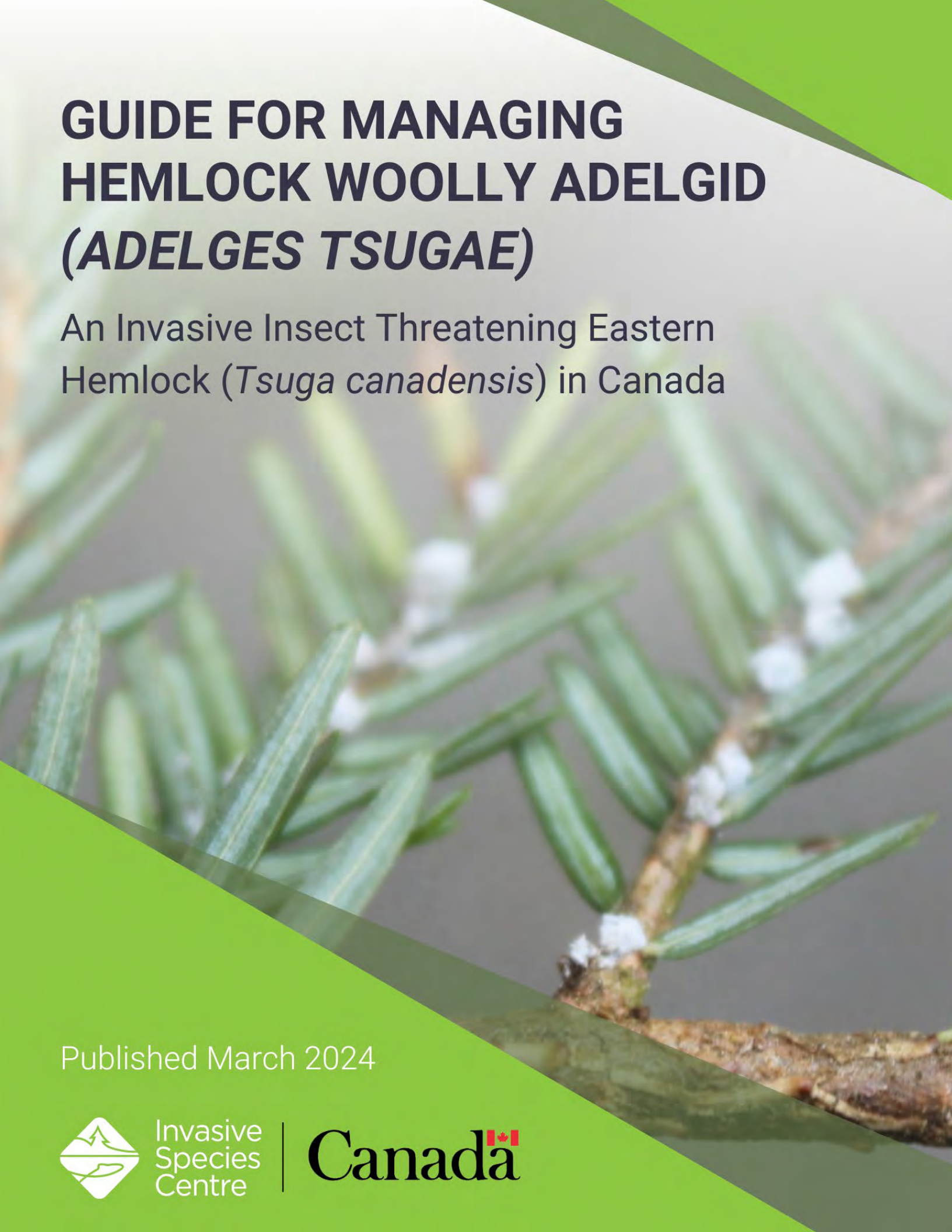
GUIDE FOR MANAGING HEMLOCK WOOLLY ADELGID *(ADELGES TSUGAE)*

An Invasive Insect Threatening Eastern Hemlock (*Tsuga canadensis*) in Canada



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Invasive Species Centre | Canada

Preface

This guide presents the most up-to-date information available to inform management decisions for hemlock woolly adelgid (HWA) in Ontario. The guide will be updated based on insect monitoring results, research advances, and program development. If you notice a gap in topics covered or find an error, please contact the Invasive Species Centre (ISC) at info@invasivespeciescentre.ca. If you have implemented a management strategy to prevent or control HWA and have results to share, please reach out to the ISC at the email listed above.

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- invasivespeciescentre.ca
- natural-resources.canada.ca
- inspection.canada.ca

Background

Hemlock woolly adelgid (Adelges tsugae), is a non-native, invasive aphid-like insect that was likely introduced to eastern North America from Japan in the early 20th century, but was first detected in Virginia in the 1950's. In eastern North America HWA attacks eastern (Tsuga canadensis) and Carolina hemlocks (T. carolinana). Since its discovery, the invasion of HWA has progressed through much of the range of eastern hemlock in the eastern U.S. and as far west as Michigan and Ohio (Figure 1). The insect was first detected in eastern Canada (Etobicoke, ON) in 2012 but was successfully eradicated. Unfortunately, HWA was detected again in Ontario a few years later and has remained on the landscape ever since. As of 2023, the affected areas in Ontario include seven sites in the Golden Horseshoe (the Niagara Gorge, Fort Erie, Wainfleet, Pelham, Hamilton, Haldimand County, and Lincoln) and one site just east of the Greater Toronto Area, in Grafton. HWA was also confirmed in Nova Scotia in 2017 and has since spread through most of the southwestern region of the province.

HWA attacks and kills eastern hemlock by inserting its mouthparts into the youngest available fully formed shoots and feeding on the tree's nutrient rich fluids. This feeding results in reduced photosynthesis and increased signs of water stress, with infestations in some areas ultimately killing up to 95% of the hemlocks in a stand over a 3 to 15-year period. The loss of these trees could be devastating, as hemlocks contribute significantly to Ontario's ecology, economy, and society.

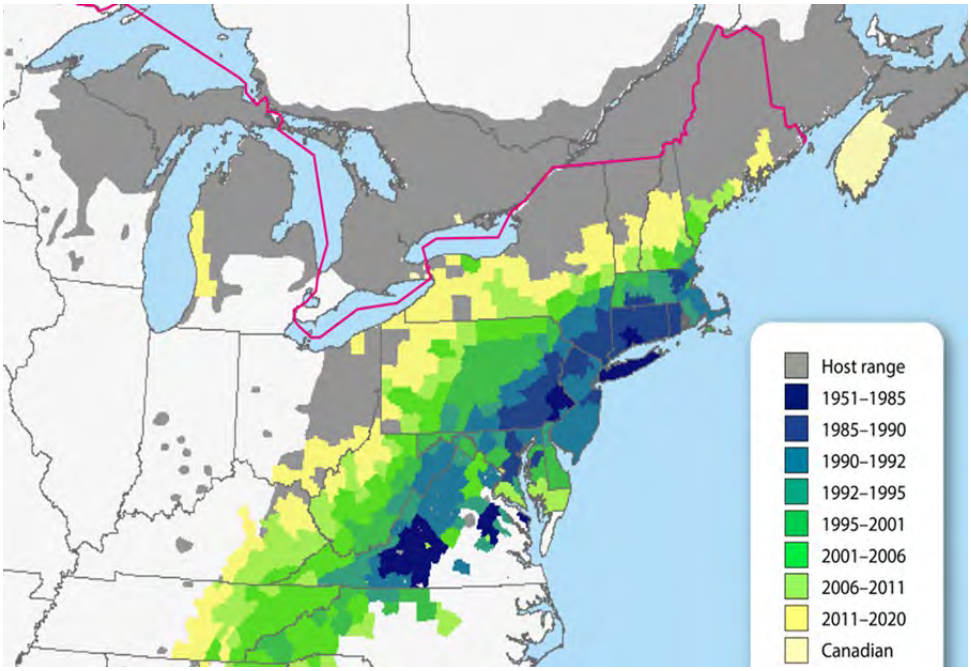


Figure 1. A map of the range of eastern hemlock (Tsuga canadensis; grey shading) and the invasion history if hemlock woolly adelgid.

Eastern hemlocks are foundation species that define the ecosystems they inhabit, influencing both the structure and function of terrestrial and aquatic communities. These large, slow-growing, shade-tolerant and long-lived trees influence both the structure and function of forest communities by creating unique soil and water conditions that support a variety of organisms. Some species, like Blackburnian warblers and black-throated green warblers, rely on hemlock trees and forests almost exclusively. Cool, shaded understories of hemlock forests can attract birds, animals, and fish seeking refuge from warm, dry summers and cold, windy winters. Loss of hemlock trees would impact species like the white-tailed deer and the roughly 90 species of birds that rely on hemlock for food, shelter, and habitat. Streams that flow through hemlock stands tend to have better water quality which promotes higher aquatic diversity than is seen in streams that flow through hardwood forests. Healthy hemlocks also protect these waterways from erosion, flooding, and nutrient run-off, enabling high-value fish, like brook trout, to thrive in the cool water.

Hemlock is less commercially valuable than other eastern conifers, with a much lower demand than species like black and white spruce or eastern white pine. They have several inherent qualities that deem them undesirable as a commercial species, including their uneven texture, moderate strength, and splintery wood. Nevertheless, there are still some good hemlock products commonly used in construction, landscape, and forestry, including pulpwood, dimension lumber (i.e., studs, boards, etc.), plywood core

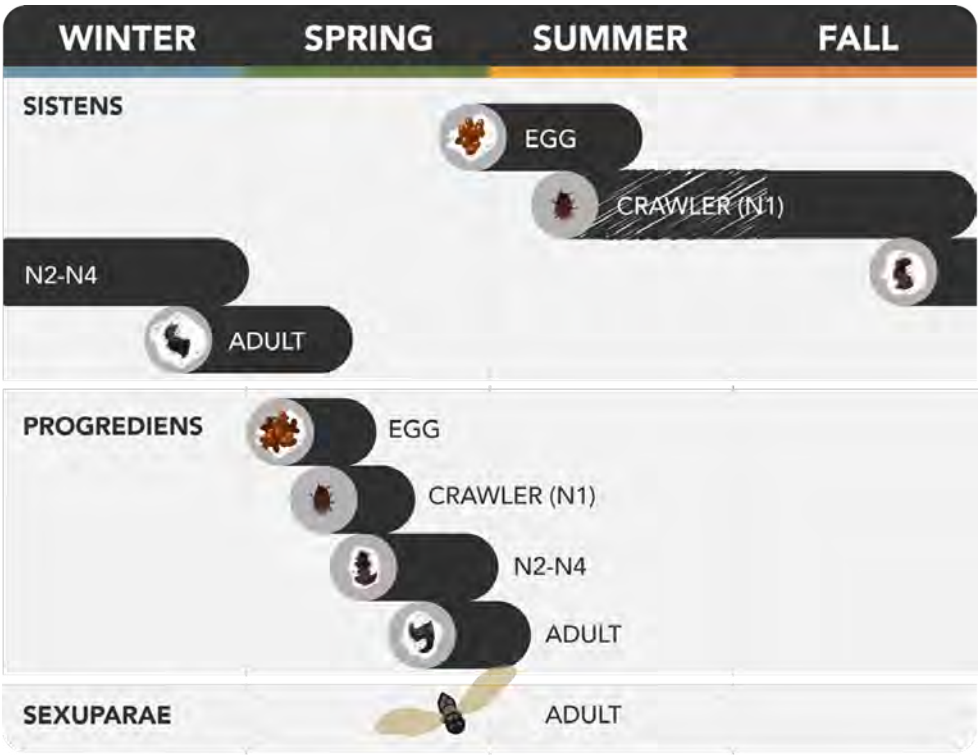
veneers, landscape timbers, barn siding, mulch, and firewood. The timber is generally resistant to rot, and so is often used for large framing members in construction and in retaining walls. Hemlock may become particularly useful when producing cross-laminated timber panels, which are preferred when constructing shear walls, floor diaphragms, and roof assemblies. Using timber as an alternative to concrete could be a green, low-carbon product alternative to concrete and steel systems, creating a larger space in the market for hemlock.

The loss of hemlocks would also impact the cultural value and the aesthetic beauty of forests. In particular, the enjoyment of outdoor recreational activities would all be severely diminished. Trees infested with HWA have discoloured foliage, experience needle loss, branch dieback, and thinning crowns. Apart from being visually unappealing, these dead and dying trees can be hazardous, expensive to remove, and can lower property values.

Knowing the signs and symptoms of hemlock woolly adelgid is important for early detection and rapid response. Report any signs or symptoms of HWA immediately to the Canadian Food Inspection Agency. A good report includes a clear picture (e.g., pictures of white woolly ovisacs, tree symptoms) and an accurate location of the suspected infestation. Upon receipt of the report, the information will be examined and infestations confirmed by the CFIA.

Lifecycle

HWA can reproduce without mating and since eggs or crawlers can spread by wind, wildlife, or humans, it only takes a very small number of insects (perhaps as few as a single crawler or egg) to start a new infestation. Hemlock woolly adelgid has a complex lifecycle with two generations per year: the sistens generation, which develops slowly starting in summer through the following spring, and the progrediens generation, which develops over a 4–6-week period in spring (Figure 2). Each generation includes eggs,



Created by the Invasive Species Centre in collaboration with the Canadian Forest Service.

Figure 2. The lifecycle of hemlock woolly adelgid by season in eastern Canada. Both the sistens and progrediens generations have the same 3 life stages, including eggs, nymphs, and adults. Sexuparae (winged adults) do not survive in North America since there is no suitable spruce host.

four nymphal stages, and adults. The only mobile life stage is the first nymphal stage known as the crawler, which hatches and makes its way up to new shoots to settle on the twig near the base of needles. Once settled, the crawler inserts its mouthparts, stops moving, and begins its remaining life stages. The sistens generation has a dormant period where it does not feed or grow. During the dormant period the insect looks like it is flat with a halo or fringe of white wool around it (Figure 3). The progrediens generation can develop into both winged and wingless adults (sexuparae and sistentes, respectively): in its native range the winged adults would fly to spruce where a sexual phase of reproduction would occur. The winged adults are not able to successfully attack any spruce in North America and die without reproducing. Ovisacs also tend to differ slightly between sistens and progrediens generations: to survive winter the sistens generation produces a more compact, dry wool to protect from the cold, while the progrediens generation produces looser, fluffy ovisacs.

Figure 3. Image of two aestivating (dormant) sistens.

Spread and Dispersal

HWA are readily dispersed by the wind and birds, as well as deer and other mammals, including humans. Birds can pick up HWA eggs or crawlers on infested hemlock trees and carry them long distances northward during spring migration. New infestations can arise through the movement of infested nursery stock, wood products, logs, and firewood. Wind can also disperse insects within stands during the crawler stage. The sexuparae stage (Figure 2) can also disperse by flight but this stage of the insect cannot establish new infestations and does not contribute to spread (see Lifecycle section).

Biosecurity and Canadian Food Inspection Agency Phytosanitary Requirements

In Canada, the Canadian Food Inspection Agency (CFIA) is responsible for surveillance and monitoring of potentially invasive pests. When the presence of a non-native pest is confirmed by the CFIA, regulatory measures may be put in place to reduce the risk of movement and spread of the pest. For HWA in Ontario the CFIA has regulated areas where HWA is known to be with Infested Places Orders and Prohibitions of Movement. As of 2024, there are three areas regulated by Infested Places Orders in Ontario: the city of Niagara Falls, Wainfleet Township, and Fort Erie Township (Figure 4). Notices of Prohibition of Movement have been implemented for the infested sites in Pelham, Grafton, Hamilton, Haldimand County, and Lincoln. These regulatory tools prohibit the movement of hemlock plant material and firewood of all species (HWA regulated articles) originating in an area regulated by an Infested Places Order or Prohibition of Movement. Moving HWA or HWA regulated articles out of one of these areas requires CFIA approval and appropriate permits. Research on HWA outside of the known infestations must be done in a CFIA-approved biocontainment facility. Information on obtaining permission to move infested hemlock material or conduct research in a biocontainment facility can be obtained by contacting the CFIA. Harvesting material from an HWA infested site and moving it to a mill needs permitting. In addition, the mill needs to be approved by CFIA to process HWA-infested materials.

To reduce the risk of accidentally moving HWA, biosecurity measures should be taken when working or spending leisure time in any hemlock stand, particularly in southern Ontario and during periods when crawlers are active (approximately April to July). Footwear, clothing, and equipment that can be machine washed or easily cleaned is recommended. A lint roller can be used to remove crawlers from clothing and hair, equipment can be wiped with ethanol wipes, and footwear should be cleaned with soapy water. Outer

clothing worn in a hemlock stand should be bagged until it can be washed, and all clothing should be washed before it is worn again to visit a hemlock stand. For organizations that work in stands regularly, an additional measure to disinfect footwear and equipment is recommended; a product such as PreVail can be used to kill anything that may linger after the initial step of cleaning footwear.

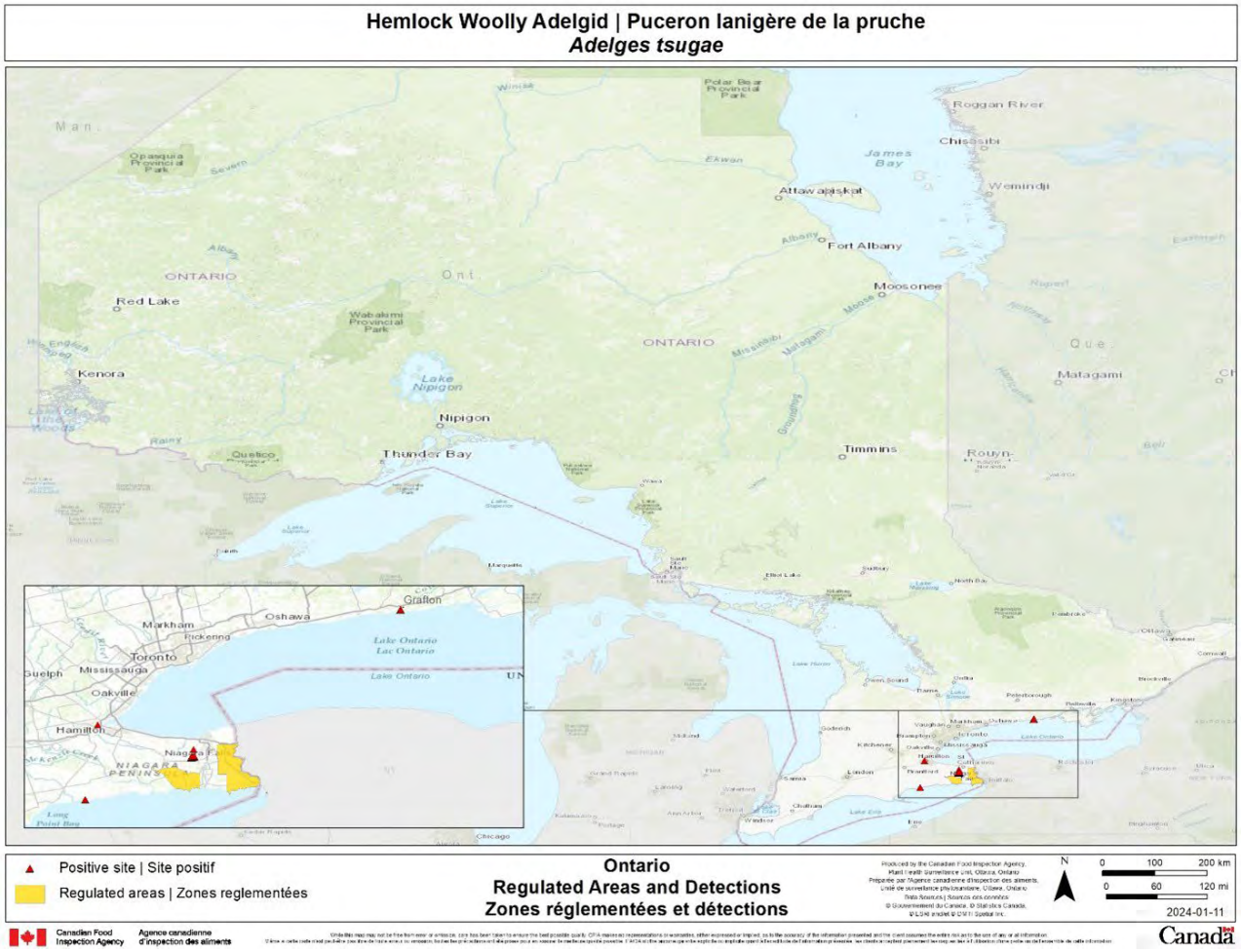


Figure 4. Map of Ontario's Infested Places Orders (yellow) and positive sites with Notices of Prohibition of Movement (red triangles) with an inlay map of the affected portion of the province

Prevention

Prevention is the most cost-effective solution for managing invasive species and is much less expensive than management once a population is established (Figure 5). There are several actions that can be taken to lower the chances of HWA arriving in a stand and, if it does, mitigating the impacts of its spread.

HWA can be moved on branches from infested sites to new, healthy stands. The transport of nursery stock is a major human-mediated pathway since hemlocks are commonly cultivated for use in landscapes (e.g., as hedges). Small infestations on nursery stock can go unnoticed because HWA are usually too small to see without the presence of white ovisacs. To reduce the risk of introducing HWA, avoid transporting infested hemlock seedlings, limbs, or firewood.

Reducing environmental stress on hemlocks may be one way to increase the tolerance of these trees to HWA. Some stress-relieving actions can include watering during dry periods, mulching around trees, and targeting specific trees for removal. Research on silviculture in HWA-threatened hemlock stands is still ongoing, but it seems as though thinning uninfested stands may give hemlocks a survival advantage against HWA in the future.

Learn more about prevention in the following documents:

- Applying three decades of research to mitigate the impacts of hemlock woolly adelgid on Ontario's forests
- Hemlock woolly adelgid: Management guidelines to increase the resilience of Ontario's eastern hemlock resource to an exotic, invasive insect

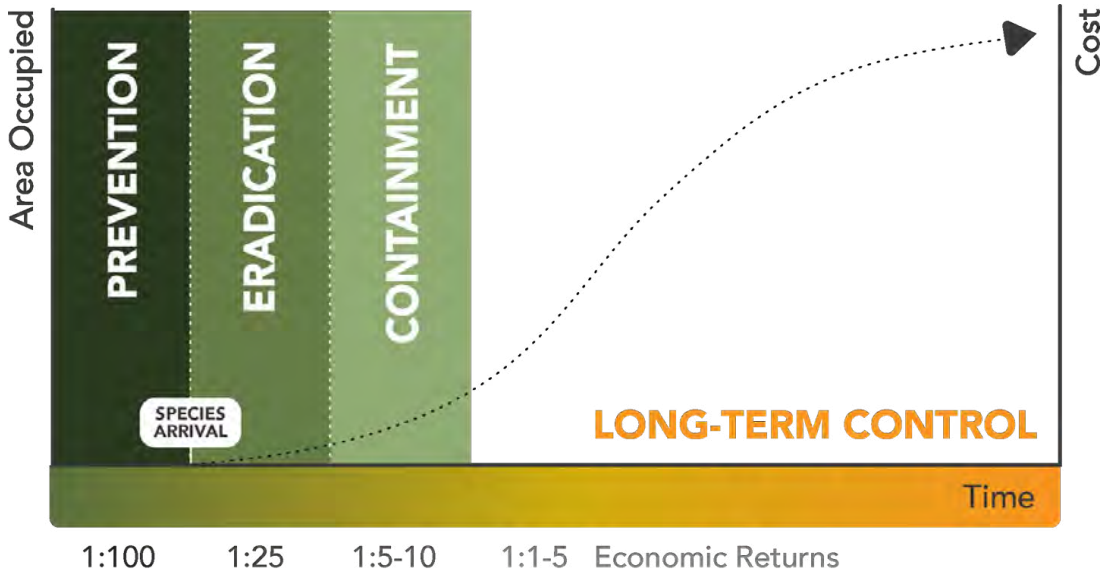


Figure 5. Invasion curve showing the stages of invasive species management from pre-arrival (prevention) to long-term control. Chart adapted by the Invasive Species Centre - Generalized Invasion Curve (Agriculture Victoria, 2009).

Hemlock Health and Monitoring

It is important to monitor eastern hemlock in Ontario with the current threat of hemlock woolly adelgid. A tree exhibiting symptoms of poor health could be a sign of the presence of a pest or other stressor reducing its vigor. Early detection and monitoring can help to reduce the impact of HWA introduction and hemlock mortality. Hemlocks that are in poor condition may have discoloured foliage, a thinning crown, or visible injuries. These signs of decline may be due to environmental stressors such as overcrowding, water stress, or storm damage, but they may also be a sign of pests or pathogens.

There are several different ways to detect hemlock woolly adelgid. Most of these methods are inexpensive and can be done without specialized equipment. Each method also has advantages and disadvantages depending on the goal of the survey and the number of trees that the surveyor wishes to investigate (Table 1). When possible, using more than one survey method can increase the probability that the survey will detect HWA if it is in the stand; individually, ball and stem sampling may have a 90% probability of detection, but when used together the probability of detection rises to nearly 100% (Macquarrie et al. 2021). Similarly, sampling with more effort and on more trees increases the probability the insect will be found: for ball sampling, the probability of detection in a small infestation in one tree rises from 35% with 5 shots through the crown to 80% with 30 shots through the crown (Fidgen et al. 2021).

Protocols for how to implement most of these survey methods can be found in Appendix A. Most of these survey methods work best in the spring or early summer, as the ovisacs are much more obvious during that time, though a few can be used year-round. New infestations should be reported to the CFIA immediately. HWA sightings and HWA damage in regulated areas can also be reported to EDDMapS and the Invasive Species Centre.

Table 1. Summary of detection methods for hemlock woolly adelgid. See Appendix A for specific methods.

Method	Equipment Required	Relative Cost	Time of Year	Pros	Cons
Visual Surveys (foliage, stem, forest floor)	• Binoculars (optional) • Hand lens (optional) • High powered head lamp (optional)	Low	Can be done year-round, higher wool abundance in spring and early summer	Affordable Useable in most stands Fallen branches on forest floor can be surveyed after a wind event	Unreliable, especially in stands with very tall trees; Difficult to detect early infestations
Destructive Sampling	Pole pruner with extension poles Hand lens	Low - Moderate	Year-round	Affordable Useable in most stands Can detect early infestations	Labour intensive; Equipment can be heavy; Damages tree
Traps	Traps (e.g., sticky cards, 3D printed microscope slide trap) and Microscope	Moderate - High	Spring	Useable in most stands Low effort to sample Best when can be integrated into existing trapping efforts.	Requires a microscope and training to ID HWA Sticky traps can collect a lot of bycatch; Time consuming and requires multiple visits to each stand; No commercial supplier of traps, must be constructed in-house
Ball Sampling	• Tennis ball slingshot & replacement slings • Raquet balls • Wooden beads • Black VELCRO® • Toothbrush • Gloves • Hard hat • Safety glasses	Moderate	Spring and summer	Can detect early infestations Equipment can be reused	Labour intensive; No commercial supplier of equipment, must be constructed in-house; Can be difficult in some terrain (e.g., slopes, along waterbodies, etc.)

Method	Equipment Required	Relative Cost	Time of Year	Pros	Cons
Environmental DNA (eDNA)	Equipment to sample DNA from the environment (e.g., microscope slide trap, DNA water extraction filters, suspect hemlock foliage) and Equipment and facilities to extract and amplify eDNA (e.g., extraction kits, thermocyclers, DNA sequencers)	High	Depends on method	Low sampling effort; Best when can be integrated into existing eDNA sampling efforts or where infrastructure to amplify and sequence DNA already exist. Can detect early infestations	Expensive; Requires specialized equipment and trained staff

Hemlock Silviculture

Silviculture can be used to reduce competition to support healthy hemlocks in stands without hemlock woolly adelgid. This can include the removal of damaged or suppressed hemlocks which reduces competition among the remaining trees. Silvicultural techniques applied to existing hemlock stands may also create suboptimal conditions for HWA survival, should a stand become infested. Reduction in stand density to achieve minimum acceptable stocking levels (70% crown closure) through either partial harvesting or crown release on 2-3 sides of hemlocks can promote tree growth and potential resilience to HWA. Once established, and depending on the stage of HWA infestation, different management approaches can be used to minimize the spread and impacts of HWA (Table 2) (Parker et al., 2023). Land managers and landowners should avoid pre-emptive removal of hemlock as it may contribute to more negative ecological effects than HWA-induced mortality alone, and pre-emptive removal reduces the ability to potentially find and breed resistant hemlock for future restoration efforts. Some environmental conditions that favour hemlock survival include trees with live crown ratios ≥ 50% and stands with 70% crown closure, adequate soil moisture during the growing season, and cool, mesic topography with deep, fertile, loamy soils.

Table 2. General management recommendations for hemlock stands at 4 stages of HWA invasion (Adapted from Table 1 in 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 ecological function of hemlock 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 advance regeneration of hemlock and evergreen conifers	Protect advance regeneration of hemlock and evergreen conifers	Protect advance regeneration of evergreen conifers Plant climate adapted evergreen conifers	Facilitate development of evergreen conifer Plant climate adapted evergreen conifers, hemlock, or resistant hemlock

Stage of invasion:	Not present	Low abundance, isolated populations	High abundance or widely established	High abundance or endemic
Best management practices:	Avoid pre-emptive salvage harvest of healthy hemlock Avoid harvest of infested hemlock until >60% needle loss to retain potentially resistant trees Minimize soil disturbance and logging damage to maintain vigour of residual canopy trees Minimize spread by human activity			

Control Options

Chemical Control

The Pest Management Regulatory Agency (PMRA) regulates and approves pest control products for use in Canada. Provinces, through their own pesticide regulations and acts, also control the use of these products within their jurisdiction. Municipalities, Conservation Authorities and other landowners or land managers may also have policies for the use of pest control products. Before selecting a product for use, landowners and land managers should become familiar with their efficacy, target and non-target effects. If unsure, consult a professional. All pest control products should be applied by a licensed applicator, following the label and manufacturer's instructions. Mention of specific products in this document does not imply endorsement by the Invasive Species Centre or any of the authors of this document.

In Ontario, there are three chemical control options fully registered for use against HWA: TreeAzin® (Azadirachtin 5%) and IMA-jet (Imidacloprid 5%) and IMA-jet 10 (Imidacloprid 10%). These three products are delivered by stem injection. The active ingredient in TreeAzin® is derived from the neem tree and moves rapidly throughout the treated tree (approx. 48 hours). Recent evidence suggests that it provides 2 years of protection. IMA-jet and IMA-jet 10 take approximately 6-9 months to show reductions in HWA abundance on treated trees but provide approximately 4-7 years of protection against HWA. In Ontario and Nova Scotia two additional products are available for control of HWA under Emergency Use Registrations through the fall of 2024: Starkle 20SG (Dinotefuran 20%) and Xytect 2F (Imidacloprid 233g/L). Both are administered as basal bark applications. Starkle 20SG moves into the tree canopy rapidly, usually within 2 to 3 weeks, making it useful for heavily infested, declining trees, and offers 1-2 years of protection against HWA. Xytect 2F reduces the abundance of HWA on treated trees in approximately 6-9 months and protects for 4-7 years. In some jurisdictions, Starkle 20SG and Xytect 2F can be applied at the same time, as a tank mix.

Refer to Appendix A for additional information.

Biological Control

Biological control has been used in attempts to control HWA in the eastern United States. Predatory beetles (*Laricobius nigrinus* and *Laricobius osakensis*) and flies (*Leucotaraxis argenticollis* and *Leucotaraxis piniperda*) have been collected from the native range of HWA and released into HWA infested areas. The

intent of these programs is to establish specialized predators that eat HWA in its native range to the areas in eastern North America where HWA has become a pest. The adult beetles feed on the nymphs during fall, winter, and early spring, while the young beetles and flies feed on HWA eggs in the spring. These predators are native to the Pacific Northwest and contribute to keeping the insect at an endemic level there. One beetle, *L. osakensis*, is native to Japan, but has become widely established in the eastern U.S.

In Canada there are active research programs evaluating these predatory insects for management against HWA. Releases of some species began in Nova Scotia in the fall of 2023.

Destruction/Removal/Thinning

After hemlock woolly adelgid is found in an area, density regulation by thinning of hemlock stands can increase light levels and reduce water stress in remaining trees. This can complement other forms of management by increasing tree vigor in under- to mid-story hemlocks. Increased vigor can reduce tree decline and increase overall hemlock resilience by increasing the accessibility of light, moisture, and nutrients. Though changes in foliar nutrients can affect HWA feeding, the changes caused by stand thinning are not significant enough to cause an uptake in feeding.

Where there are small and localized infestations of HWA, removal and destruction of infested trees can minimize further spread. Salvaging trees pre-emptively or removing HWA infested trees with more than 60% of the live crown is not recommended (Parker et al., 2023). In hemlock dominated forests, stand conversion may be an option to mitigate widescale ecological impacts caused by HWA. While this is an option depending on the severity of infestation, other strategies may be more useful when trying to keep ecologically important hemlocks present on the landscape. For example, heavier cutting will result in the regeneration of other pioneer species, but will be less favourable for hemlock regeneration.

Resources

There are many resources online to learn more about HWA in Ontario. On the Invasive Species Centre's YouTube channel, there are:

1. Educational videos that demonstrate proper HWA monitoring using ball sampling and sticky trap sampling
2. Recorded webinars as part of a Monthly Webinar Series, including:

    » Research, Awareness and Community Science: Limiting the Spread of Hemlock Woolly Adelgid, which discusses identification, impacts, and the importance of education, awareness, and community science to prevent further spread of this pest

    » Hemlock Woolly Adelgid Expert Panel – Question and Answer Session, which answers several frequently asked questions about HWA

The Invasive Species Centre (ISC) also offers an Invasive Forest Pest Training course which dedicates an entire lesson to HWA. Upcoming events, such as workshops or information sessions, will be posted on the ISC's events page, which is updated regularly with educational opportunities hosted by ISC or partners.

Some additional resources include the ISC's HWA species profile, the CFIA's HWA info page, and Nova Scotia's Hemlock Initiative.

Partnerships

Recently, the Invasive Species Centre partnered with Natural Resources Canada and the Canadian Food Inspection Agency to increase awareness of HWA and enable early detection through the HWA Monitoring Network. Community members interested in contributing to pest surveillance will be able to conduct HWA surveys on their property using an innovate environmental DNA trap that was developed by the Partridge Lab at Grand Valley State University.

There are several not-for-profit organizations that offer resources and opportunities for collaboration, including the Invasive Species Centre, Eastern Ontario Model Forest, Ontario Woodlot Association, and Forests Ontario. Some of these organizations work closely with individuals and non-government groups to support invasive species awareness, prevention, and management. One example is the Hemlock Woolly Adelgid Working Group that's facilitated by Silv-Econ, which aims to connect people who are interested in HWA (e.g., landowners, municipalities, park staff etc.) and discuss recommendations for prevention and management. If you're interested in joining this working group, contact Kathleen Ryan, Forest Entomologist at Silv-Econ.

The Ontario HWA Science Working Group, coordinated by CFIA and NRCan with ISC as the Secretariat, was established in 2023. The purpose of this working group is to address management, research, and communication needs in Ontario, as well as be an advisory body when new populations of HWA are detected. Members of this group each represent the needs, concerns, and abilities of their respective organizations, which can include federal, provincial, NGO, industry, and private woodlot owners.

Local naturalist and conservation clubs may also be a good source of collaboration and partnership.

References

Brantley, S.T., Mayfield III, A.E., Jetton, R.M, Miniat, C.F., Zietlow, D.R., Brown, C.L., & Rhea, J.R. (2017). Elevated light levels reduce hemlock woolly adelgid infestation and improve carbon balance of infested eastern hemlock seedlings. Forest Ecology and Management, 385: 150-160.

Coots, C., P. Lambdin, J. Franklin, J. Grant, and R. Rhea. 2015. Influence of hemlock woolly adelgid infestations levels on water stress in eastern hemlocks within the Great Smoky Mountains National Park, U.S.A. Forests 6: 271-279 doi: 10.3390/f6010271.

He, M., Sun, X., & Li, Z. (2018). Bending and compressive properties of cross-laminated timber (CLT) panels made from Canadian hemlock. Construction and Building Materials, 185: 175-183.

Hickin, M. & Preisser, E. L. (2015). Effects of Light and Water Availability on the Performance Hemlock Woolly Adelgid (Hemiptera: Adelgidae). Environmental Entomology, 44(1): 128-135.

Howard, T., Sendak, P., Codrescu, C. (2000). Eastern hemlock: a market perspective. In: McManus, Katherine A.; Shields, Kathleen S.; Souto, Dennis R., eds. Proceedings: Symposium on sustainable management of hemlock ecosystems in eastern North America. Gen. Tech. Rep. NE-267. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 161-166.

Kaboli, H. (2019). Northeastern species in hybrid cross laminated timber. Doctoral dissertation. University of Massachusetts Amherst.

Miniat, C.F., Zietlow, D.R., Brantley, S.T., Brown, C.L., Mayfield III, A.E., Jetton, R.M., Rhea, J.R., & Arnold, P. (2020). Physiological responses of eastern hemlock (Tsuga Canadensis) to light, adelgid infestation, and biological control: Implications for hemlock restoration. Forest Ecology and Management, 460: 117903.

Parker, W.C., Derry, V., Elliott K.A., MacQuarrie, C.J.K., and Reed, S. 2023. Applying three decades of research to mitigate the impacts of hemlock woolly adelgid on Ontario's forests. The Forestry Chronicle, 99(2), 205-225.

Trotter, R.T., Morin, R.S., Oswalt, S.N., & Liebhold, A. (2013). Changes in the regional abundance of hemlock associated with the invasion of hemlock woolly adelgid (Adelges tsugae Annand). Biological Invasions, 15: 2667-2679.

Appendix A - Survey Methods

Sampling techniques to detect canopy infestations of the hemlock woolly adelgid

Appendix B - Pesticide Information

Starkle Insecticide - Woolly Adelgid Control

IMA-jet Insecticide Solution

IMA-jet Insecticide Solution

Medway Community Forest Cooperative: Hemlock Woolly Adelgid Treatment Decision Key for Imidacloprid Use Only

Starkle 20 SG Water Soluble Granules

Treeazin Systemic Insecticide

Treeazin Systemic Insecticide Specimen Label

Xytect 2F Suspension

Invasive Species Centre

Canada