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Hemlock Woolly Adelgid Management Plan for Canada

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List of Abbreviations

AAFC	....	Agriculture and Agri-Food Canada
CFIA	....	Canadian Food Inspection Agency
HWA	....	Hemlock Woolly Adelgid
ISC	....	Invasive Species Centre
NTSC	....	National Tree Seed Centre
OMNRF	....	Ontario Ministry of Natural Resources and Forestry
PMRA	....	Pest Management Regulatory Agency of Health Canada
UAV	....	Unmanned aerial vehicle or drone

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Executive Summary

This report outlines the components for a hemlock woolly adelgid (*Adelges tsugae*, Annand, HWA) management plan for all the eastern provinces except for Newfoundland by building on previous risk assessments and reviewing HWA research and management practices implemented in the eastern US. To date, no single management tactic has been found to control the widespread hemlock mortality resulting from HWA in the eastern US, suggesting the need for an integrated management approach. The following are a list of potential HWA management tactics that could be implemented in Canada, along with the associated potential research needs and recommendations.

1. Continue to closely monitor hemlock stands for further HWA incursions

The early detection of HWA incursions is a critical part of controlling HWA spread and establishment in eastern Canada. Current visual surveys should be further developed and complemented with other methods to improve the detection of HWA at low densities. Furthermore, a complete hemlock inventory needs to be compiled to allow for the successful prioritization of monitoring and detection efforts.

2. Cut, remove, and monitor hemlock stands where HWA is found locally

Where HWA incursions are small and localized, and where eradication is deemed possible, the removal and incineration of hemlock trees should continue to be performed, along with the implementation of delimitation surveys for five years following detection. Formal criteria need to be defined to declare when the infestation is small enough to attempt eradication.

3. Treat high value trees with systemic insecticides

Insecticides are a valuable, rapid response tool that can be used to maintain survivorship of high value hemlock trees through HWA infestations, to slow the dispersal of HWA by treating hemlock trees surrounding an HWA infestation, and to buy time for biological control and or other management actions to become effective. Therefore, the certification of an imidacloprid-based systemic insecticide (eg., IMA-jet® or Confidor®) for use against HWA in Canada should be explored. Additionally, to assess the risk associated with imidacloprid-based tree injections for use against HWA in Canada, research on the influence of imidacloprid in fallen foliage on the ecosystem should be performed. Alternatively, the efficacy and certification of TreeAzin®, a botanical-based injectable insecticide, for HWA treatment in Canada should be explored.

4. Develop a biological control program for HWA in Canada

Biological control is a long-term management option that will be a critical tool now that HWA has become established in Nova Scotia. Federal and provincial departments should collect and study HWA predators found in western Canada and work alongside the US to further study and perfect rearing techniques for the most promising predators identified to date. Additionally, researchers in Canada should begin biological control field trials and research on the established populations in southwestern Nova Scotia. The development of field insectaries for rearing in Nova Scotia could also be explored.

5. Perform silvicultural management, including thinning, the reduction of hemlock in managed forests, and trimming and physical barriers to reduce HWA dispersal

Early research has shown that increased light exposure can reduce HWA survivorship and increase hemlock photosynthesis. Federal and provincial governments should invest in further research in this area to assess if silvicultural thinning is a viable management technique for HWA. In particular, it should be investigated if the positive impacts of thinning for HWA management can be achieved

without compromising the biota associated with the unique, shaded habitat of dense hemlock stands. Another potential management tactic that could be used is to increase the buffer zone (defined based on an analysis of the infestation) between infested and high value, non-infested stands by cutting down hemlock in managed forests to reduce the number of available host trees for dispersal. Again, this would be dependent on a complete hemlock inventory to identify hemlock stands of high value. Additionally, when eradication is not feasible, mechanical control options could be adopted to slow the spread of HWA by limiting contact with potential vectors (i.e. humans, vehicles, and animals).

6. Start collecting eastern hemlock seeds for preservation of genetic diversity and future restoration efforts

The preservation of eastern hemlock genetic diversity is important for future restoration and rehabilitation efforts. Therefore, Natural Resources Canada should build on and ensure the persistence of the eastern hemlock seed collection currently stored at the National Tree Seed Centre (NTSC) in Fredericton, New Brunswick by collecting and preserving a greater number of eastern hemlock seeds across eastern Canada. In particular, the collection of eastern hemlock seeds from southwestern Nova Scotia should be prioritized given the established HWA populations in this region currently causing hemlock mortality. Research on naturally resistant eastern hemlock individuals should be pursued through a partnership with the eastern US to help identify naturally occurring resistant host genes for breeding. Additionally, two outplanting field trials that contain eastern hemlock individuals from across its range in eastern Canada were developed in 2011 and present the opportunity for further research on genetic and phenotypic variability.

7. Develop a dual invasive species response framework to be applied to established HWA in Nova Scotia and new incursions of HWA in the rest of eastern Canada

An invasive species response framework is beneficial because it helps to prevent duplication of services, while allowing for action to be taken in a timely manner. Once developed, an invasive species framework can be tested using emergency response exercises and mock scenarios to ensure preparedness for future situations. Given that HWA populations are already established in parts of Nova Scotia, a dual framework should be developed to outline the response in the case of: (1) established HWA populations, and (2) newly discovered HWA incursions.

8. Assess and document established HWA population dynamics and impacts on hemlock stands in southwestern Nova Scotia

The discovery of HWA and associated hemlock mortality in southwestern Nova Scotia is the first case of established HWA populations in eastern Canada. Therefore, the study of HWA population dynamics and impacts on hemlock stands in Nova Scotia is critical to developing an effective management plan for HWA in Nova Scotia and all of eastern Canada. In particular, life table analysis looking at aestivating sistens mortality in the summer and sistens nymph mortality during the cold winter months would give an understanding of the impact of weather in Nova Scotia on HWA. Additionally, observing trends in HWA populations and hemlock mortality in relation to variables such as climatic variation, drought and pale-winged grey (*Iridopsis ephyraria)* defoliation may prove informative.

9. Continue to work on outreach and education to ensure constituency support

Community and stakeholder awareness and support is critical to the success of any management program, as it facilitates the ability to act within an effective time frame, prevents pushback that arises from misunderstanding, and provides more eyes on the ground for reporting of pest incursions. A recent survey distributed to stakeholders in Ontario by the Invasive Species Centre and Silv-Econ identified the specific need for a pest fact sheet available in electronic and hard copy form, and an HWA Best Management Practices brochure for woodlot owners. Therefore, provincial departments, independent agencies, and municipalities should further invest in community and stakeholder outreach and education by disseminating what is known about HWA and its current detection and management strategies. Community and stakeholder outreach should be continued through pest-information sheets, websites, and future events.

Introduction

The hemlock woolly adelgid (*Adelges tsugae* Annand, HWA) from the order Hemiptera, is an invasive aphid-like pest native to Asia that causes mortality of eastern and Carolina hemlock (*Tsuga* spp.) in the eastern US (Havill et al. 2006). Hemlock woolly adelgid is of growing concern in eastern Canada for its establishment and spread on eastern hemlock (*Tsuga canadensis*), especially given the recent discovery of established HWA populations in southwestern Nova Scotia. Hemlock is an important natural resource as a foundation species providing unique conditions in its terrestrial and riparian habitats. Hemlock trees are slow growing, and long-lived, with their canopies providing cool, shaded habitat and consistent hydrology (Ward et al. 2004). Many mammals, birds, insects and aquatic organisms rely on the unique habitat that hemlock provide (Tingley et al. 2002, Ward et al. 2004). Along with the provision of critical habitat for biota, hemlock also have great social value being renowned for their massive canopies and long-lived qualities. Eastern hemlock is the only hemlock species of concern for HWA in Eastern Canada and its native distribution is mainly restricted below the 49th parallel in Ontario, Quebec and Atlantic Canada, except Newfoundland (Figure 1). Although eastern hemlock is not a major source of revenue in Canada, a small amount is still used in pulp and paper mills and as lumber for construction.

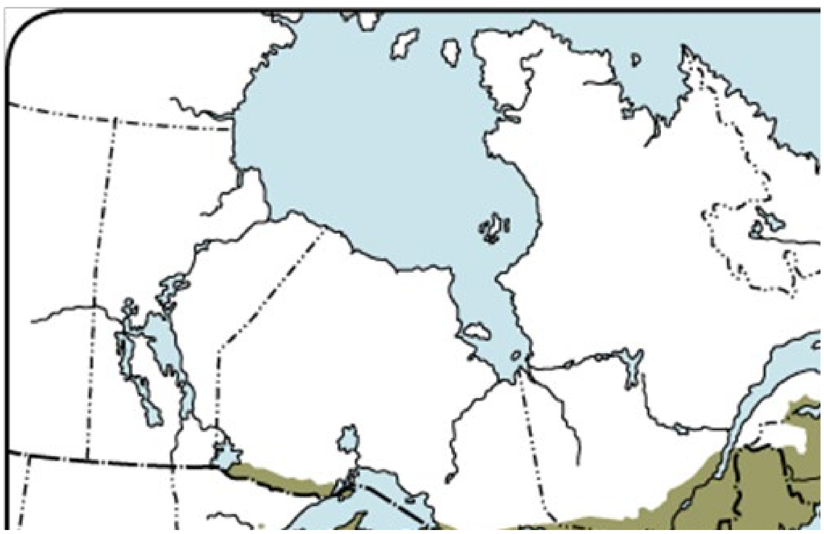

Figure 1. *Natural Resources Canada map showing the distribution of eastern hemlock across eastern Canada and bordering States. Source: https://tidcf.nrcan.gc.ca/en/trees/factsheet/75 [accessed February 27, 2018].*

HWA causes hemlock mortality by feeding on xylem ray parenchyma cells in hemlock twigs and shoots at the base of needles, which causes the buds to be killed off and prevents the tree from creating new growth. HWA has two successful generations per year on hemlock: a wingless sistens and wingless progrediens generation, both reproducing asexually. In its host range HWA switches to spruce as a primary host, reproducing via sexual reproduction (Havill et al. 2014). In North America however, HWA has not been successful in establishing or reproducing on native North American spruce species (McClure 1989).

In its native range in Asia, HWA does not cause significant host mortality due to a combination of native predators and greater host resistance. A distinct lineage of HWA also exists in western North America, but these western populations of HWA are considered native and do not cause significant hemlock mortality due to the presence of co-evolved predators (Havill et al. 2014). HWA was first reported in eastern North America in the early 1900's in Richmond, Virginia and was found to have originated from southern Japan (Havill et al. 2006). Since its discovery it has spread at a rate of 7.6–

20.4 km/year (Trotter et al. 2013) and is now established in the US from northern Georgia and Alabama in the south, to the northern States bordering with the eastern provinces of Canada (Figure 2). In Canada, HWA was confirmed in a small number of landscape trees in Etobicoke, Ontario in 2012 and had likely been introduced on infested nursery stock from Pennsylvania. A very small population was also detected in the Niagara Gorge in 2013 that was speculated to have arrived via bird migration, but this was never confirmed. All HWA infested trees that were detected in surveys were destroyed at both sites and surveys have been conducted every year since HWA was first detected in an attempt to eradicate HWA from Ontario (Fidgen et al. 2013).

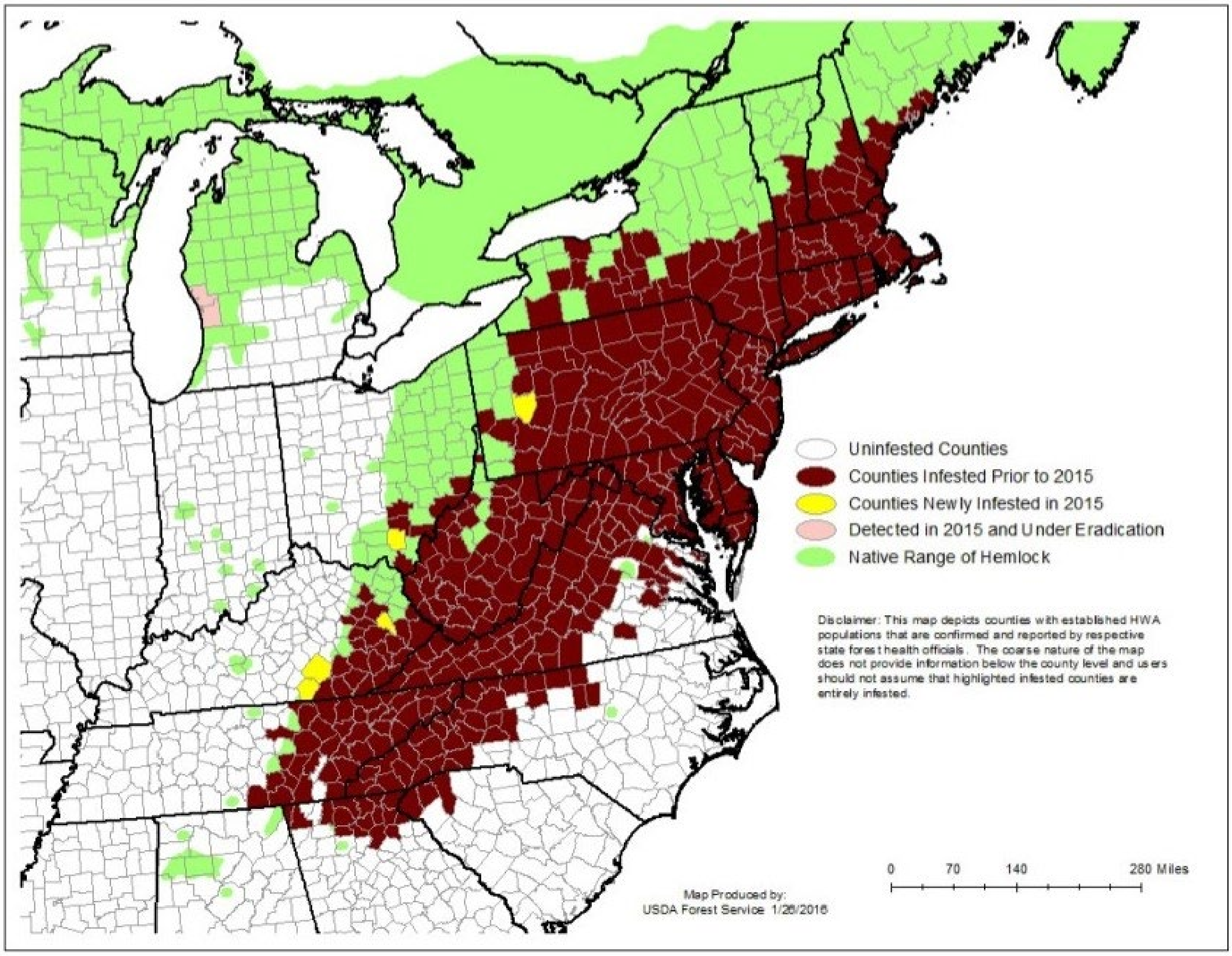

Figure 2. *Map published by the US Department of Agriculture showing hemlock range and the spread of the HWA infestation as of 2015. Green indicates hemlock distribution, yellow indicates areas newly infested in 2015, and red indicates areas infested prior to 2015. Source:* *https://www.fs.usda.gov/naspf/resources/2015-hemlock-woolly-adelgid-infestation-map* *[accessed February 27, 2018].*

In June 2017, HWA was found to be well established in five counties in southwestern Nova Scotia (Canadian Food Inspection Agency (CFIA) 2017a). The detection of HWA in one location lead to surveys that uncovered several sites in the southwestern region of the province also infested with HWA (CFIA 2017b). Based on the extent of the population it is estimated that HWA has been in southwestern Nova Scotia for 10 years or more. The detection in 2017 is coincident with drought in recent years that potentially accelerated the decline of HWA infested hemlock stands. The HWA incursions documented in eastern Canada and the continued northward expansion of HWA in the eastern US, confirms the threat that HWA may spread throughout the range of eastern hemlock in eastern Canada. Actions to reduce the risk of HWA spread to and within eastern Canada include the implementation of phytosanitary requirements (CFIA 2015a), and the promotion of community and stakeholder awareness (Fidgen et al. 2013, Ryan 2013, CFIA 2016). However, given the extent and severity of the HWA outbreak in the eastern US, the recent discovery of established populations in southwestern Nova Scotia and the risk of HWA spread to other parts of eastern Canada, an HWA management plan is needed to identify critical research gaps and ensure that immediate actions can be taken.

Objectives and Approach

The main objective of this report is to build on previous risk assessments (Biological Section of Agriculture 1988, Agriculture and Agrifood Canada (AAFC) 1994, Dumouchel-CFIA 2000) to outline the components for an HWA management plan for eastern Canada. To identify next steps, we review the factors that could influence HWA spread and impact on eastern hemlock in Canada (Risk Assessment), the current detection tools and surveillance methods (Detection and Monitoring), and current management actions being taken in eastern Canada along with future management options (Risk Management). We also identify potential research gaps that need to be addressed (Research Needs), discuss current policy and regulations (Policy and Regulations) and develop an outreach plan (Outreach and Education) in order to ensure effective management and response to current HWA establishment and future range expansion across eastern Canada.

Risk Assessment

Likelihood of introduction

The **risk that HWA may be introduced to new areas in eastern Canada is high** now that it has established over a large area of southwestern Nova Scotia and has also expanded its range in the US to 19 states, including Maine.

Although the natural spread of HWA during the crawler stage and via rain, wind and animals is considered local (≤ 30km/year), there are cases of **natural dispersal occurring over longer distances. Bird migration and movement** is a dispersal pathway of concern for introduction and spread of HWA from the US into Canada, as HWA eggs and crawlers can move on birds allowing for longer range dispersal to uninfested stands (McClure 1990, Russo et al. 2016).

HWA may also be spread by humans via nursery stock, logs and firewood moved from infested areas. In the most recent HWA risk assessment, the introduction of eggs or crawlers on logs of hemlock and associated hardwood species from infested areas when these stages are abundant (i.e., March to July) and the introduction of HWA on infested seedlings and nursery stock were identified as a medium and high risk respectively (Dumouchel 2000). In 2007, hemlock, Yeddo spruce, and Tiger-tail spruce propagative (plants for planting and nursery stock) and non-propagative (Christmas trees, wreaths, foliage, branches, forest products with bark attached, logs, bark chips and firewood) materials were designated regulated articles for import into Canada. After the documented HWA occurrence in Etobicoke in 2012, where HWA was introduced via nursery stock imported from Pennsylvania, the movement of HWA-regulated materials was further regulated under phytosanitary legislation and included imports from HWA infested and non-infested (for propagative materials only) areas of the US to all areas of Canada (CFIA 2015a, 2015b). For areas with HWA in Nova Scotia, an Infested Place Order has also been declared to control the movement of regulated articles (CFIA 2017b) and a firewood importation ban has been implemented by Parks Canada for Kejimkujik National Park. McClure (1990) noted comparable densities of HWA eggs on the trunks of associated hardwood species. **Given that large-scale**

harvesting operations are not currently restricted in forests with HWA, movement of HWA on the trunks of other associated tree species is still a potential dispersal pathway of concern. Additionally, risk of movement by humans undertaking recreational activities in infested areas is especially high during the months of March-July when eggs and crawlers are most abundant.

Resource at risk analysis

All eastern hemlock trees in Canada are susceptible to HWA. Age and resistance do not appear to be limiting factors when assessing mortality caused by HWA (Koch et al. 2006). In Canada, eastern hemlock occurs across southern Ontario, southwestern Quebec, New Brunswick, Nova Scotia, and Prince Edward Island. Hemlock woolly adelgid is currently found in Plant Hardiness Zones 5-6. In the southern US HWA usually kills trees in 3–4 years (Shields and Cheah 2004), but can take > 10 years to kill trees in colder regions. Hemlock woolly adelgid populations can suffer significant mortality following extreme low winter temperatures (Paradis et al. 2008). However, HWA populations can rebound in years following extreme cold weather events (Fidgen et al. 2013), and it was recently demonstrated that eastern North American HWA populations are already beginning to adapt to colder conditions (Lombardo and Elkinton 2017). Northward expansion of HWA due to increasing winter temperatures has also been predicted from climate change models (Paradis et al. 2008, McAvoy et al. 2017). Therefore, it cannot be assumed that cold winter temperatures will prevent the spread of HWA into hemlock stands currently located in Plant Hardiness Zone 4. In fact, climate change will likely exacerbate their decline in this region; eastern hemlock was listed as one of five tree species in the northeastern USA with the lowest adaptive capacity to climate change, based on the combination of its susceptibility to HWA and its relative drought intolerance (Janowiak et al. 2018).

In Ontario hemlock represents about 1% of the total growing stock and is found across a total area (i.e., crown, parks and protected areas, and other) of 1 065 952 ha, often found near water, in association with yellow birch and maple (Ontario Ministry of Natural Resources and Forestry (OMNRF) 2016). The average annual harvest of hemlock between the years 2014–2016 in Ontario was 20 430 cubic metres, with an average of 22 mills reported to have processed hemlock for composite products, fuelwood, pulp or saw logs (McCormack email correspondence 2017).

In Quebec, a 79 350 ha area is dominated by hemlock (i.e., it occupies ≥ 25 % of the basal area in a stand) and hemlock comprises 0.246% of the productive forest. Between the years 2014–2016, an average of 12 114 cubic metres of hemlock were harvested annually, with an average of 31 mills reported to have processed hemlock for pulp, saw logs, cogeneration or other purposes (Lacroix email correspondence 2017).

In New Brunswick, hemlock occurs across approximately 97 629 ha (1.6 % of total forest area) where it comprises 10-100 % of the forest stand. On average, 11 311 cubic metres of hemlock were harvested annually between the years 2014–2016. Four to six mills were recorded as having processed hemlock each year from 2014–2016 (Gannon email correspondence 2017).

Prince Edward Island is comprised of 90% privately owned land and hemlock area and harvest is negligible. Hemlock is typically found on river banks and is limited to private use by farmers for barn beams (Bain email correspondence 2017).

In Nova Scotia photo-interpreted-based forest inventory indicates that of the 2.8 million hectares of reproductively mature forests, 4% (112 000 ha) are considered mature hemlock forests. The permanent sample plot data collected between 2012 and 2016 across the entire province indicates that approximately 2.5% of the basal area is eastern hemlock (McGarrigle email correspondence

2018). A range of 48–57 mills, including all small-scale operators and portable sawmills, reported processing some quantity of hemlock annually from 2014 to 2016. In general, the quantity of hemlock processed at each of these mills only made up a small percentage of the total wood processed (Hudson email correspondence 2017).

Identifying areas of high risk for HWA invasion will be critical to the success of monitoring and tracking efforts. Therefore, the **lack of a complete hemlock inventory showing the location and quantity of hemlock in eastern Canada** is one of the **greatest barriers to successful management and control** and one that needs to be addressed. Once a more complete hemlock inventory is available, various factors can be used to prioritize management efforts. For example, to prioritize monitoring efforts and promote early detection of HWA, information on the distribution and infestation level of established HWA populations and their proximity to uninfested stands (e.g., within a 100 km radius), locations with hemlock nursery stock, tree health and habitat type (e.g., Livingston et al. 2017), bird migratory routes, as well as the social and economic value of the stand at risk can be utilized. Previous models of a spatial risk rating system (e.g., for Brown Spruce Longhorn Beetle by CFS and CFIA) could be used to develop a landscape-wide risk rating system for HWA.

Silv-Econ has started compiling a database of hemlock stands across Ontario from existing sources such as conservation authorities, upper and lower tier municipalities, sustainable forestry licences, OMNRF, and private citizens. This hemlock database includes percentage (%) hemlock cover, description of the stand composition, data source, and provides for survey and detection data input (Ryan email correspondence 2017). The database is constantly being updated, but is not yet complete and requires further data input, especially in southern Ontario where most of the land is privately owned (Figure 3). Hemlock inventory data also exists for the Maritime Provinces, but this data could be improved on, especially in urban areas. The collection of data for a hemlock database in eastern Canada could be obtained via further community outreach to encourage the reporting of hemlock stand information and through remote sensing techniques such as LiDAR and/or high resolution imagery.

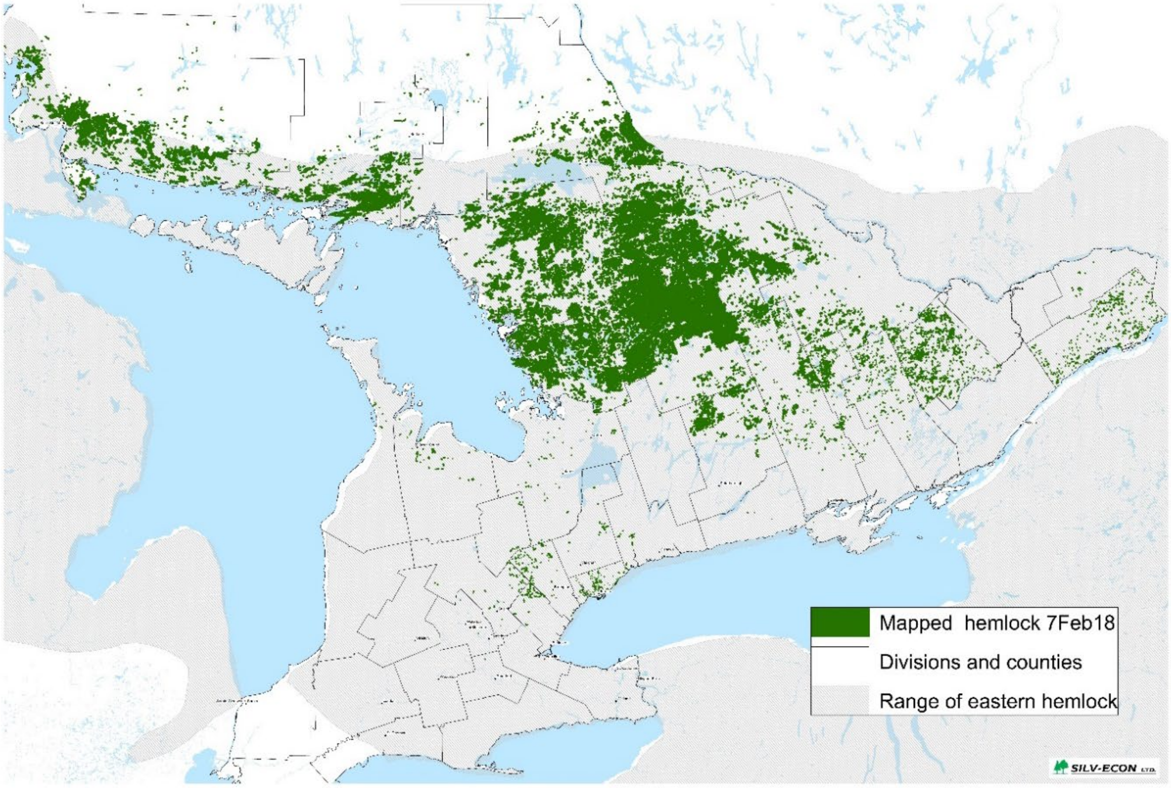

Figure 3. *Mapped (green) and expected (light grey) distribution of eastern hemlock in Ontario. A collaboration of the hemlock woolly adelgid forest managers working group. Updated 17 January 2018. Produced using information under License with the Grey Sauble Conservation Authority © Grey Sauble Conservation Authority, 2018.*

Consequences of introduction

Environmental and economic impact: HWA spread in the eastern US is not controlled and has caused up to 100 % mortality in some hemlock stands (Havill et al. 2014, Brantley et al. 2015). The invasion of HWA and subsequent mortality of hemlock in eastern Canada has implications for the provision of ecosystem services and on critical habitats, aesthetic values, hunting, property values, tourism and, to a lesser degree, will impact the availability of forest products made from hemlock.

In terms of environmental impacts, the mortality of hemlock stands in eastern Canada would result in a complete change in the associated terrestrial and aquatic ecosystems. Successional changes that occur after the death of slow growing hemlock stands result in a shift to deciduous hardwood species (Spaulding and Rieske 2010, Ingwell et al. 2012) and an increased probability of exotic plant species invasion (Eschtruth et al. 2006). For example, *Alliaria petiolata* (garlic mustard), an aggressive invasive plant species in eastern Canada, has been reported in stands following hemlock mortality in the US (Eschtruth and Battles 2009). Similarly, glossy buckthorn (*Frangula alnus*), an invasive plant species found in regions across eastern Canada and whose spread has been found to be inhibited by dark shade, may spread more readily following the reduction of shaded habitat by HWA-caused hemlock mortality (Cunard and Lee 2009). With these successional changes comes a complete change in ecosystem services including nutrient and energy cycling and water use and availability (Jenkins et al. 1999, Hadley et al. 2008, Cobb 2010), along with changes in key habitat characteristics which many species are known to depend on (Tingley et al. 2002, Ward et al. 2004).

The economic impacts of HWA-caused hemlock mortality are not limited to the disappearance of the timber resource. For instance, hemlock stands also potentially contribute to hunting tourism via the provision of ideal overwintering habitat for deer and moose. As well, property values and revenue from eco-tourism would be expected to decrease as a result of the loss in aesthetic appeal and the unique natural environment that hemlock stands are known for.

Detection and Monitoring

Detection methods

Early detection and monitoring of HWA is critical to rapid response and control of HWA in Canada. However, early detection is a challenge because effectively identifying hemlock stands of high priority for surveying is difficult without access to a complete inventory of hemlock stands in Canada and because HWA infestations can be very small and hard to detect visually from the ground. The current Canadian early detection survey protocol, modified from a US Department of Agriculture (USDA) Forest Service protocol (Costa and Onken 2006), is a visual survey targeting nymphs, adults and white egg sacs and is ideally performed from March to May (CFIA 2018). Information including aerial photos, forest inventories, wind patterns, bird migratory routes and proximity to importers of hemlock nursery products and the eastern US (≤100km) can be used to select stands with a major component of hemlock and that are at least 4 ha in size for surveying. Surveyors refresh their search image for individual HWA and small clusters of woolly masses prior to beginning their survey and then follow a step-by-step procedure that also includes instructions for sample collection. Procedures for the examination of nursery stock in plantations, urban parks, and green spaces also exist (CFIA 2018).

Visual detection surveys were successful in identifying HWA in the Niagara Gorge in 2013 and thus continue to be the primary survey method for detection of this pest. Efficacy testing may be an important area of research to ensure successful early detection and monitoring of future and current HWA incursions. Other tactics may also need to be incorporated into existing survey protocols. For example, **in riparian areas, where it is feasible, lake-side surveys may complement the existing visual assessment protocol**. Lake-side surveys are performed in the spring from a boat and examine riparian hemlock to assess if new growth is apparent. Hemlock trees with HWA will have little to no new growth in the spring and this can be detected visually from the stream or lake. Lake-side surveys have been used in New York State because they allow for rapid and easy access and assessment of riparian hemlock stands (Whitmore pers. comm. 2017). This technique may prove useful in hemlock riparian stands in Canada. Additionally, the development of methods for assessing hemlock spring growth using unmanned aerial vehicles (UAV) or drones are being explored and, although these techniques are in an early stage, they may show promise in the future.

Other detection methods that are based on sample collection include branch sampling, sticky traps and ball sampling. These methods tend to be more time intensive than visual surveys, but provide an alternative option that may prove more sensitive and useful in certain scenarios and may detect HWA where visual surveys do not. For example, **ball sampling has advantages where canopies are too high for branch sampling or visual assessment** (Fidgen et al. 2016), but can also be time-intensive because the surveyor must find and retrieve the balls after firing them high into the canopy. Sticky traps provide a sampling method that targets crawlers and are more sensitive at detecting infested trees than branch sampling, which is currently conducted for detection or delimitation in high risk or suspect areas. However, sticky traps require identification of the crawlers after collection, especially in stands that also contain white pine or balsam fir that can host the adelgids *Adelges piceae* (Ratzeburg) or *Pineus strobi* (Hartig)(Fidgen et al. 2015). In conclusion**, the further development of monitoring techniques to improve detection of HWA at low densities and to monitor dispersal of established populations is required. This could lead to the development of survey and detection protocols that are location-specific by integrating more than one tactic.** Additionally, **developing a scenario-based response framework** would be an asset as it would **identify when and where each survey tool is best suited**.

Identification

There are no other adelgids found on hemlock in eastern Canada. However, HWA can be confused with other insects (e.g., spittlebugs, oak skeletonizer) other arthropods (e.g., spider egg sacs, mealybugs), spider mite injury or even drops of pine sap when using visual assessments (USDA Forest Service 2005). HWA can be distinguished from these look-alikes by the following characteristics; balls of wool are waxy, it occurs in separate distinct balls and is permanently attached to the twig or branch at the base of the needle (Ancient Forest Exploration and Research). Pictures and locations of suspected HWA can be submitted to the CFIA by telephone (1-800-442-2342), or email Surveillance@inspection.gc.ca and by using the EDDMaps Ontario app (eddmaps.org/Ontario; Ontario only). **Official confirmation of new HWA incursions outside an established regulated area is made by the CFIA's Entomology Laboratory**. The way that HWA incursions are reported, confirmed and documented should be standardized and made readily available to all eastern provinces of concern for HWA.

Delimitation and monitoring

Following the detection of HWA, delimitation survey protocols were outlined and implemented in response to the HWA incursions in Ontario and Nova Scotia. The delimitation survey protocol includes visual surveys and branch sampling of the positive trees and surrounding area to determine the extent of the infestation and to monitor any potential spread over time (CFIA et al. 2017).

Risk Management

To date, no single control method has been found that can successfully control HWA and prevent mortality and spread in eastern North America. Instead, it is likely that an integrated pest management program is required that includes a suite of different management tactics applied based on the stage of infestation, the location of the infested trees and the value of the stand or tree in question. Here we present the latest chemical, biological and silvicultural control tactics that have been developed and tested in the US. Some of these tactics could be adapted for use in eastern Canada, along with a plan for potential restoration and an invasive species response framework.

Chemical control

Chemical insecticides can provide short-term protection from HWA and buy time for the development of an effective biological control program. Therefore, **it is essential that pest managers in Canada have access to chemical treatment against HWA** to ensure that we can maintain hemlock genetic diversity, aesthetic-social value and ecological integrity, while biological control methods are being developed.

In the US systemic insecticides from the neonicotinoid family are commonly used to help save and protect hemlock trees from HWA infestations. The insecticides are applied via soil drench, soil injections, soil tablets, basal bark sprays, or tree injection. Imidacloprid is the main chemical compound used and is available in different formulations, including a soil drench product available to homeowners. When applied to the soil, imidacloprid can take anywhere from 3 to 12 or more months to spread to hemlock tissue depending on the application technique used and the canopy stratum examined (Coots et al. 2013, Benton et al. 2015). Significant treatment effects have been demonstrated within 2-3 years following soil or trunk imidacloprid injections (Eisenback et al. 2014) and the effectiveness of imidacloprid along with its metabolites is estimated to last between 4 and 7 years before re-application is required (Benton et al. 2015, 2016). Dinotefuran, another neonicotinoid, is also sold in the US. It is transported to the tree canopy much more rapidly than imidacloprid and can have more immediate impacts on feeding HWA. However, dinotefuran is only effective for 1 year, so is often applied in combination with imidacloprid to trees that require immediate treatment (Havill et al. 2014).

In Canada, the use of neonicotinoids is regulated by the Pest Management Regulatory Agency (PMRA). The only method of application currently permitted is via trunk injection because of the known effects on pollinators and persistence as a contaminant in soils and water (Bonmatin et al. 2015, Woodcock et al. 2017). Individual provinces may also further regulate the use of these or other insecticides. Confidor®, an imidacloprid based systemic insecticide, was registered for use in Canada in the past (Bayer 2016), but has since been discontinued. IMA-jet®(ARBORjet 2014) is another imidacloprid-based systemic insecticide that may prove useful against HWA, but is only currently registered in Canada for use against emerald ash borer and Asian longhorned beetle. Tree injections do not guarantee that environmental contamination is prevented, as foliage from some deciduous tree species contain concentrations of injected imidacloprid after leaf fall and these concentrations of imidacloprid can have impacts on decomposition organisms and processes (Kreutzweiser et al. 2009). However, this may not be true for all tree species. Therefore, to determine how viable these imidacloprid based systemic insecticides are for HWA control, **research is needed to assess if concentrations of these neonicotinoids in fallen hemlock tree foliage following tree treatment are detrimental to the surrounding ecosystem**. Alternatively, the **use and efficacy of non-neonicotinoid tree injection insecticides should be explored. For**

example, Azadirachtin, a botanical injectable derived from neem tree seed is currently certified (as TreeAzin®) for treatment of HWA in the US (BioForest Technologies Inc. 2017), but efficacy testing has not been performed. In Canada, TreeAzin® is currently registered for treatment of emerald ash borer and 8 other tree pests, but not HWA.

Biological control

The development of a biological control program is critical to the successful management of HWA in Canada. Building on the research done in the eastern US (Onken and Reardon 2011, Havill et al. 2014, Letheren et al. 2017), Federal and provincial departments **should pursue the most promising biological control agents with emphasis on collection of predators from western North America and the development of our own lab and field insectaries for predator rearing**. Field trials and research should begin in southwestern Nova Scotia where there are currently established HWA populations.

Following introduction of HWA to eastern North America, native predators were unable to control HWA populations, making the introduction of non-native predators a necessity aiming for successful long-term, biological control (Wallace and Hain 2000). Biological control of HWA in the eastern US has primarily focused on the release of predator species because there are no known parasitoids of HWA. The biological control program for HWA in the eastern US began in 1992 and releases have been ongoing since the early 2000's. Several biological control agents have been explored including Coccinellid beetles from Asia (*Sasajiscymnus tsugae* Sasaji and McClure, *Scymnus sinuanodulus* Yu and Yao, *Scymnus ningshanensis* Yu and Yao, and *Scymnus camptodromus* Yu and Liu), *Laricobius* (Derodontidae) beetles from western North America and Japan (*Laricobius nigrinus* Fender and *Laricobius osakensis* Montgomery and Shiyake respectively) and species of silver flies from the family Chamaemyiidae native to western North America, *Leucopis argenticollis* and *L. piniperda* (Onken and Reardon 2011). The potential use of entomopathogenic fungi has also been explored (Reid et al. 2010), although non-target impacts are of greater concern with entomopathogenic fungi than with predators (Table 1).

Table 1 Summary of HWA biological control agents explored in the US to date.

Biological Control Agent	Type	Origin	First Release in US	Quantity released as of 2014	Issues
Laricobius nigrinus	beetle	Western North America	2003	~200 000 over 200 sites	Inadequate numbers for release, hybridization with native *L. rubidus*
Laricobius osakensis	beetle	Japan	2012	Limited release	Good recovery rates not yet achieved
Sasajiscymnus tsugae	beetle	Japan	1995 (Discontinued 2014)	>2 000 000 over 400 sites	Inconsistent success results
Scymnus sinuanodulus	beetle	China	2004	Limited release	No recoveries and difficulties in mass rearing
Scymnus ningshanensis	beetle	China	2004	Limited release	No recoveries and difficulties in mass rearing
Scymnus camptodromus	beetle	China	Being prepared for release	N/A	Difficulties rearing
Leucopis spp.	fly	Western North America	2017	1800	Little known about biology
Beauveria bassiana, Lecanicillium lecanii, Metarhizium anisopliae	Entomopathogenic fungi	Eastern USA & China	Tested in a lab setting only (Reid et al. 2010)	N/A	Greater concern for non-target impacts

Currently, the most widely released biological control agents in the eastern US are *L. nigrinus* and *S. tsugae*. *Sasajiscymnus tsugae* was one of the first HWA predators imported, studied, reared and released. However, its establishment and effectiveness as a biological control agent of HWA have been inconsistent and so its use was phased out in 2014 (Havill et al. 2014). *Laricobius nigrinus* shows more potential and has had better recovery rates than *S. tsugae*. *Laricobius nigrinus* is a predatory beetle native to the Pacific Northwest that feeds exclusively on adelgids and only completes full development on an HWA. *Laricobius nigrinus* has one generation per year and, like adelgids, is active in the fall, winter and spring and dormant in the summer. Adult *L. nigrinus* feed on sistens nymphs through fall and winter. An individual *L. nigrinus* larva feeds on hundreds of progrediens eggs in early spring. Densities of *L. nigrinus* increase with HWA densities and release size and minimum winter temperatures have been shown to be positively associated with establishment (Onken and Reardon 2011). However, three main issues with *L. nigrinus* remain including; inadequate numbers for release due to difficulty in collecting *L. nigrinus* in high numbers in its native Pacific Northwest range, the challenges and high cost of rearing, which are still being refined in Virginia, Tennessee, and New York and the hybridization of *L. nigrinus* with *Laricobius rubidus* (LeConte). *Laricobius rubidus* is a predatory beetle native to eastern North America that feeds preferentially on pine bark adelgids found on white pine, but can survive and develop on HWA found on eastern hemlock. Hybridization of *L. nigrinus* and *L. rubidus* has been documented at rates from 10-25%, with hybridization rates stabilizing at around 11 % over time (Fischer 2013, Mayfield et al. 2015).

Another predatory beetle, *Laricobius osakensis*, is currently being explored for its potential effectiveness as a biological control agent of HWA. *Laricobius osakensis* is native to the same region in Japan that eastern North American HWA originated from and shows potential as a more voracious predator on HWA than *L. nigrinus*. As with *L. nigrinus*, *L. osakensis* preys on HWA sistens nymphs in the fall and winter and larvae consume progrediens eggs in early spring months. The first release of *L. osakensis* in the eastern US occurred in 2012 (Havill et al. 2014). Although good recovery rates have not yet been achieved, the potential for *L. osakensis* as a more aggressive predator warrants further study.

Although *Laricobius* beetles are showing promise, they are unlikely to control HWA on their own. Therefore, the complementary use of other biological control agents is being explored. For example, silver flies, *Leucopis argenticollis* and *L. piniperda* from western North America are a potential predator that may complement *Laricobius* spp. as they do in the Pacific Northwest. *Leucopis* spp. larvae feed on both progrediens and sistens eggs in early and late spring, whereas *Laricobius* spp. larvae only feed on progrediens eggs. Additionally, *Leucopis* spp. have been successfully collected in the wild in high numbers (e.g., recent collections recovered 4000 individuals on 80 lbs of branches; Whitmore personal communication 2017). *Leucopis* spp. also display cold tolerance and a synchronous lifecycle with HWA and have been established experimentally (Grubin and Ross 2011), and in the field (Whitmore personal communication 2018). However, many questions remain about the biology and ecology of *Leucopis* spp., and this is a current area of research. Other *Scymnus* (*Neopullus*) species are also being explored as a potential candidate to complement *Laricobius* spp., including *Scymnus* (*Pullus*) *coniferarum* (Crotch) native to western North America and *Scymnus camptodromnus* native to China. *Scymnus* spp. have the potential to complement the other predators because they can feed on HWA in the summer when others do not. However, *Scymnus* spp. are very difficult to rear and releases of *Scymnus sinuanodulus* and *S. ningshanensis* made in 2004 yielded no subsequent recoveries. *Scymnus camptodromus* shows promise (Limbu et al. 2016), but is currently on hold because the lab colony was lost just before release was approved and efforts to bring this species back from China are not being planned. *Scymnus coniferarum* has been released in North Carolina and work indicates that this species is more of a facultative HWA predator, potentially allowing them to maintain populations when HWA densities are low. However, they may not sufficiently impact HWA populations for biocontrol.

The biggest challenge associated with current biological control efforts in the eastern US is the availability of adequate predator numbers for release because native collections have been inadequate so far and lab rearing methods are expensive and still being refined**.** Along with refining rearing techniques in the lab, field insectaries have been developed in the eastern US that allow for the rearing and accessible harvest of HWA predators (Onken and Reardon 2011). Field insectaries are comprised of trimmed hemlock hedges (≤ 8ft tall) that house predators of HWA for rearing, collection and release. Factors such as the amount of UV radiation and the timing of hedge trimming are being studied and refined to allow for optimal rearing results (Whitmore personal communication 2017).

A good predatory biological control agent has high prey specificity, a life cycle that is synchronous with its host, feeds on multiple life stages of its prey and has quick generation time. Overall, the most promising biological control agents are *Laricobius* spp. in combination with both *Leucopis* spp. Current research is working on improving recovery rates of these predators. To track the status and success of their biological control program, the US initiated a centralized database for predator release and monitoring in 2007, called the HWA Predator Release and Recovery Database. **Researchers in Canada should partner with the US on a joint predator release and monitoring database for HWA to track and follow the success of HWA biological control in North America**. The certification of a new biological control agent in Canada would require following the guidelines set out by AAFC (De Clerck-Floate et al. 2006). Additionally, past evaluations of Canadian biological control programs should be taken into consideration (MacQuarrie et al. 2016).

Silvicultural management

The current management approach in Canada for HWA incursions is tree removal and destruction where the incursion is small and localized and eradication is deemed possible. However, this will not remain a viable option for long-term management as incursions become more frequent and HWA begins to establish over large contiguous areas, nor is it applicable to well-established infestations in Nova Scotia.

Silvicultural management options that target the maintenance and promotion of hemlock health and resilience have been studied and show promise. For example, **silvicultural thinning to increase light penetration in infested hemlock stands may be a beneficial management tactic**. Early research on infested hemlock seedlings has shown that increasing light penetration by 30-50% can help to decrease HWA survivorship through increased exposure to UV radiation, while also increasing hemlock photosynthesis potential and carbon balance (Brantley et al. 2017). Other studies have found higher nitrogen concentrations in foliage are associated with increased densities of HWA (Pontius et al. 2006) and fertilization with nitrogen increased HWA fecundity (Joseph et al. 2011). Silvicultural trials have been underway in eastern US with 30-40% stand thinning prioritized to release midstory and understory hemlock, including in stands without but in close proximity to HWA infestations (Fajvan personal communication 2017). Similar approaches still need to be tested in the context of the Acadian forest in Nova Scotia, with the aim of mitigating

HWA impacts on tree health while other control measures are being developed or used in combination.

Another potential silvicultural management approach is to **prune and cut infested stands to prevent contact of infested branches with other trees and potential dispersal vectors** such as vehicles, humans and animals. For example, in Maine, management techniques have targeted the pruning of trees infested with HWA in public areas to remove branches and trees overhanging parking lots or hiking trails (State of Maine 2017). The strategic removal of hemlock trees from managed forests and the use of physical barriers such as fences around infested stands to prevent contact with people and animals may also be viable tactics to help reduce dispersal to hemlock stands of high value (McClure 1995).

Restoration and rehabilitation

The conservation of hemlock genetic diversity is critical to the restoration and rehabilitation of hemlock stands impacted by HWA in eastern North America. As the HWA outbreak will continue to spread in eastern Canada**, the collection and conservation of eastern hemlock genetic diversity should be incorporated into the HWA management plan**. In the US the Hemlock Gene Conservation Program was initiated in 2003 by the USDA Forest Service and Camcore. To date, seeds from 750 eastern hemlock mother trees across 76 populations and 168 Carolina hemlock mother trees across 24 populations having been sampled and stored (Hodge et al. 2017). Seed zone delineations were used to prioritize locations for hemlock seed collection and recently a model that incorporates information on climate, population disjunctiveness, HWA abundances, seed collection density, and genetic parameters has been put forward to further help prioritize eastern and Carolina hemlock conservation efforts in the eastern US (Hastings et al. 2017). Long term conservation of hemlock seeds can be done via cold storage, cryogenic storage in liquid nitrogen, or planting in protected orchards located in other countries or uninfested areas (Jetton et al. 2013, Oten et al. 2014, Hodge et al. 2017). The **National Tree Seed Centre (NTSC)** at the Atlantic Forestry Centre in Fredericton, New Brunswick (Natural Resources Canada, Canadian Forest Service – NRCan, CFS) can process and store a centralized library of eastern hemlock seeds in Canada. However, **financial support would be required to fund future eastern hemlock seed collection, processing, storing and viability testing**. Partnerships between the NTSC, the Invasive Species Centre (ISC) and groups like the Forest Gene Conservation Association could be developed to help support eastern hemlock conservation efforts. This effort would be an extension of the current initiative for ash conservation in response to emerald ash borer and could incorporate existing provincial and national hemlock conservation programs. For example, the Nova Scotia Department of Natural Resources has collected and stored seed in the past and is currently planning to collect eastern hemlock seeds in the fall of 2018. Eastern hemlock seeds have been collected from Ontario, Quebec, New Brunswick, Nova Scotia and Prince Edward Islands between 1997 and 2006 for research and general conservation purposes (Figure 4) and are currently stored at the NTSC. These seeds are tested by NTSC staff for viability every 10 years. Viability testing results have demonstrated the successful storage of eastern hemlock seeds (viability generally ≥ 80 %) for 20 years, with 30-year viability testing due to occur in 2018.

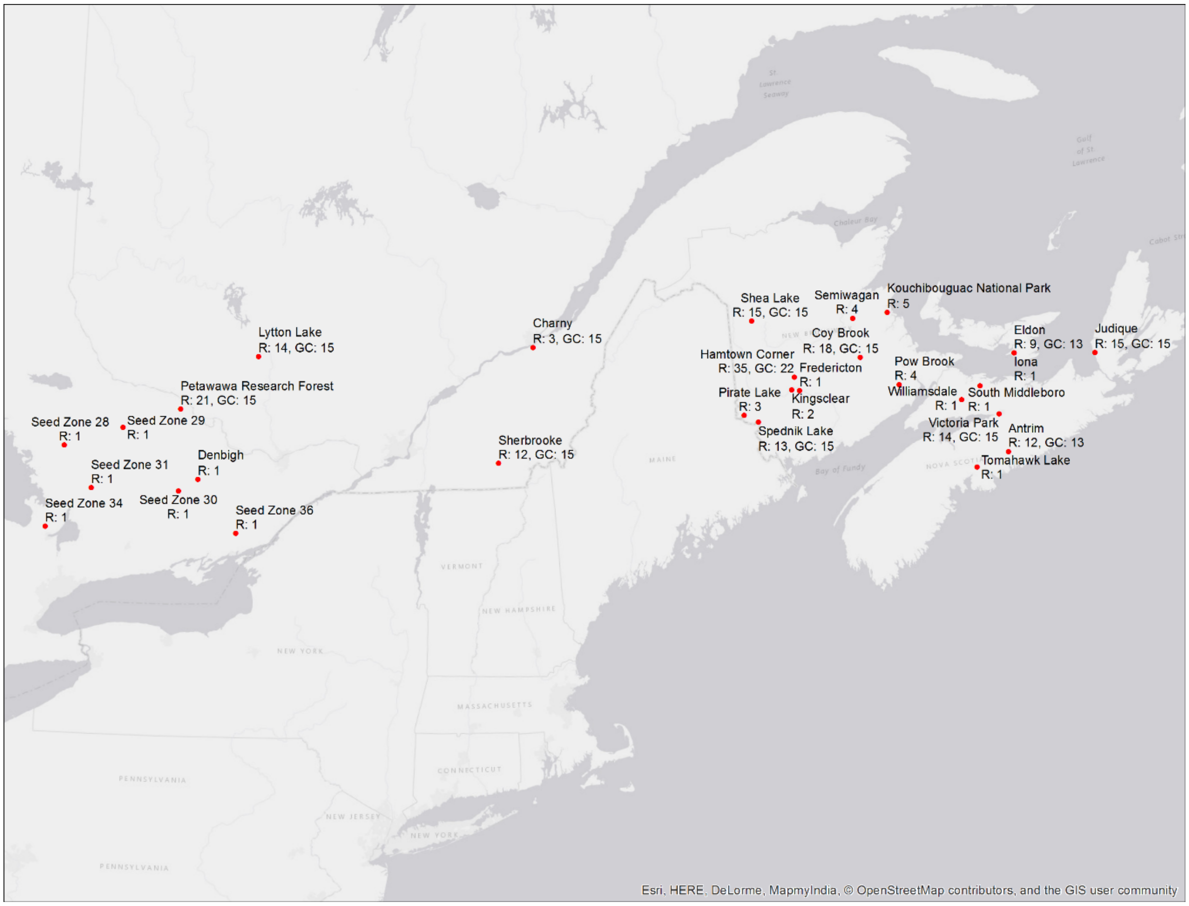

Figure 4. *Map showing locations of the eastern hemlock seed collections made across eastern Canada to date and currently stored at the National Tree Seed Centre in Fredericton, New Brunswick. R represents seed collected for research purposes, and GC represents seed collected for general conservation purposes. Numbers represent the number of individual trees sampled. Note the lack of collections from the southwestern portion of Nova Scotia currently infested with HWA.*

Low genetic diversity of eastern hemlock was found across 60 populations in North America (Lemieux et al. 2011), which included 22 populations from eastern Canada. Low genetic diversity means that potentially fewer collections will be required to conserve eastern hemlock in eastern Canada. However, the more collections the better and collections are still required to supplement the existing stock at NTSC and maintain a viable collection through time. In particular, **collection and preservation of seeds from southwestern Nova Scotia should be a first priority** due to the established HWA populations currently causing hemlock mortality in this region. The best time for eastern hemlock seed collection is in the fall from mid-September to mid-October. Due to the size of mature hemlock stands, non-destructive collection of cones usually requires climbing or collection from a helicopter. However, if mortality of the tree is imminent more destructive sampling methods (e.g., saws, pruners) can be used, which reduces the time and effort required for sample collection. Two out-planting field tests with eastern hemlock seedlings from Ontario, Quebec, New Brunswick, Nova Scotia and Prince Edward Island were set up in the spring of 2011 by NRCan-CFS. These field trials are ongoing and provide opportunity for further research on the genetic and phenotypic diversity of eastern hemlock across its range in eastern Canada (McPhee personal communication 2017).

Along with the preservation of genetic diversity, studying individuals with natural resistant to HWA is of particular interest when looking to preserve and replace eastern hemlock on the landscape.

Research in the US has focused on preserving and studying individual resistant eastern and Carolina hemlock trees. Trees reported to have survived HWA infestations are vegetatively propagated, infested with HWA to confirm resistance and then placed in a breeding population pool for further study and crossing (Oten et al. 2014). Researchers in **Canada could examine the mechanisms and genes behind intraspecific host resistance in eastern hemlock** to aid in future eastern hemlock conservation and HWA control**.**

Restoration efforts in the eastern US have explored replanting hemlock forests with resistant hemlock species. For example, recent research has shown that the HWA-resistant Chinese hemlock (*Tsuga chinensis*) can grow successfully in the eastern US (Harper and Weston 2016) and that crosses between native and non-native hemlock species can be created to increase HWA host resistance (Montgomery et al. 2009, Jonas et al. 2012). However, tree replacement with non-native hemlock does not contribute to the conservation of eastern hemlock as a species. Furthermore, cross-breeding of more resistant hemlock has not been as successful with eastern hemlock as with Carolina hemlock (Bentz et al. 2002) **and replacement with non-native hemlock species would require further research to examine the resulting changes and implications at the ecosystem scale.**

Invasive species response framework

A rapid response is critical in order to effectively manage incursions and infestations of invasive species. Therefore, to ensure adequate response time to current and future HWA incursions, a formal agreement among organizations and stakeholders should be created to prevent duplication of services and ensure that action can be taken immediately. **A dual HWA response framework should be developed that identifies the actions that would be taken following the discovery of: (1) an established HWA population (i.e., the current situation in Nova Scotia), and (2) new HWA incursions (i.e., the rest of eastern Canada at risk).** Following the development of a dual HWA response framework and implementation in Nova Scotia, emergency response scenario testing should be done in the other eastern provinces where hemlock is at risk to refine both a general HWA response framework and frameworks specific to each province. These exercises would bring together a group of qualified individuals to brainstorm the step-by-step actions to be taken for different incursion scenarios in order to ensure preparedness for future incursions. This has been done in Ontario by the OMNRF, the Department of Fisheries and Oceans and the Invasive Species Centre (ISC) who used a 'mock disaster' emergency response exercises to test response frameworks for Asian carp and mountain pine beetle.

Policy and Legislation

Phytosanitary legislation is used by the CFIA to regulate the movement of all propagative and non-propagative commodities of *Tsuga* spp. (hemlock) from regulated areas in Canada and the US to non-regulated areas of Canada to control the entry and spread of HWA. The movement of Tiger-tail (*Picea polita*) and Yeddo (*Picea jezoensis*) spruce, the native alternate host of HWA in Asia, is also regulated. Western Canada is included under the regulation to prevent the introduction of the genetically distinct eastern strain of HWA to the west. Briefly, this legislation states that movement of HWA-regulated materials to Canada is prohibited unless the regulated materials are from an unregulated area free of HWA, have been designated HWA-free and from an approved grower, or have been treated with insecticide or heat-treated in accordance with the phytosanitary requirements outlined in D-07-05 - *Phytosanitary requirements to prevent the introduction and spread of the hemlock woolly adelgid (Adelges tsugae* Annand*) from the US and within Canada* (CFIA 2015a). An Infested Place Order is declared when new infestations are detected outside an established regulated area to restrict or prohibit the movement of the pest or regulated articles. Movement bans on all firewood species have also been implemented by Parks Canada for Kejimkujik National Park in Nova Scotia where there are established populations of HWA.

The Invasive Species Act is a piece of legislation unique to Ontario that allows for action to be taken regardless of the ownership (i.e. private, crown, public) of the land where a monitored invasive species is found (Government of Ontario 2015). This type of legislation may prove useful for HWA management in the other eastern provinces of concern and should be considered.

Outreach and Education

Outreach and education prior to a major HWA infestation is critical because it facilitates stakeholder and community awareness and support, which in turn allows for rapid action to be taken when required. Community and stakeholder awareness has already begun with pest information on HWA being provided and distributed through the CFIA pest fact sheet (CFIA 2016), CFS publications (Fidgen et al. 2013), OMNRF inclusion of HWA in the Annual Forest Health Review, ISC inclusion of HWA on their Forest Invasives website (ISC 2015) and social media campaign on Twitter, and Silv-Econ inclusion of HWA on their Invasive Insects website (Ryan 2013) along with the creation of an HWA working group for managers to provide a forum for discussion and communication.

There are other options that could be used after the discovery of HWA in an area. Citizen science programs and workshops can be used to educate and increase awareness about HWA prevention and monitoring; web platforms and social media campaigns can be used to target specific demographics to increase impact. In particular, citizen science can be a powerful way to engage and inform the public, while increasing the potential for early HWA detection. A number of these initiatives and tools have been developed by the ISC with partners in Ontario and could be expanded to other parts of Canada. For instance, the ISC and Ontario Invasive Plant Council created the Early Detection and Rapid Response (EDRR) Citizen Science network based on the identification and reporting of invasive species. Through this network, volunteers have been trained on HWA detection using the ball sampling technique. In a related initiative the ISC, OMNRF and the Ontario Federation of Anglers and Hunters developed a version of the Early Detection and Distribution Mapping System (EDDMapS Ontario) for HWA that allows for the reporting and documenting of HWA incursions using a smartphone app. The ISC and Silv-Econ created an HWA survey for stakeholders that helped to identify outreach needs in Ontario. The results of this survey identified the need for a centralized HWA fact sheet and a Best Management Practices brochure for woodlot owners.

Research Needs

Research efforts are required to ensure preparedness for continued HWA incursions in eastern Canada and to address current establishment of HWA in Nova Scotia. To complement previous and current research conducted in the US, further work in Canada should be coordinated through a comprehensive research plan (e.g., modeled after a plan developed by CFS for emerald ash borer), with a focus on the following areas:

1. Improving early detection and monitoring of HWA incursions:
    - Compile complete hemlock inventory for eastern Canada to enable areas of high value and high risk for HWA incursions to be prioritized for monitoring.
    - Improve and or develop methods to better detect HWA at low densities.

2. Quantifying the importance of migratory birds as a pathway into and throughout eastern Canada
    - Identify and locate migratory bird routes, from available databases, that coincide with eastern hemlock distribution.
    - Survey various migratory bird species at migratory stopping points that contain hemlock, annually in the field, inspect for crawlers, quantify and then survey nearby hemlock trees.
3. Identifying a systemic insecticide for protection of high value hemlock trees in Canada:
    - Assess the potential certification of Confidor®, IMA-jet®, and TreeAzin® for use against HWA in Canada.
    - Assess the risk of certified systemic imidacloprid use to the ecosystem in relation to potentially hazardous concentrations of imidacloprid and its metabolites in fallen hemlock tree foliage following treatment.
4. Exploring and preparing the most promising predators for biological control of HWA in Canada:
    - Collect and study HWA predators from western Canada.
    - Collaborate with the US to perfect lab and field rearing techniques.
    - Start field trials and research for biological control agents on southwestern Nova Scotia HWA populations.
5. Identifying the mechanisms and genes behind intraspecific host resistance in eastern hemlock:
    - Begin looking for natural host-resistance in eastern hemlock individuals in southwestern Nova Scotia and across eastern Canada as more HWA incursions occur.
    - Perform genetic and phenotypic studies on eastern hemlock.
6. Exploring the use of silvicultural techniques to reduce hemlock mortality caused by HWA:
    - Build on existing research by further testing the efficacy of thinning for reduction of HWA densities and hemlock mortality.
    - Explore the efficacy of barriers and pruning to help slow dispersal of HWA.
7. Developing a dual invasive species response framework for HWA incursions in eastern Canada:
    - Create a dual response framework in relation to the case of: (1) established HWA populations (i.e. Nova Scotia), and (2) new incursions of HWA (i.e. across eastern Canada).
    - Directly apply established HWA response framework to current situation in Nova Scotia and track success.
    - Perform emergency response scenario testing based on potential HWA incursion scenarios across eastern Canada.
8. Assessing established HWA population dynamics and tree impact:
    - Assess the factors that influence the dynamics of established HWA populations and associated hemlock mortality in Nova Scotia. In particular, life table analysis looking at aestivating sistens mortality in the summer and sistens nymph mortality in the cold winter months would give an understanding of the impact of weather in Nova Scotia on HWA.
    - Monitor and assess the rate of spread and dispersal mechanisms of HWA in Nova Scotia.

9. Identifying and addressing communication and outreach needs:
    - Create and distribute a survey to stakeholders in Quebec, New Brunswick, Nova Scotia and Prince Edward Island to assess communication needs specific to each province.

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