (top right), AR5RCP 4.5 (bottom left), AR5RCP 8.5 (bottom right).

Actions Accomplished to Date

Communications

Upon first detection of HWA, RBG installed signage at the location of infestation to warn trail-users of the invasive forest pest. Regulatory signage provided by CFIA were also installed near the infested site and at non-infested hemlock locations visible to the public (see Appendix A - HWA Infestation and Awareness Signs for examples). A blog was written and posted on our website and social media accounts (https://www.rbg.ca/hemlock-woolly-adelgid/).

In September 2024, RBG and other local stakeholders (McMaster University and the City of Hamilton) hosted an information session to engage private landowners in Hamilton. Information that was provided focused on outlining impacts of HWA and what they can do to help manage these impacts on their property.

Inventory and Mapping

An inventory and health assessment of hemlock stands on the South Shore has been completed. Most hemlocks are mapped, however, approximately 25% of the remaining mapped areas still require ground-truthing to confirm hemlock occurrence. Hemlocks planted in the gardens also require confirmation.

Chemical Treatment of Infested Trees 2023

Trees located at the infestation site were injected with TreeAzin. As a means of rapid response to slow the decline of Eastern Hemlock trees adjacent to RBG's Caleb's Walk Trail in the fall of 2023, RBG sought funds through the Invasive Species Centre and was awarded $5,000 for preliminary management. About $3,500 from these funds was used to treat hemlock trees, with remainder supporting signage and collaboration work. In total, 16 Eastern Hemlocks were injected with TreeAzin on October 22, 2023, using a contractor (Arborwood Tree Service Inc.). RBG prioritized hemlock trees for treatment based on criteria such as proximity to the trail and crown condition. Please see "Appendix B – Treated Trees" for a map of injected trees and full description of criteria used for prioritizing trees for treatment. Additional trees were treated in November, 2024 and a summary report for these treatments will be available in 2025.

Stakeholder Engagement

Upon detection of HWA at RBG, the Invasive Species Centre, CFIA and other agencies have requested site tours and the use of RBG facilities for training events and meetings. The funding from the Invasive Species Centre allowed RBG to host the Ontario HWA Science Working Group meeting on February 27, 2023, which was an informative session on regulation, monitoring and management of the pest. Site tours have also taken place, including a tour for CFIA staff from all over Canada, where a representative from Nova Scotia who is currently dealing with a rapidly growing population of HWA was present as well as a representative from British Columbia who is a key researcher in the biocontrol of HWA.

Hemlock Woolly Adelgid Response Options

The following is a list of objectives RBG may choose to take in response to HWA. RBG's recommended approach (presented later in this document) will be based on a combination of these objectives. Note: Eradication of HWA from the local area of Hamilton is not a viable option as the abundance of the HWA population and number of affected trees is too extensive.

No Management

Do not manage the HWA infestation and allow the invasive pest to spread. Continue to manage hazard trees in public spaces (trails) as they occur, as per RBG's Tree Risk Management Program. Caleb's Walk, Sassafras Point, Ravine Road Trail and Hickory Valley Trail will all be impacted by hemlocks that die from HWA. It is anticipated that within the next 2-6 years, all hemlock trees associated with the South Shore trails will be dead or in severe decline and require abatement action. A very recent detection on North Shore of Cootes Paradise at Hickory Valley Trail is estimated to cause hemlock dieback at 8-10 years with no intervention. Hazard tree mitigation costs are estimated between $30,000 and $40,000 based on current contractor costs plus the Terrestrial Ecologist and Terrestrial Intern's time associated with tree risk management.

The consequences of this option are profuse. There is a prohibition of movement on all hemlock materials within the Cootes Paradise Nature Sanctuary, therefore, all wood and debris will remain on site. The added abundance of woody debris and the loss of canopy cover will have negative impacts on the ecology of the site (decreased water quality, increased slope erosion, habitat loss) as well as trail-user experience. Understory plant growth will be smothered with hemlock debris and the presence of large logs will attract adventure-seeking trail users to climb on the logs. This promotes off trail use which disturbs and compacts soil. These soil impacts will cause further damage by increasing erosion and promoting the growth of invasive species leading to native plant loss and loss of biodiversity. This approach does nothing to slow the spread of this invasive species to other areas, reducing RBG's credibility as a centre of excellence in ecological stewardship.

Inventory, Mapping, and Monitoring

Undertake surveys to quantify the status of HWA and hemlock health on RBG property as the infestation progresses. Eastern Hemlock inventory data and mapping is required prior to management activities to inform management actions and quantify costs for the effective control of HWA. RBG lacks finite data regarding Eastern Hemlock on the property across nature sanctuaries. As part of safety risk mitigation, monitoring trails and property edges will occur as part of the on-going Tree Risk Mitigation Program, regardless of other options pursued.

Mapping will guide where HWA monitoring occurs. Visual surveys for HWA on the South Shore of Cootes Paradise were completed in spring and summer of 2024. The North Shore of Cootes Paradise and Hendrie Valley should follow in 2025. ELC records do not show Eastern Hemlock present at Rock Chapel or Berry Tract nature sanctuaries, however, these properties should be thoroughly surveyed to confirm hemlock absence.

Visual surveys are performed by visiting hemlock stands and looking for signs and symptoms of HWA. Branches are sampled with pole-pruners and inspected for HWA in the form of white-cottony egg sacs. Survey methods are clearly described in CFIA's HWA Survey Protocol and data can be inputted into the Community Science – Survey 123 field app. Ecological information such as proximity to water, rare species and/or Species-at-Risk, significant slopes etc. and tree health information associated with each hemlock should also be noted to guide stand treatment prioritization. Prioritization frameworks are further discussed in the following section under Chemical Control.

HWA monitoring surveys may occur on a bi-annual basis to ensure the early detection of spread to other areas. If a treatment plan is to be implemented, hemlocks that are treated should be tagged to keep track of their health throughout the management process. To monitor effectiveness of treatments, annual and/or biannual health monitoring will occur from the end of May to early June. This timeline is best for noting new growth on branch tips (presence, absence, and percent total throughout each tree), which indicates the vigor of the tree. Overall health assessment of trees should include data on canopy cover, stem integrity, slope stability, and injection sites should be monitored.

Records should be maintained by keeping a database of information collected and by updating mapping records within the GIS database should be maintained.

The cost of monitoring is the cost of staff time. It is estimated that, per year, approximately 4% of time for each Terrestrial team member will be required to completed inventory and monitoring assessments.

Control Measures for Hemlock Woolly Adelgid Populations

Presently, there are only two management practices available in Ontario for HWA control: chemical control using pesticides and silviculture techniques. These are short term solutions that may help slow the spread and reduce the impacts of HWA but are not viable long-term solutions as the pest persists. The options presented are intended to be used in the near-term (ten years) until a long-term solution is available and established in Ontario (ex. biocontrol). Various approaches and/or levels of management exist under each of these options below.

Chemical Control Options

In Ontario, there are currently five systemic chemical insecticide products available for control of HWA. Two products, TreeAzin (azadirachtin) and IMA-jet (imidacloprid 5%) are all registered for use in Canada while IMA-jet (imidacloprid 10%), Xytect 2F (imidacloprid) and Starkle 20SG (dinotefuran) are registered for Emergency Use in Ontario and Nova Scotia. These insecticides are used for the management of insect pests of forests, trees and landscape ornamentals. Table 3 provides a summary and comparison of all chemical treatment options including impacted insects, costs, timing, effectiveness and environmental concerns. Note that the information presented in this table is based on information obtained in 2024. All chemicals available, save TreeAzin, are neonicotinoids. TreeAzin and IMA-jet (5% and 10%) can only be applied by stem injections. Xytect 2F and Starkle 20SG can be applied by basal truck spray and can be tank mixed. Since xylem sap flow is essential for transporting and distributing the pesticide from the trunk to the canopy of the tree, treatment should be applied prior to severe damage to the trees and be timed for spring or fall when water uptake by the trees is greatest (Havill et al. 2014). Currently, RBG's pesticide policy prohibits the use of neonicotinoids on the property due to the broad sweeping devastating effects to the insect community. All chemical treatment options should be considered, however, TreeAzin will be the primary chemical used for any initial chemical treatments. To remain effective, TreeAzin needs to be applied every two years.

Table 3. Chemical treatment options for controlling HWA available in Ontario, 2024

Product Name	TreeAzin	IMA-jet 5%	IMA-jet 10%	Xytect 2F	Starkle 20SG
Active Ingredient	Azadirachtin (5%)	Imidacloprid	Imidacloprid	Imidacloprid	Dinotefuran
Registrant	Lallemand Inc.	Arborjet Inc.	Arborjet Inc.	Rainbow Ecoscience	Mitsui Chemical Agro Inc.
Status	Registered - No. 30559	Registered - No. 31375	Emergency registration (exp. Dec. 31, 2028)	Emergency registration (exp. August 23, 2027)	Emergency Registration (exp. October 12, 2024 – extension requested)
Classification	Commercial	Commercial and Restricted	Commercial and Restricted		
Description	Microinjectable systemic insecticide containing azadirachtin used to manage various insect pests of trees.	Microinjectable systemic insecticide. Broad spectrum insect control	Microinjectable systemic insecticide. Broad spectrum insect control	Basal trunk spray for control of HWA. Broad spectrum insect control	Basal trunk spray for the control of in forests, woodlands and other treed areas. Broad spectrum insect control
Mode of Application and Equipment	Tree injection; EcoJect, CHEMJET	Tree injection; EcoJect, Arborjet	Tree injection; QUIK-jet AIR, Arborjet	Backpack sprayer	Backpack sprayer
Application Rate	3 mL per cm DBH	15-30 cm DBH tree: 1.6 mL/DBH >30 cm DBH tree: 2.4 mL/cm DBH	(half the rate IMA-jet 5%) 15-30 cm DBH tree: 0.8 mL/cm DBH > 30 cm DBH tree: 1.7 mL/cm DBH	1.16 mL/cm DBH	3.52 mL/cm DBH
Annual Limit	no limit	no limit	no limit	1.9 L/ha/yr (1638 cm) (40 trees per hectare at 40 cm DBH)	3052 g/ha/yr (2525 cm); do not exceed more than 1 application per year
No Spray Zones (for protection of aquatic environment)	no limit	Do not apply directly to water, to areas where surface water is present or to intertidal areas below the mean high-water mark. Can be applied up to water's edge.	Do not apply directly to water, to areas where surface water is present or to intertidal areas below the mean high-water mark. Can be applied up to water's edge.	It is recommend not applying the insecticide within 10 feet of water sources Benton and Cowles (2016)	5-7m
Cost for 40cm DBH tree	$72.00	$ 13.76	$ 13.68	$3.48	$3.88
Timing	June and September (before 1st frost, fall applications appear to be more successful with hemlock – DeJonge pers. Communication)	Apply in early spring prior to bud break; alternatively apply in late summer, when adelgids resume feeding activity.	Apply in early spring prior to bud break; alternatively apply in late summer, when adelgids resume feeding activity.	Mid-April to Mid-May and/or Early-Sept. to mid-October (*Professional Guide to Emerald Ash Borer Insecticide Treatments*, n.d.)	Apply when hemlocks are actively growing and transporting water in xylem (March-November) (Belchim Crop Protection Canada Inc., 2022)
Product Uptake	1- 3 months	6-9 months	6-9 months	6-9 months	3-4 weeks
Number of Years of Protection	1 to 2 years	4 to 5 years	4 to 5 years	5 to 7 years	1 to 2 years
Benefits	• Not a neonicotinoid • Works quickly • Can use near water	• Longer protection • Cost effective • Can be injected by water	• Longer protection • Cost effective • Can be injected by water	• Can tank mix with Starkle 20SG • Longer span of protection • Time and cost effective	• Fast acting • Can mix with Xytect 2F • Time and cost effective
Concerns	• Labour intensive and requires injection. • Not a long-term solution, will need to re-inject every 1-2 years. • Expensive.	• Neonicotinoid. This pesticide is highly toxic to fish and aquatic invertebrates. • From label: Do not contaminate water. This product is highly toxic to honeybees exposed to direct treatment or residues on blooming trees and shrubs. • Trees may require 2 applications before significant control is seen.	• Neonicotinoid. This pesticide is highly toxic to fish and aquatic invertebrates. • From label: Do not contaminate water This product is highly toxic to honeybees exposed to direct treatment or residues on blooming trees and shrubs. • Trees may require 2 applications before significant control is seen.	• Neonicotinoid. This product is highly toxic to aquatic invertebrates. This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. • This chemical demonstrates the properties and characteristics associated with chemicals detected in groundwater. • Limits to amount used per hectare.	• Neonicotinoid. Very toxic to aquatic life. Highly toxic to bees and will kill bees foraging in a treated crop or in hives which are accidentally sprayed or contaminated by spray drift. • Spray residues remain toxic to bees for 2-3 days after application. • Toxic to beneficial arthropods. • Limits to amount used per hectare.

As mentioned previously, there are multiple options for chemical management of HWA. One of these options is a basal bark treatment of select hemlocks. When choosing these hemlocks, proximity to sensitive plants should be considered, as well as weather conditions such as wind to minimize drift and any potential non-target exposure. Additionally, if this work is completed by a contractor, they must be accompanied by an RBG Ecologist or other experienced staff member who is familiar with the locations and identification of sensitive species, to ensure that while completing treatment these species are not trampled. This also applies to chemical injections of hemlocks.

With the use of systemic insecticides, the presence of Species-at-Risk within the approximated root zone of a hemlock should be a factor in determining if the tree is chemically treated. The science of tree communication and nutrient exchange through underground networks of roots and mycorrhizal fungi is a relatively new field of study, and much is still not understood (Boyno & Demir, 2022). Therefore, the possibility of systemic pesticides being transferred through these underground networks with other plants within their root zones has not yet been quantified. RBG operates out of an abundance of caution and does not currently use pesticides within the root zones of Species-at-Risk.

There are various levels of action and treatment scenarios to consider when using pesticides to control HWA. The following sections describe three levels of management strategy and intensity involving the treatment of hemlocks. While there may be more strategies to consider, these three levels provide a good description of actions that may be taken.

Level 1 – Maintain Trail Safety and Aesthetic

This option aims to maintain visitor safety and reduce esthetic impacts along RBG's trails. Trail safety is maintained by treating infested trees that are within striking distance of the trail and/or are important trees with regards to slope stabilization. By treating these trees, RBG will also maintain the aesthetic appeal of the trail by keeping them alive. The prioritization criteria developed for treating trees along trails is presented below. The cost to maintain RBG's trail safety is currently estimated at $10,000 (per treatment year), however, as the HWA population expands to new areas, costs could increase to $15,000 – $20,000 per treatment year. It is recommended that annual treatments are applied to heavily infested trees and that once monitoring shows that HWA populations have been knocked down, a biennial treatment schedule can be applied (Monica Liedtke, personal communication).

Prioritization Criteria: Nature Trails

The following factors play a role in prioritizing which trees to inject as funds were only able to cover management of a subset of trees within the infested area during 2023 initial injections:

1. Proximity to trail system that passes through infested area with respect to
    a. preventing trail users from spreading HWA further, and
    b. the likelihood that the tree would become hazardous to the trail once dead.
2. Proximity to creek with respect to
    a. keeping the creek shaded and cool, and
    b. the likelihood that we would be unable to use a different control product within proximity to the water.
3. Tree structure (root and stem defects) and location on slope with respect to
    a. whether the tree may already be hazardous or become hazardous because of its structure and/or position on slope,
    b. whether the tree was integral to keeping the slope intact, and
    c. the ability of the tree to uptake the product.
4. Level of infestation and dieback (trees expressing severe symptoms from HWA, but who met the above criteria were not injected).

Level 2 - Reduce HWA Population and Retain Valued Trees

This option aims to slow the spread of HWA by reducing the population and retain high value trees and/or hemlock stands by treating all infested trees initially with pesticide(s) until a long-term solution is available in Ontario (i.e. biocontrol). Delaying the spread of HWA across the landscape will provide more time for RBG and other land managers to develop strategies for managing this pest. The same chemicals and process, as noted above, and would also be required for this option. Cost will vary depending on the chemical strategy chosen. Choosing to use TreeAzin and avoiding the use of neonicotinoids and thus their environmental impacts would come at a higher cost. Trees within 7 meters of water can only be controlled with TreeAzin and/or IMA-jet, however IMA-jet takes longer to act, which is not ideal for initial treatment of heavily infested trees. Opting for any of the other chemical options would come at a lower cost, though a combination of products would be required like TreeAzin and/or IMA-jet will need to be applied to trees within 5-7 meters of standing water.

South Shore Scenarios:

Preliminary surveys show that the average DBH of RBG hemlock trees on the South Shore of Cootes Paradise is approximately 30cm.There are about 250-300 trees that we know are infested with HWA, roughly 50 of these are in proximity to water.

Table 4 below provides estimates for various chemical treatment scenarios over the next six years. More importantly, we wanted to examine whether in-house chemical treatment would be worth considering which would require the purchase of expensive equipment in year 1. However, due to the high demand for staff time, the use of a contractor appears to be more cost effective. Because staff and contractor time was estimated, these numbers will vary when executed.

If any products other that TreeAzin and IMA-jet 5% are considered, it should be stressed that they are all under emergency registration and they may be difficult to obtain and will require shipping and customs costs not considered in this budget. Effective communication between RBG and the Ontario Ministry of Natural Resources and Forestry is important as they need to keep close track of where the product(s) are being used, by whom and how much. The use of neonicotinoids is also banned under RBG's pesticide policy. Special permission and a risk assessment is required to use them.

The first two scenarios in Table 4 involve the treatment of HWA solely with TreeAzin and complies with RBG's pesticide policy. It is estimated that the product cost $54 per tree (average DBH 30) and it is anticipated that we would require a contractor for approximately eight days to complete injections. Arborwood Tree Care also provided us with an estimate that matches this cost breakdown. Staff time coordinating injections was estimated at 7-9 days or approximately 3.5% of ecologists time. If completing these injections in-house, the (one time) cost of an Eco-Ject system is $5,050. An additional consideration for this scenario is whether RBG has suitable storage for the equipment and product. Staff time associated with this scenario increases to a minimum of 2 ecologists at 6.5% of their time. Because TreeAzin is only effective for 1-2 years, it is anticipated that the trees will be injected consecutively for the first two years followed by every other year after that. Monitoring new growth on the treated trees will help to determine when treatment is required. The same contractor and staff time estimates were used for the IMA-jet 10 contractor and in-house scenarios. Like TreeAzin, an injection system for IMA-jet could also be purchased and used in house. The use of IMA-jet is less than one third the cost of TreeAzin because it remains effective for much longer and therefore requires only 2 treatments within the first six years. IMA-jet 10 might not be the best option for initial treatment on highly infested trees however, because it takes 6-9 months to become effective. Another scenario to consider would be to treat trees initially with TreeAzin and follow up with IMA-jet 10 for the second or third treatment.

Starkle 20SG, a product registered for emergency use and used as a fast-acting treatment of HWA infested trees, is another chemical option. This scenario would need to be combined with TreeAzin injections to treat the 50 trees closer to water. IMA-jet 10 is also an option for the 50 trees, however, this option wasn't included in Table 4, but the cost can be easily extrapolated from this budget if needed. These products only remain effective for 1-2 years, therefore consecutive treatments for the first two years are suggested followed by treatments every other year.

For the last scenario, fast-acting TreeAzin injections could be followed up with a treatment using Xytect 2F which takes longer to act but provides longer protection. Combining these treatments could reduce the cost of solely using TreeAzin while limiting the use of neonicotinoids. This scenario also provides RBG with the time it might take to acquire Xytect 2F (registered for emergency use only). Trees closer to water will continue to require TreeAzin injections.

Table 4. Estimated budget outlook over six years for different chemical treatment scenarios, including staff time and contractor costs.

		TreeAzin (contractor)	TreeAzin (in house)	IMA-jet 10 (contractor)	IMA-jet 10 (in house)	Starkle 20SG and TreeAzin	TreeAzin and Xytect 2F
Year 1	Product(s)	$16,200	$16,200	$3,078	$3,078	$3,428	$16,200
	Contractor	$10,000	0	$10,000	0	$3,000	$10,000
	Staff Time	$2,625	$9,750	$2,625	$9,750	$6,000	$2,625
	Equipment	0	$5,050	0	$5,050	0	0
	Subtotal	**$28,825**	**$31,000**	**$15,703**	**$17,878**	**$12,428**	**$28,825**
Year 2	Product(s)	$16,200	$16,200	0	0	$3,428	$16,200
	Contractor	$10,000	0	0	0	$3,000	$10,000
	Staff Time	$2,625	$9,750	0	0	$6,000	$2,625
	Subtotal	**$28,825**	**$25,950**	**0**	**0**	**$12,428**	**$28,825**
Year 3 (break, save last option)	Product(s)	0	0	0	0	0	$653
	Equipment	0	0	0	0	0	$600
	Staff Time	0	0	0	0	0	$6,000
	Subtotal	**0**	**0**	**0**	**0**	**0**	**$7,253**
Year 4	Product(s)	$16,200	$16,200	0	0	$3,428	$2,700
	Contractor	$10,000	0	0	0	$3,000	$3,000
	Staff Time	$2,625	$9,750	0	0	$46,000	$1,125
	Subtotal	**$28,825**	**$25,950**	**0**	**0**	**$12,428**	**$6,825**
Year 5 (break)		**0**	**0**	**0**	**0**	**0**	**0**
Year 6	Product(s)	$16,200	$16,200	$3,078	$3,078	$3,428	$2,700
	Contractor	$10,000	0	$10,000	0	$3,000	$3,000
	Staff	$2,625	$9,750	$2,625	$9,750	$6,000	$1,125
	Subtotal	**$28,825**	**$25,950**	**$15,703**	**$12,828**	**$12,428**	**$6,825**
Total	Product/ Equipment	$64,800	$69,850	$6,156	$11,206	$13,710	$39,053
	Contactor	$40,000	0	$20,000	0	$12,000	$26,000
	Staff	$10,500	$39,000	$5,250	$19,500	$24,000	$13,500
	Grand Total	**$115,300**	**$108,850**	**31,406**	**$30,706**	**$49,710**	**$78,553**

Level 3 - Prevent and Preserve

This last option aims to retain high value trees and high value hemlock stands by proactively treating **non-infested** trees with pesticide(s) until a long-term solution is available in Ontario (i.e. biocontrol). IMA-jet and Xytect 2F are chemical options that are best used for the prevention of HWA. While these chemicals take longer to act, they also remain effective for over four years which reduces the need to re-apply and could prevent an infestation from forming in nearby high value hemlock stands. The same scenarios in Table 4 apply to this option with the addition of more trees. To use IMA-jet a contractor would be required, and the cost would be about $2,000 for product and $4,000 for contractor costs for an additional 100 trees. Staff time is estimated at about 2.5% for one ecologist. Should Xytect be considered for preventative treatment, RBG could apply this pesticide in house. Product would cost approximately $600 and staff time is estimated at 4% for two ecologists. Should this chemical management option be chosen and Xytect 2F is selected for preventative treatment, it would be prudent to combine this approach with the last scenario presented in Table 4 where Xytect 2F is also applied to hemlock trees away from water that were initially injected with TreeAzin.

Prioritization Framework and Criteria for Managing HWA with Chemical Treatments

The option to treat every tree is neither realistic nor cost effective. A prioritization framework is required to identify trees that can receive treatment for any approach of chemical management chosen, this information is gathered during monitoring. With reference to prioritization frameworks developed in New York and Nova Scotia, the following framework for prioritizing treatment beyond the safety response is presented below.

Reducing HWA populations using chemical treatment and thereby retaining large swaths of hemlock stands on the property, is important for the interim until biological control can be established in Ontario. Limited Eastern Hemlock data had been collected at RBG historically, and therefore, inventorying hemlock stands on is essential to collect baseline data required for future HWA treatment. The goal of surveys is threefold:

1. collect baseline hemlock data
2. delineate the infestation area
3. collect data required to prioritize hemlock trees for chemical treatment

During surveys, visual inspection of every hemlock in a stand for HWA was completed and the tree’s vigor was assessed. The following data is collected:

- DBH, tree status (alive or dead)
- canopy cover (categorically percentages)
- new growth present (yes or no)
- proximity to standing water (> 7m or < 7m)
- and HWA present (light, moderate, or heavy)

Other notes (such as any insect present on the sample, stem defects, other wildlife presence, etc.) were recorded as well. An example of an entry for a single tree can be found in Table 5 below.

Additional hemlock stand information recorded includes:

- number of trees in stand
- stand size, size class
- hemlock density
- associated species
- whether the stand provides direct shade to water
- slope steepness

- rare species or hemlock-dependent species
- hazard trees (if trails are present)
- environmental stressors (invasive species, soil compaction, deer browse)

Not only does this information provide baseline hemlock data, but it also provides a very detailed survey to determine the extent of HWA the property.

Table 5. An example of a survey sheet template for initial hemlock inventory surveys at RBG in 2024.

Date	Stand Number	Tree Number	Canopy Cover	DBH (cm)	Tree Status	New Growth (Yes/No)	Proximity to Water	HWA Infestation Levels	Notes
2024-05-13	1a	1	61% - 81%, foliage starting to thin, most of canopy in good colour	31.6	AS (alive, standing)	Yes	>7m	none	Tree is smothered by grapevine

Should RBG wish to gather additional tree health information and/or standardize our survey protocol, Kejimkujik National Park and National Historic Site has developed a draft protocol to monitor canopy health in hemlock stands adopted from "Conducting Hemlock Health Assessments and Sampling for Hemlock Woolly Adelgid and Hemlock Scale" (McAvoy et al. 2019). Additional data gathered in their protocol includes average length of new tips, percent live branches, percent live branch tips, percent new foliage, percent foliage density and additional stand information such as canopy closure, soil drainage, and surface rockiness.

When deciding which trees are candidate trees for treatment, and which chemical is best suited for the situation, RBG will heavily reference the decision-making key provided in Figure 22 from the Medway Community Forest Cooperative Ltd and other prioritization tools created by experienced organizations listed below:

- Hemlock Stand Prioritization Framework: Draft treatment prioritization results for Hemlock Woolly Adelgid (HWA) protection in Kejimkujik National Park and National Historic Site, 2021.
- Regional Prioritization of Hemlocks, New York State Hemlock Initiative of Cornell University.

Of note: many of these prioritization frameworks are based on a larger scale and in areas where there are many hemlock stands. RBG is dealing with HWA and hemlock trees on a much smaller scale. Figure 22 in Appendix C will be the most relevant resource when choosing trees for treatment.

Candidate trees for treatment are those that have no stem defects (open or closed wounds) and have a relatively full canopy (> 60% canopy cover). HWA infestation levels are not as heavily weighted against chemical treatment as is the tree's structure and canopy health. Trees that exhibit 41- 60% canopy cover, or less and show no signs of new growth, are a lower priority for treatment. These trees are already showing significant signs of decline and may not recover, even with chemical treatment.

Trees that are not yet infested and are high quality, candidate trees for chemical treatment (good structure and full canopy) fall under the category of tree preservation. These trees may be young or old, grow in unique habitats, or have distinct characteristics that make them a highly desirable tree for treatment. In areas where HWA is yet to be detected, it can be tempting to treat all hemlocks with the goal of saving them from HWA-induced mortality. The information gathered through monitoring will help determine trees for preservation.

Protecting trees that symbolize biological legacy should be considered in RBG's treatment strategy. These trees are significant mature trees in the landscape that have been left behind from previous disturbance on the land (i.e. forest fires or logging practices).

One example of a biological legacy is the largest known hemlock on RBG property, which is in the interior forest on the North Shore of Cootes Paradise, and measures 91.1 cm DBH. Currently, HWA has not been observed on this tree, and therefore, it is a candidate tree for preservation treatment. For HWA prevention, neonicotinoid-based chemicals are preferred because they remain effective for long periods of time.

Figure 16. Example of a Biological Legacy Eastern Hemlock at RBG, measuring 91cm DBH.

Silviculture

There are two types of silvicultural management approaches associated with HWA control. One is to slow the spread of HWA by cutting down infested trees and the other is to promote more vigorous growth and natural tree defense against HWA impacts and slow the spread of HWA through stand management.

Silvicultural management approaches are advised for infested locations that are localized and small-scale, thereby removal of few infested trees will drastically reduce or remove the HWA population in total. RBG may consider removing a small percentage of trees within the infested stands that are showing significant signs of decline (ex. <41-60% canopy cover). However, it is well known that removing all infested hemlocks, long-term, will not be a viable management technique as the pest continues its spread.

In general, silvicultural management of HWA promotes hemlock health and resilience when infestation levels are low. Increasing light penetration through silvicultural thinning in infested hemlock stands is a beneficial management option as research that has shown increased light penetration by 30-50% decreased HWA survivorship by increasing exposure to UV radiation (Brantley et al. 2017). The same study suggested that a beneficial by-product of thinning is increased hemlock photosynthesis potential and carbon balance.

The extent of infestation currently known on RBG property is likely too advanced for silvicultural treatment, however nearby properties with no current knowledge of infestation (such as the Dundas Valley Conservation Area) might consider hemlock thinning in anticipation of the arrival of HWA to their property. The most likely silviculture-related scenario for RBG beyond hazard tree management will be to cut trees in situations where they are unable to receive chemical treatment due to the severity of infestation and dieback or the structure of the tree is compromised.

Biological Control Options

The current barrier to this control option is that there is no biocontrol available for release in Ontario. A reliable and successful predatory biological control agent is a highly specified predator of the target pest, a life cycle that is synchronous with its prey, has a rapid reproduction rate, and feeds on all life stages of the pest (Emilson et al. 2018). Predatory insects are still in the research stages with varying levels of success in laboratory and field studies. The largest challenge facing biological control studies is the lack of adequate predatory insects for release (Emilson et al. 2018). Laboratory space and expensive costs related to rearing insects and transporting them are some aspects stalling research. The two most successful and well-studied biological control agents are outlined in more detail below.

Figure 17. Photo of two biocontrol agents for HWA management in North America. Left: adult female *L. argenticollis* (Cornell University Insect Collection), Right: *L. nigrinus* feeding on HWA on right (New York State Hemlock Initiative, Cornell University).

Silver Flies

There are two species of Silver Flies, *Leucotaraxis argenticollis* and *Leucotaraxis piniperda*, which are abundant and effective predators of HWA on the West Coast of North America. The larvae of these species prey on the eggs of HWA throughout HWA's spring egg-laying season (New York State Hemlock Initiative). Recent research has shown that *L. argenticollis* can survive winters in their dormant stage throughout the climatic range of Eastern Hemlock, and reproductive evidence has also been documented in New York State and Vermont, and therefore it can be deduced that there are early indications of establishment in those states (Dietschler et al. 2023). Additionally, across seven *Leucotaraxis* sites in the eastern United States, Dietschler et al. (2023) found that the probability of overwinter survival increased with latitude. This is promising news for the success of future *Leucotaraxis argenticollis* releases in Ontario.

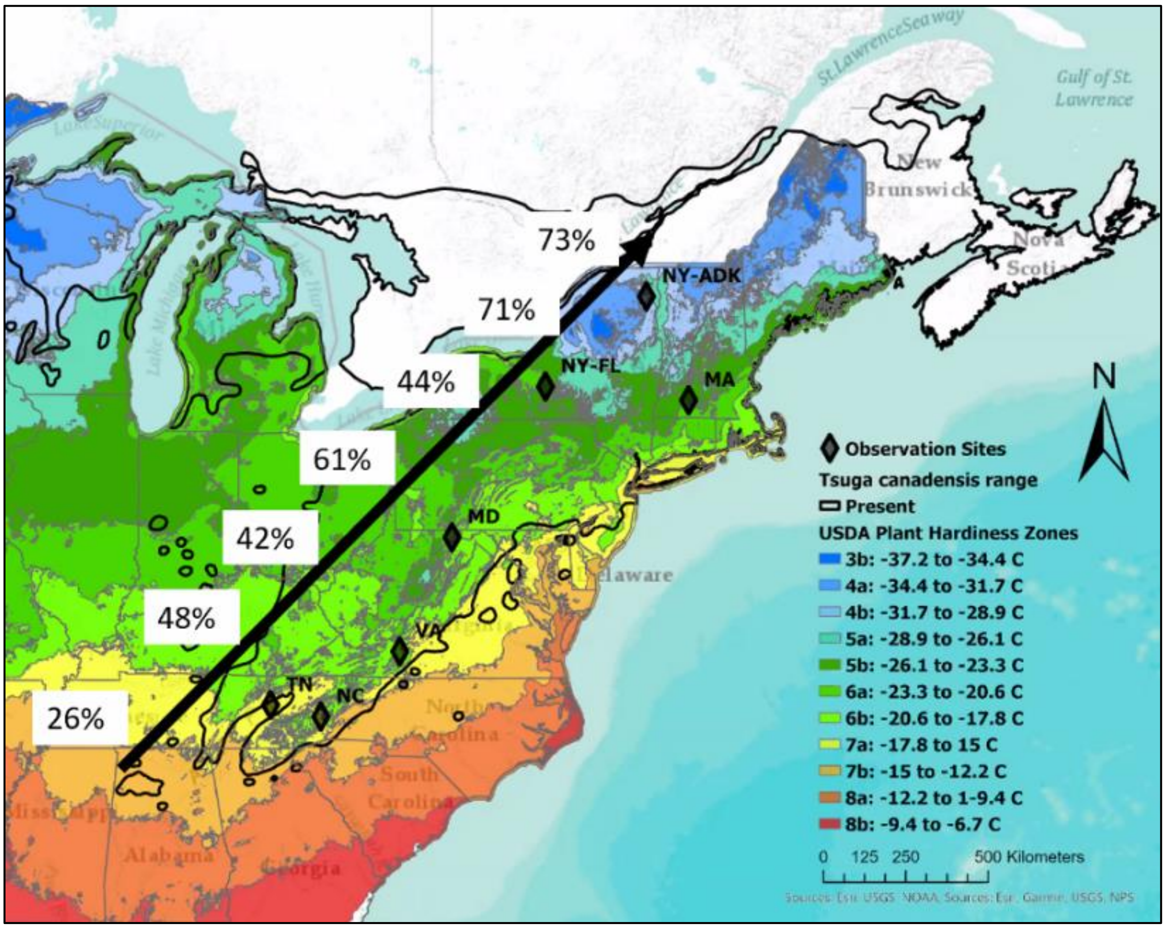

Figure 18. From Dietschler et al. (2023), in seven eastern United States sites where Leucotaraxis argenticollis was released, probability of overwinter survival increases with latitude.

Laricobius Beetles

Laricobius nigrinus is a species of beetle native to the Pacific Northwest, where HWA is a native pest of Western Hemlock (*Tsuga heterophylla*). In 1997, *Laricobius nigrinus* was found to feed exclusively on HWA in a laboratory setting (Havill et al. 2014). Its lifecycle is also synchronous with HWA, which allows for intense predation to occur. The genus *Laricobius* exclusively feeds on adelgids, and *L. nigrinus* is a predator specialized in feeding exclusively on in-star and adult HWA throughout the fall and winter (New York State Hemlock Initiative). Nova Scotia received their first shipment of predatory beetles in

2023, 6 years after HWA was first detected in Nova Scotia in 2017. Preliminary research has shown a 60% survival rate over the first winter after release. It cost $144,000 to ship 3,600 beetles from British Columbia to Nova Scotia (Hounsell, 2023). This is the first time this kind of biocontrol has been used in Canada on HWA. In the U.S., releases of *L. nigrinus* first began in 2003. Evaluations after release showed that establishment is positively correlated with minimum winter temperature and with the number of beetles released (Havill et al. 2014). In a recent field study in Virginia by (Preston et al. 2023) results strongly suggest that *L. nigrinus* is an important biological control agent of HWA and can have a positive impact on hemlock tree health, however, additional management strategies are needed to further reduce the negative effects to hemlock tree health caused by HWA. While the *L. nigrinus* predation of HWA on treatment branches lead to an increase in the number of new shoots produced at the end of the growing season, the final HWA density was above the damaging threshold which would potentially cause a reduction in the number of new shoots produced the following year.

A 2024 study showed promising results in a *Laricobius* release in New York State. There has been confirmed over-wintering, establishment, and dispersal of *Laricobius* in various study sites across the state, as well as correct phenology for predation of HWA in the eastern United States (Preston et al. 2023). One of the successful established populations in New York State occurred in Rochester, which is less than 200km from RBG's infestation on Caleb's Walk (Figure 19). It could be assumed that successful establishment in Rochester of *Laricobius*, would result in successful releases at RBG too.

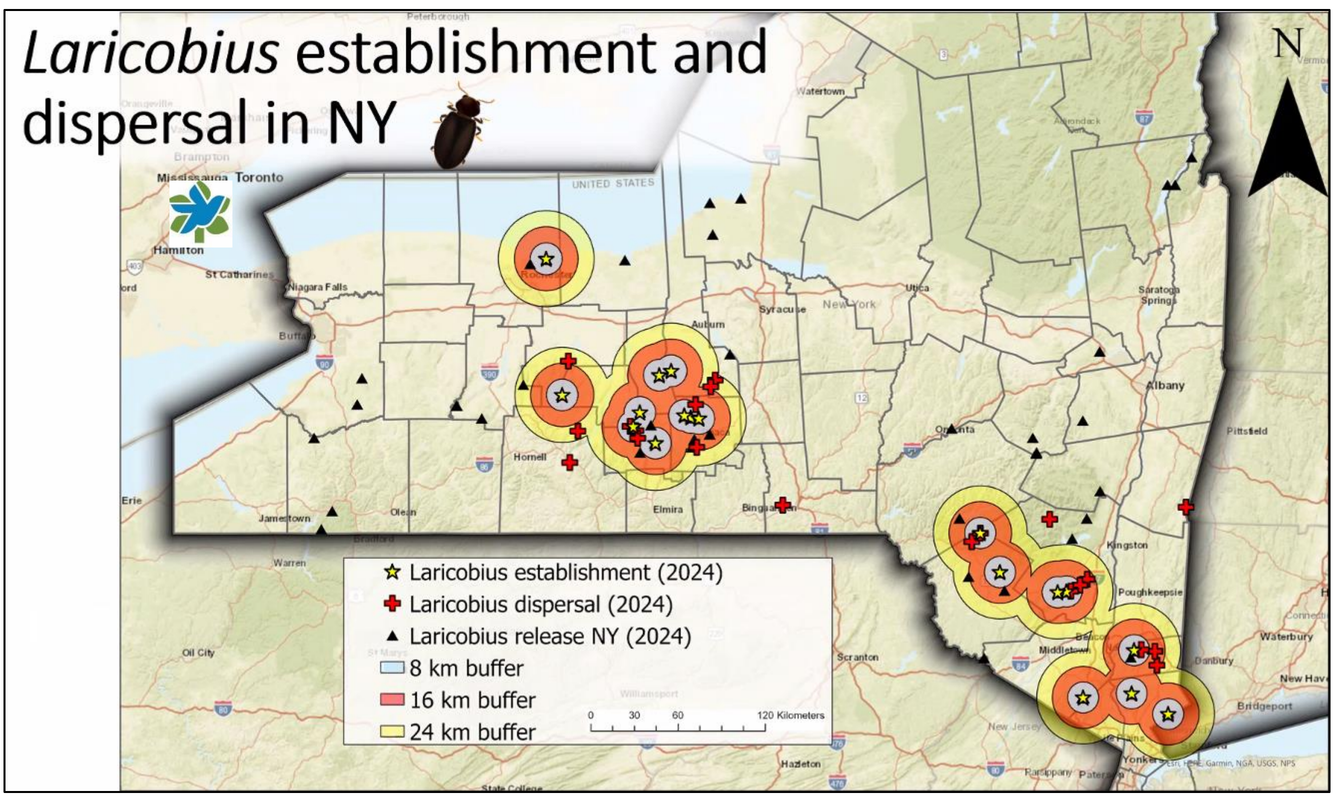

Figure 19. Map of *Laricobius* establishment and dispersal in New York State (created by Nicholas Dietschler) with RBG's location noted for proximity.

Through connections with CFIA, RBG has discussed possible releases of predatory beetles on RBG property with enthusiasm from CFIA. However, further discussions surrounding legality and logistics are needed in the future. Two main factors that will impact eligibility to be a biocontrol release site are:

1. Hemlock density and area (for biocontrol release, only hemlock stands greater than 4 hectares are considered in the US); and

2. History of insecticidal treatment. (Mayfield et al. 2020)

Research

RBG has been a part of exciting discoveries in botany and ecology in the past, and many outside researchers have undertaken research at RBG. As one of very few locations with HWA present in Ontario and with the structure in place to welcome outside research activities, RBG is poised to become a leading partner in generating new knowledge about HWA and hemlock ecology in Ontario. Opportunities for research will present themselves over time. Priority projects to consider should focus on collaboration with researchers to develop new, leading-edge monitoring and management techniques for HWA and establishing a biocontrol program for Ontario.

Ecological Restoration

Eastern Hemlocks not only provide habitat for wildlife and stabilization to steep slopes, but also provide shade required for cool-water stream habitats and reduced snow-melt runoff. RBG is anticipating HWA-induced hemlock mortality and the ecological impacts that will follow.

HWA can cause Eastern Hemlock mortality in as little as four years. Immediately post-hemlock mortality, the once shaded forest floor experiences a dramatic increase in light penetration (Havill et al. 2014), resulting in a complete change in the flora and fauna communities which will survive in this new environment. Increased light availability on the forest floor increases the likelihood of invasion of non-native species, as well, the drastic change in light eventually leads to the loss of shade tolerant invertebrate species (both terrestrial and aquatic), amphibians, fish, and plants associated with the unique characteristics of a hemlock forest (Havill et al. 2019).

Successional dynamics and regrowth after large scale HWA-induced hemlock mortality in northern New England is affected by existing species composition, site conditions, and site disturbance (Krebs 2014). If disturbance is high in hemlock dominant stands, it has been found that Pin Cherry, White Birch, White Pine, and Trembling Aspen will colonize the site followed by shade tolerant species after establishment (Krebs, 2014). In areas of sporadic hemlock presence and low density, there will likely be very little change in the species composition at the site (Krebs 2014). Brooks (2004) found that in mixed deciduous forests Red Maple, Black Cherry, White Pine, Sugar Maple, and various Oak species will colonize the site. In northern deciduous forests, Sugar Maple, Yellow Birch, and American Beech are most likely to replace hemlock in the landscape (Eschtruth et al. 2006) – the later 2 deciduous forest types are associated with RBG's hemlock stands as all these species are currently growing within them. Unfortunately, Beech Bark Disease and Beech Leaf Disease are prevalent throughout the American Beech trees that exist within the infested hemlock stands and therefore the loss of canopy beech trees is also inevitable, providing even more reason to consider a carefully crafted restoration plan for impacted sites.

The following options can be considered to restore some of the ecological services provided by a hemlock forest post HWA-induced hemlock mortality:

- re-planting with alternative conifers
- re-planting with a mix of native coniferous and deciduous trees
- sourcing and planting resistant Eastern Hemlocks
- planting hybrid-hemlocks or resistant non-native hemlocks

Option 1: Re-planting with Alternative Conifer Species

Option 1 is the most likely option in areas where HWA has resulted in hemlock mortality. The goal of this option is to develop a plan that includes re-planting with different conifer species that can provide similar ecosystem services to Eastern Hemlock, whilst taking Climate Change range shifts into account. This can either be done as an underplanting in preparation for HWA-related hemlock mortality, or it can be done as a complete reforestation project following hemlock death. While seedling establishment would be easier and quicker in the full sun provided by hemlock death, this is not the recommended approach. Waiting for full hemlock death will leave the watercourse that follows Caleb's Walk open to full-sun, create a longer time period whereby there is no canopy cover and vertical habitat structure, as well as a loss of slope stabilization.

Underplanting in preparation for hemlock mortality can ensure that upon hemlock death, there is a sufficient understory ready to grow and replace the lost canopy cover. However, there are several considerations with this approach. Any saplings planted will need to be tolerant of shade, as they will likely not receive much sun under the existing hemlock canopy, as well be somewhat resistant to deer forage due to the high population of deer present in Hamilton's natural areas. Lastly, native range and current presence on RBG property can be indicators of success.

Natural Resources Canada outlines species' range shifts as climate changes through 2100 (Government of Canada, 2024). Their mapping predicts habitat suitability for species in North America, and how those ranges will shift with various climate warming scenarios. This information will be included when planning restoration projects for areas previously dominated by Eastern Hemlock. The range maps include information on core and range habitats for species. Core habitats are crucial areas where a species thrives and will successfully reproduce, compared to range habitats that encompass the entire span of habitat in a given geographical area which have less than ideal conditions when compared to the core habitat (Craighead and Cross 2007).

Some candidate conifer species are presented in Table 6 and ranked on their suitability for HWA restoration based on the above characteristics. The rating scheme is as follows: Excellent (mimics the ecosystem restoration services of hemlock and is prevalent on RBG property), Good (mimics some ecosystem services of hemlock and is at least present on RBG property), Fair (mimics some ecosystem services of hemlock, but may not thrive under the available conditions), Poor (does not tolerate the available conditions).

Table 6. Pros, cons, and ratings of conifer alternatives as part of the Eastern Hemlock replacement restoration plan.

Species Name	Pros	Cons	Projected Suitability 2075-2100	Rating
White Pine (Pinus strobus)	White pine is within its native range and is currently present naturally growing on RBG across the property. White Pine does not retain its lower limbs for shading. Grow quite tall and can replace some of the upper canopy habitat structure. Seedlings are semi-shade tolerant.	White Pine is sometimes foraged by deer, which adds complexity as RBG has a large deer population. Heavy clay is not ideal for White Pine. White pine does not retain its lower limb structure which will not mimic the shade of hemlock does.	YES (Range)	FAIR
Red Pine (Pinus resinosa)	Conifer within its native range.	Does not currently occur on RBG property. Seedlings and saplings are shade intolerant. Relies on fire for regeneration.	NO	POOR
Eastern White Cedar (Thuja occidentalis)	Within its native range and is already present in Cootes Paradise Nature Sanctuary. The species is shade tolerant, and adaptable to most soils. This species also has a bush-like appearance when grown, meaning it will provide ample shade as a hemlock does.	Eastern White Cedar is the preferred forage of deer, which will add a layer of complexity at RBG, given the large deer population.	YES (Range)	GOOD
Eastern Red Cedar (Juniperus virginiana)	Within its native range and is already present in Cootes Paradise Nature Sanctuary.	Extremely shade intolerant and prefers dry sites.	YES (Core)	POOR
White Spruce (Picea glauca)	White Spruce is tolerant of a wide variety of soils, is typically found in riparian areas, tolerates some shade. This species also retains its lower limb structure for shade providing capabilities. It is also not much of a preferred browse species for deer.	The native range of White Spruce does not encompass RBG. While it is present at RBG, it does not form part of any natural plant community and is affected by climate change	NO	POOR
Balsam Fir (Abies balsamea)	Not a preferred forage of deer. Retains its lower limbs to provide similar thermal effects to hemlocks.	The range of Balsam Fir does encompass RBG, and is at the southern extreme of its range, and expected to be greatly affected by climate change. Does not tolerate heavy clay, or prolonged heat.	NO	POOR

(table adapted from Eckenwalder et al., 2023; Jackson, n.d; Collier et al., 2022)

Option 2: Re-planting with a Mix of Native Coniferous and Deciduous Trees

Because of the limited availability of suitable coniferous trees that could be planted to replicate the ecosystem services that Eastern Hemlocks provide, incorporating deciduous trees in the re-planting plan might be the most-appropriate restoration solution. Currently mixed in, and surrounding, Eastern Hemlock stands on RBG property are species such as American Beech (*Fagus grandifolia*), Sugar Maple (*Acer saccharum*), Red Maple (*Acer rubrum*), Yellow Birch (*Betula alleghaniensis*), White Birch (*Betula papyrifera*), Red Oak (*Quercus rubra*), White Oak (*Quercus alba*), and Eastern White Pine (*Pinus strobus*). Although, as mentioned earlier, these species will not replicate the current, shade-casting conditions that the Eastern Hemlock stand currently provides, these species are representative of the surrounding mixed forest conditions found in RBG's nature sanctuaries. Species should be selected with caution, as some of the ideal re-planting species have threats (diseases, fungi, or pests) that jeopardize their future on RBG property (i.e., Beech Bark Disease).

Option 3. Re-planting Eastern Hemlocks

Although replanting Eastern Hemlocks following HWA-related induced hemlock mortality can be done, it is not recommended for RBG as it would require intensive monitoring and protection from HWA re-infestation through the repeated application of horticultural oils (Ward et al., 2004). Re-planting Eastern Hemlock would be the ideal situation, which could be possible if HWA-resistant Eastern Hemlocks are located, their seed collected, and propagated, which would preserve these genetic traits (Emilson, 2019). There is promise in long-term survivability and vigor of hemlocks showing resistant traits, however, Eastern Hemlock displays low genetic diversity across much of its range, which means HWA-resistant hemlocks are not common (Kinahan et al, 2020, Prasad & Potter, 2017; as cited in the Nova Scotia Hemlock Woolly Adelgid Management Plan, 2021). This option should not be the primary restoration tactic and should rather be treated as a long-term experimental program, with potential for widespread use in coming decades.

Option 4: Planting Resistant Hybrids or Non-native Hemlocks

The third option is planting hemlocks that have been hybridized with non-native resistant hemlock species, or to plant the non-native resistant hemlocks themselves.

A commonly referenced study by Bentz et al. (2002), detailed controlled pollinations between five hemlock species native to either North America or Asia, with the goal of determining which species could hybridize and reproduce. While several of the Asiatic Hemlocks were able to hybridize, crossbreeding between Eastern Hemlock and other species was unsuccessful. The Carolina Hemlock (*Tsuga carolinia*) was the only hemlock native to Eastern North America to successfully hybridize with Asiatic Hemlocks that display resistance to HWA. Therefore, this is a significant roadblock to planting hybrid-resistant Eastern Hemlocks as a restoration tool post-HWA hemlock mortality.

This leaves the other option of planting other hemlock species that show resistance to HWA. Two possible species include Chinese Hemlock (*Tsuga chinensis*) and Western Hemlock (*Tsuga heterophylla*). Long-term studies on Chinese Hemlock indicate potential for their use in Eastern North American landscapes. Trial plots included seven *Tsuga* species planted in New York state (hardiness zone 6b) in the year 2003. For reference, RBG is within hardiness zone 6a, therefore the climate within the region of study is comparable. Over twelve years of research, Chinese Hemlock showed the greatest survivability, overall health, and resistance to HWA (Harper & Weston, 2016). Western Hemlock, however, grows in much different climactic conditions to what is present at RBG. These trees grow along much of the coast of the Pacific Ocean and thrive in humid climates with mild conditions and frequent fog (USDA, n.d.). Additionally, the Western Hemlock has a very low tolerance to frost and is susceptible to blow-down by windy conditions (Government of British Columbia, 2024). The lineage of HWA that occurs on Western Hemlock is genetically unique from the HWA on the East Coast of

North America meaning its resistance to the HWA present in Eastern North America has not been scientifically understood (CFIA, 2021).

While research on hybridization and potential hemlocks that can be planted outside their native range continues, at this point in time, it is not the position of the Government of Canada to plant anything that is non-native as a tool for restoration (Emilson et al., 2018). Planting of alternative hemlocks do nothing to preserve Eastern Hemlock in our landscapes, and it is currently uncertain how any non-native species will respond to a novel environment in a naturalized setting. In conclusion, this option is not viable for RBG at the time of writing.

Required Maintenance of the Site

As HWA-related hemlock deaths occur, gaps will be created in the canopy which creates new opportunities for other species to colonize the site. This includes fast-growing species such as various invasives and hardwood trees. Periodic management of the establishment of non-native plants should be removed by staff.

Some hemlock mortality has already occurred where Caleb's Walk meets Westdale Creek, planting trials can begin immediately if desired. Newly planted trees will require some form of wildlife protection akin to what was executed at Churchill Park (deer fence, rodent guards) to give them the best chance of survival.

Approximately $2,000-$5,000 should be budgeted for plants and $1,000-$2,000 for fencing each year. Staff time for planting, fencing, maintenance and invasive plant control is estimated at three positions at 5-10% of their time.

Stakeholder Engagement

Learning from, collaborating with, and informing those who have a stake in RBG's HWA infestation and, more broadly Ontario's hemlock resources, is an important process for RBG to remain relevant and transparent. Stakeholder engagement can foster connections, partnerships, confidence, and support for RBG's HWA response activities. Two main activities are key to successful stakeholder engagement:

A list of stakeholders can be found in Table 2 at the beginning of this document. Table 7 below displays an overview of various working groups and committees that provide RBG with stakeholder engagement opportunities. Currently, RBG is an active member of HWA: The Hamilton Chapter and the Ontario HWA Monitoring and Management Subcommittee of the Ontario Science Working Group. To attend working group meetings and share our information, it is estimated that it would take approximately 1-2% of the Terrestrial Ecologist's time.

Table 7. Groups and committees within Ontario regarding HWA.

Committee Name	Meeting Frequency	Included Parties	Purpose
Ontario HWA Forest Managers Working Group	Twice annually (March and November).	Led by Kathleen Ryan (private stakeholder, formerly Silv-Econ Ltd)	To keep all parties informed of the latest research regarding treatment plans, pest phylogeny, and monitoring techniques.
HWA: The Hamilton Chapter	As needed – three to four meetings, annually.	Founded by RBG. Partners include the City of Hamilton, McMaster, Hamilton Conservation Authority, and the Hamilton Naturalists Club	An opportunity for local stakeholders who have abutting properties in the Hamilton area to meet and discuss monitoring/treatment progress and strategies.
Ontario HWA Communications Subgroup	Unknown – have not yet attended.	Lead by CFIA.	A forum to discuss the best way to communicate the threats of HWA to various stakeholders including the public.
Ontario HWA Monitoring and Management Subcommittee of Science Working Group	Monthly.	Lead by the CFIA and ISC. Attendees include CFIA, RBG, HNC, OMNRF, Parks Canada, Natural Resources Canada, Ontario Woodlot Association, City of Hamilton, HCA, McMaster, Hobbitstee.	To communicate the survey results of the CFIA and ISC across the province, identify gaps in surveillance, discuss funding opportunities, and discuss options for treatment.
Ontario HWA Land Managers	n/a	Lead by the CFIA. Attendees are various land managers.	To provide a forum for communication by landowners to discuss the management of HWA on their properties. This group is specifically for landowners who have already detected HWA or have property close to a current infestation.

Communication

RBG can minimize the risk of HWA spread by people by implementing a communications program in collaboration with various partners to raise awareness of issues and actions that can be taken to prevent the decline of hemlocks in Ontario. The following activities are options can be incorporated into a communications program:

- Provide updates on RBG’s HWA activities through social media and RBG’s blog on the website.
- Maintain signage in public areas where HWA is present
- Install boot brush stations at trail entrances to promote invasive species awareness and prevention.

These actions are estimated to take up approximately 1-2% of the Terrestrial Ecologists’ time.

Rationale

The eventual loss of Eastern Hemlock at RBG is an unfortunate inevitability if no action is taken to control HWA. Inadequate climate change mitigation could also eliminate this species locally by 2100. There is no permanent solution to HWA and long-term commitment is required to respond to this pest in order to retain hemlock trees within the landscape. The option to treat infested trees with pesticide is seen as a temporary measure that can be used to slow the decline of the trees which gives land managers a chance to prepare and mitigate for the changes to come and establish longer-term solutions such as biocontrol. A "Do Nothing" approach will result in the rapid decline of the hemlock-dominated areas and ecological impacts and visitor safety risks that will be difficult to manage in a shorter period.

As per RBG's environmental status reports, our forest ecosystems are showing signs of decline as they continuously face impacts from the surrounding urban landscape, invasive species and a changing climate. The diversity of RBG's nature sanctuaries has suffered the loss of American Chestnut, American Elm, Butternut and Ash trees. Oak decline is an increasing concern that threatens the most dominant tree of RBG's forests. These changes reduce the ability of the forest ecosystem to withstand ecological impacts, therefore it is important to protect the biological diversity that remains.

Trees that symbolize biological legacy and/or Heritage Trees and connect with people on a personal and/or spiritual level, are justifiable causes to retain some hemlock trees for their cultural value.

For these reasons, and as one of the few known landowners with a confirmed HWA infestation in Ontario, RBG will respond with responsible management of the infestation through an integrated pest management and ecosystem-based approach. Emphasizing our leadership in biodiversity and ecological stewardship, it is recommended that RBG protect hemlock resources in Ontario by slowing the spread of HWA on our property and retain valued Eastern Hemlock trees within our nature sanctuaries through strategically planned actions. RBG's actions will integrate different control options to address HWA with both short-term and long-term objectives.

Table 8 below outlines general management recommendations at four stages of HWA invasion as per Parker et al. 2023 in their technical note titled Hemlock woolly adelgid: Management guidelines to increase the resilience of Ontario's eastern hemlock resource to an exotic, invasive insect. RBG's HWA invasion currently settles in between the middle two stages of this table (outlined in red): low abundance, isolated populations and high abundance, widespread. Currently RBG's HWA invasion is present in isolated populations, however some trees are severely infested with several dead trees as a result. Parker et al. 2023 recommends both manual (removing highly infested trees) and chemical control for HWA management. This table also highlights restoring ecological function by protecting advanced evergreen conifer regeneration and planting climate-adapted evergreen conifers. While this table was created for actively harvested forest stands, similar principles apply to RBG forest stands and these recommendations will be integrated into RBG's actions.

Table 8. General recommendations for hemlock at four stages of HWA invasion (per Parker et al. 2023).

Stage of Invasion:	**Not Present**	**Low Abundance, Isolated Populations**	**High Abundance or Widely Established**	**High Abundance or Endemic**
Management Objective:	Increase resilience	Minimize spread	Minimize effects.	Minimize effects.
Strategy:	Density regulation	Sanitation	Stand conversion	Restoration
Canopy Recommendations:	Remove damaged, weakened, and suppressed hemlock of all crown classes with live crown ratio < 30%. Retain healthy trees of other species to maintain hemlock ecological function and increase stand resilience to multiple stressors.	Selectively remove and destroy infested trees. Restore ecological function by retaining evergreen conifer in canopy. Consider chemical control.	Selectively remove infested trees for economic return or public safety concerns. Restore ecological function by retaining evergreen conifer in canopy. Retain potentially resistant hemlock.	Manage according to new stand structure. Identify potentially resistant hemlock.
Understory Recommendations:	Protect hemlocks and conifers and advance regeneration.	Protect hemlock and evergreen conifer advance regeneration.	Protect evergreen conifer advance regeneration. Plant climate-adapted evergreen conifers.	Facilitate evergreen conifer development. Plant climate-adapted evergreen conifers, hemlock, or resistant hemlock.
Best Management Practices:	Avoid pre-emptive salvage harvesting of healthy hemlock. Avoid harvesting infested hemlock until > 60% needle loss to retain potentially resistant trees. Minimize soil disturbance and logging damage to maintain residual canopy tree vigor. Minimize spread by human activity.			

Recommended Objectives and Actions

The following strategic actions are recommended as RBG moves forward in response to HWA. These actions will work towards achieving two main outcomes:

1) slow the invasion front of HWA within RBG's nature sanctuaries and beyond and

2) work towards introducing a biocontrol program in Ontario for long-term control of HWA.

Monitor and Assess

Objective: RBG will monitor the extent of the HWA infestation and assess the health of Eastern Hemlock trees throughout the property to prioritize management and evaluate management actions.

Actions:

- Complete visual surveys for HWA in hemlock stands throughout RBG property outside of the known infestation site bi-annually to monitor spread.
- Map new hemlock trees/stands that exist outside of our current mapping information.
- Complete tree health inventory on all hemlock trees and apply criteria discussed in this document to prioritize trees for treatment.
- Inspect trees treated for the management of HWA on an annual basis to monitor the success of treatment measures.
- Maintain a database of information and mapping associated with the above actions.

Control the HWA Population

Objective: RBG will choose to implement the Level 2 - Reduce HWA Population and Retain Valued Trees option by treating infested trees with pesticide initially and, if funding allows, continuously until a long-term solution is available in Ontario. This control option is thoroughly discussed in the previous section.

Actions:

- Begin a chemical treatment program on selected trees using a contractor to inject the systemic insecticide TreeAzin into the trunk. Refer to Prioritization Framework and Criteria for Managing HWA with Chemical Treatments outlined in this report for further details regarding selecting trees for treatment.
- Selectively remove highly infested trees by cutting them down. These trees are showing significant signs of decline (<41% canopy cover) and/or do not have the stem structure that allows for good uptake of the chemical if injected.
- Select and monitor high value trees and/or hemlock stands for HWA and incorporate into the chemical treatment program when necessary (when the tree(s) are within proximity to an infestation site or are found infested with HWA).
- If the use of additional chemical products (IMA-jet and Starkle 20SG) is to be considered for valued trees and follow up-treatments a risk assessment to the local environment will be completed prior.

Seek Research Opportunities

Objective: RBG is poised to become a leading partner in generating new knowledge about HWA and hemlock ecology in Ontario.

Actions:

- Seek partnerships with federal and provincial agencies and advocate for the release of biocontrol on our property should we be eligible.
- Promote research projects at RBG associated with HWA monitoring and management.

Restore

Objective: RBG will reduce impact of HWA on the ecosystems through restoration (plant climate adapted evergreen conifers and other native deciduous trees).

Actions:

- Create a restoration plan for HWA infested hemlock stands showing irreversible signs of decline.
- Implement restoration plan.

Engage Stakeholders

Objective: Engage with stakeholders at all levels – local, provincial, federal and global.

Actions:

- Share our management strategy and information gained from the planning and management process with HWA stakeholders (See Table 2).
- Actively participate in the Ontario HWA Working Group(s) by sharing our experience and learn from provincial and federal land managers and other local stakeholders managing HWA.
- Host quarterly meetings with local partner agencies who form the Hamilton Chapter HWA working group.
- Engage with land stewards in the United States and Nova Scotia to gain an appreciation of the impact to date and obtain guidance for future land stewardship activities.
- Engage the private landowners in Hamilton with HWA in ecological stewardship with other local stakeholders (McMaster University, City of Hamilton, Hamilton Naturalists' Club).

Inform

Objective: RBG will disseminate information gained through the management process in collaboration with various partners to raise awareness of issues and actions that can be taken to prevent the decline of hemlocks in Ontario.

Actions:

- Provide updates on RBG's HWA activities through social media and RBG's website.
- Upon request, host tours on location and discus our experience managing HWA at the frontline of the Ontario infestation.
- Maintain signage in public areas where HWA is present.
- Install boot brush stations at trail entrances to promote invasive species awareness and prevention.

Conclusion

Based on the above recommendations and review of all possible management options in this report, RBG will complete a detailed inventory of hemlock health and HWA status throughout the property and undertake temporary chemical treatments for HWA infested trees to slow the invasion to allow other local organizations to resolve their individual approaches to the issue. In addition, hemlock trees identified based on their cultural value will be treated. The recommended pesticide is TreeAzin, the only non-neonicotinoid option currently available. It is expected that treatments will initially cost approximately $30,000 per year, but as the infestation spreads, property-wide investment for initial treatments are estimated to cost $125,000. Neonicotinoid options may be considered upon further review of the environmental risks associated with them. Initial hemlock mortality has been noted, and it is expected that some hemlocks will succumb to the impacts from HWA, despite treatment given. Restoration efforts to minimize ecosystem impacts from hemlock mortality through tree planting and other stewardship activities will be completed. The only viable long-term option that is currently available is HWA control through natural predation. RBG's long term goal is to actively seek a partnership with the appropriate research agency to collaborate on experimental biocontrol work. Throughout the process RBG will maintain partnerships with the identified stakeholders in this report and communicate our management strategy to the public. RBG will look to experts in the United States and Nova Scotia who have been managing impacts from HWA longer than Ontario and update our strategic actions as new options and/or techniques are found and become available.

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Appendix A - HWA Infestation and Awareness Signs

Signs installed at access points (trailheads) near the HWA infestation location and HWA awareness sign posted at hemlock stands by trails (Hickory Valley Trail).

Figure 20. CFIA curated HWA infestation sign and CFIA curated HWA awareness sign

Appendix B – Treated Trees

Figure 21. Map of potential Eastern Hemlock trees within the infested area along Caleb's Walk considered for TreeAzin injections. Trees marked in green were treated in 2023.

Appendix C – Treatment Decision Key

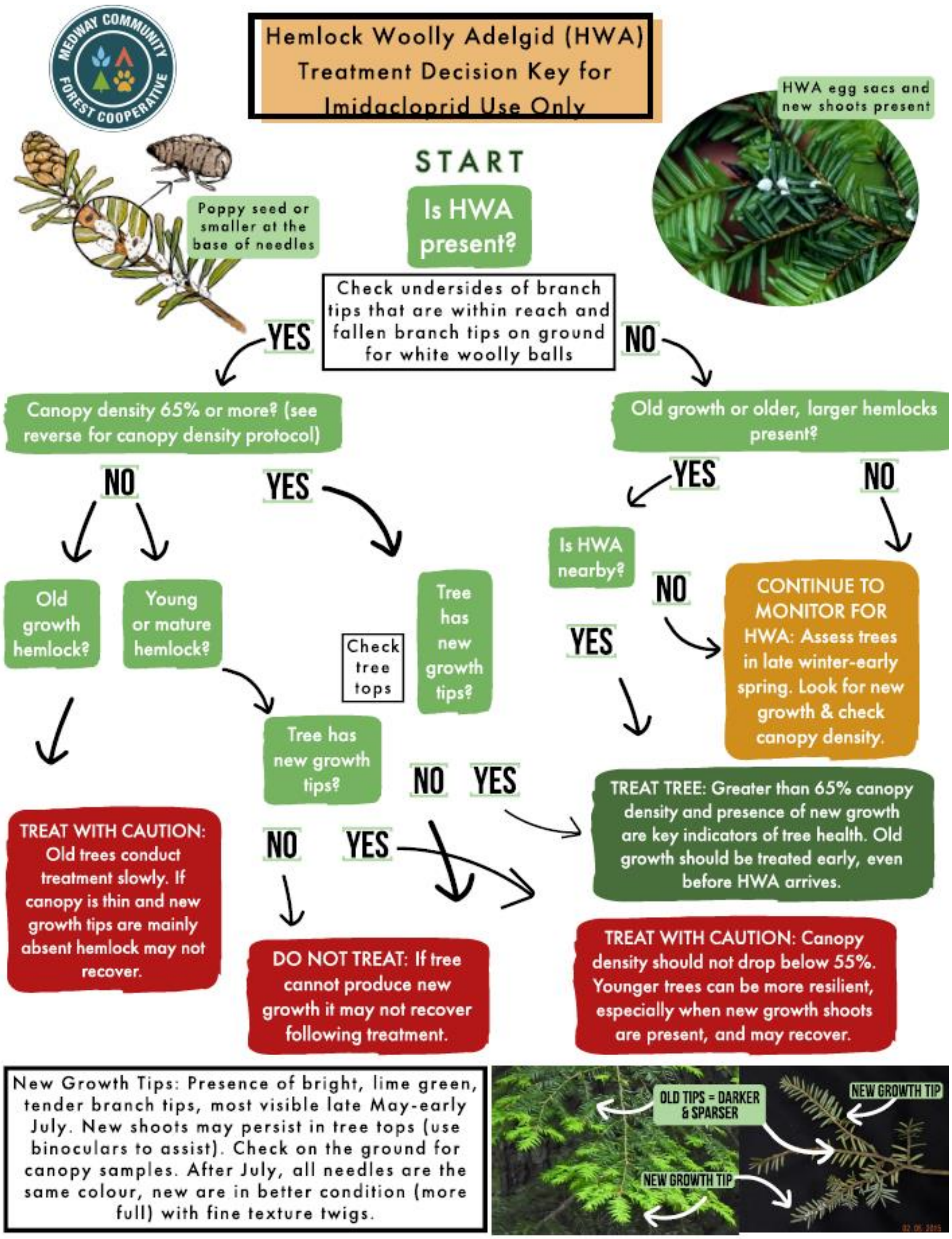

Figure 22. Decision key for using Imidacloprid to treat HWA (Medway Community Forest Cooperative and Nova Scotia Hemlock Initiative)