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Frontline

Forestry Research Applications

Canadian Forest Service – Great Lakes Forestry Centre

Technical Note No. 114

Alien, invasive hemlock woolly adelgid found in Ontario

INTRODUCTION

Several eastern hemlock trees (*Tsuga canadensis* (L.) Carrière) infested by the hemlock woolly adelgid (*Adelges tsugae* Annand) (Hemiptera: Adelgidae) (HWA) were recently discovered at two locations in Ontario. The first population was found in 2012 in Etobicoke, and the second was found in 2013 in the Niagara Gorge, about 2 kilometres north of Niagara Falls (Fig. 1). These discoveries are important because HWA is an alien, invasive insect that is native to both Asia (Japan, China and Taiwan) and western North America: British Columbia is the only province with native populations of HWA.

The first detection of HWA in eastern North America was in a private arboretum in Richmond, Virginia, in 1951. The source of that first HWA introduction was likely a population from southern Japan. Since its arrival, HWA has spread throughout the eastern United States (U.S.), killing eastern and Carolina (*T. caroliniana* Engelm.) hemlocks. HWA now occupies approximately 50% of the native range of eastern hemlock in the U.S. (Fig. 1).

Molecular analyses carried out by scientists at Agriculture and Agri-Food Canada on specimens collected at the Niagara Gorge indicate that they are more closely related to populations previously introduced to the eastern U.S. and Japanese populations than they are to populations from western North America. Whether the two reported incursions in eastern Canada are the result of natural or human-assisted dispersal is unknown. Trace-back surveys suggest that the Etobicoke infestation may have started several years ago when infested hemlock seedlings from a commercial nursery were planted. The Niagara Falls infestation could be the result of natural dispersal from the nearby infested counties in upper New York state (Fig. 1).

The Canadian Food Inspection Agency (CFIA) has already developed and implemented policy directive D-07-05 (Phytosanitary requirements to prevent the introduction and spread of the hemlock woolly adelgid [*Adelges tsugae* Annand] from the U.S. and within Canada). Based on that directive, the CFIA response to both introductions was to attempt eradication. To achieve this goal, the agency felled and burned all known infested trees. How long this response will be operationally feasible is unknown: these discoveries could signal the early phase of a natural range expansion from populations observed in New York state and northern New England.

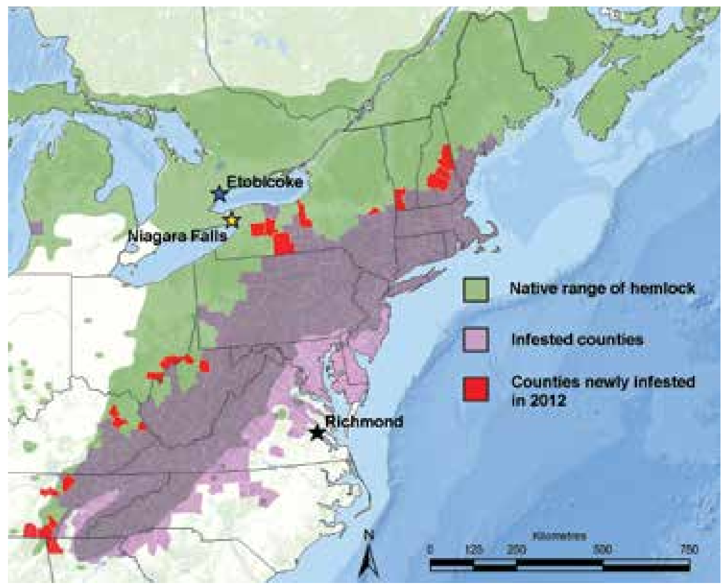

Figure 1. Native range of eastern hemlock in North America. Stars indicate 2012 (blue; Etobicoke) and 2013 (yellow; Niagara Gorge) discoveries of *A. tsugae* in Canada; Extent of the *Adelges tsugae* infestation in the U.S. where it was first introduced into eastern Virginia in the early 1950s. (na.fs.fed.us/fhp/hwa/maps/2012.pdf).

These two discoveries (Fig. 1) also highlight the need to prepare for the eventual establishment of HWA in eastern Canada. The first step of that preparation is to review what is known about this insect. The next step will be to adapt or develop survey and mitigation activities, strategies and tools to manage this alien, invasive species.

INSECT BIOLOGY

Life cycle

The life cycle of HWA is complex (Fig. 2). There are three morphologically distinct forms of HWA: sistens (plural is sistentes), progrediens (plural is progredientes) and sexuales. Sistentes and progredientes develop only on hemlock and are parthenogenetic: eggs do not need to be fertilized to produce female offspring. Conversely, sexuales infest an alternate host and reproduce sexually: eggs need to be fertilized to produce female offspring. In Asia, alternate hosts include Yeddo (*Picea jezoensis hondoensis* (Mayr) Rehd.) and Tiger-tail (*P. polita* (S.&Z.) Carrière) spruces. Research in the U.S. has determined that sexuales fail to complete development on *P. polita* transplanted in the U.S. and on all other spruce species native to North America: for this reason, this note focuses on the sistens and progrediens forms of HWA.

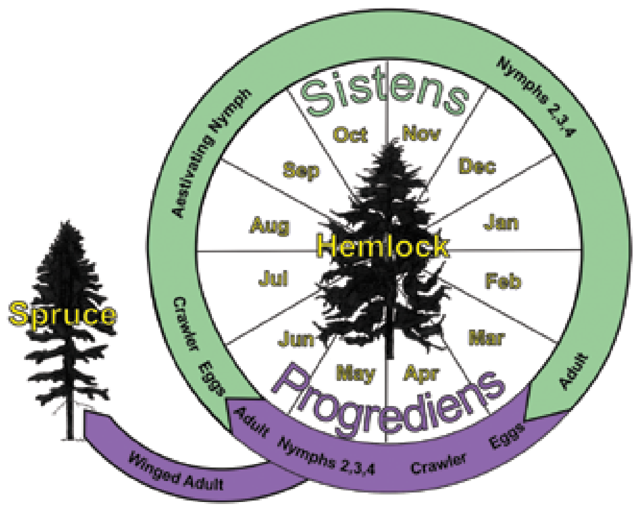

Figure 2. Reproduction of the hemlock woolly adelgid life cycle based on Reardon et al. (2004). No data on the exact timing of the occurrence of sistens and progrediens is currently available in Ontario.

The hemlock woolly adelgid has three life stages on hemlock: egg, nymph (four instars) and adult. The eggs and first instar nymphs of sistentes and progredientes are indistinguishable morphologically. Conversely, the size and shape of the body, thorax, and antennae can be used to distinguish later nymphal instars and adults of both forms. First instar nymphs are called crawlers, as they are the only mobile stage for this insect.

Typically, sistens eggs are laid in late May to early June. Sistens nymphs are found from early summer until the following spring. Sistens crawlers settle on the shoot near the base of current-year needles, insert their mouthparts into the stem and begin feeding on the contents of xylem parenchyma cells. Once settled, the nymph becomes immobile for the remainder of its life. Waxy wool is produced by glands on the periphery of the adelgid's body once feeding begins. Soon after settling, sistens nymphs undergo a summer diapause lasting about three months. Sistentes resume feeding in late September to early October. Nymphs continue to feed throughout winter when conditions are warm enough and go through three more instars before becoming adults in the spring.

Sistens adults lay about 150 progrediens eggs inside their woolly ovisacs in late April to early May (Fig. 3). In May, progrediens crawlers hatch and settle at the base of a needle on the same shoots amongst their sistens mothers (e.g., on last year's new shoots). Progrediens nymphs take about a month to complete development. Progrediens adults lay about 25 sistens eggs inside their ovisacs (Fig. 3).

Figure 3. HWA sistens nymphs and eggs inside a white woolly mass along the main stem of infested shoots of eastern hemlock near Niagara Falls, Ontario, in 2013 (Photo: Julie Holmes).

Because the sistens and progrediens forms are parthenogenetic, a single ovisac carried by an animal to a new host tree could result in a new infestation. In addition, research on the cold hardiness of HWA suggests that it can survive winter conditions over much of the range of hemlock in eastern Canada. While high mortality of HWA has been noted at temperatures below -18ºC, rapid resurgence of populations has been observed. In addition, adelgids feeding on understory regeneration can be protected from extreme low winter temperatures by the insulating effects of snow cover.

DAMAGE AND IMPACT

Signs and symptoms of injury

The presence of white woolly masses on shoots on the underside of hemlock twigs is a clear sign that trees are infested by HWA (Fig. 3). Some of the symptoms of injury include abortion of buds, chlorosis (yellowing of foliage), needle loss and dieback of new shoots (Fig. 4a). Heavily infested hemlock trees will look greyish-green from a distance, with thinning crowns (Fig. 4b, 4c). Once significant dieback of shoots and needles occurs on the tree, the accompanying loss of tree vigour exerts a

Figure 4a. Shoot dieback and chlorosis of older needles of eastern hemlock infested by the hemlock woolly adelgid (Photo: Chris Evans).

Figure 4b. Yellowish-grey-green colour of foliage of infested trees (Photo: James Johnson).

Figure 4c. Groups of infested trees with yellowish-grey-green coloured foliage (Photo: William Cielsa).

negative influence on populations of HWA. Because survival of sistens nymphs is significantly higher on new shoots than older shoots, the decreasing number of new shoots to infest, due to bud abortion and dieback, causes the population of HWA to decline rapidly.

At this point, the severely stressed trees may succumb to secondary organisms, such as the hemlock borer, *Melanophila fulvoguttata* (Harris) (Fig. 5a, 5b) or root disease, *Armillaria mellea* (Vahl:Fr.) Kummer. If instead the tree begins to recover and produce new shoots, the HWA population will eventually rebound as well. Rebounding HWA populations often cause too much stress for recovering trees and lead to tree death. Observations in the U.S. indicate that HWA has resulted in greater than 90% mortality of infested hemlocks.

Figure 5a. Sign of the presence of the hemlock borer, *Melanophila fulvoguttata* (Harris), which can often attack hemlock trees stressed by the hemlock woolly adelgid, as revealed by foraging woodpeckers (Photo: Steven Katovich).

Impact

To understand the potential impacts of HWA on hemlock, it is important to visualize a healthy hemlock-dominated ecosystem. Eastern hemlock is a medium-sized, long-lived shade-tolerant tree that prefers cool, moist sites. The dense crowns of this species cast a deep shade that excludes most other tree species in the canopy and understory, and it is considered a foundational tree species, particularly in riparian habitats, where it creates a unique ecosystem structure (Fig. 6). Hemlock-dominated ecosystems have low rates of soil decomposition and nutrient cycling, resulting in the rapid accumulation of a duff layer. Such conditions also stabilize flow rates and minimize water temperature variation of streams that support a small but dependent group of aquatic and terrestrial animals. In mixed stands, hemlock is found in association with yellow birch, sugar maple, American beech, eastern white pine and red and white spruces.

The thermal properties of hemlock crowns and canopies are such that these stands provide critical microhabitats for several bird and mammal species throughout the year. Invasion of hemlock stands by HWA may cause a cascade of changes that ultimately affect the structure and function of this distinctive ecosystem in Canada.

At the tree level, the damage caused by HWA appears to be more complicated than just sap sucking; nymphs inject toxic saliva that causes needle loss and inhibits new growth. Heavily infested crowns undergo noticeable thinning and colour change (Fig. 4c). Infestations usually begin in the middle and upper crown of mature trees.

However, tree mortality is usually first observed in hemlock saplings and seedlings because they are stressed from growing in the low light conditions of the understory and become heavily infested by HWA much sooner than canopy trees. However, in as little as four years, morbidity and mortality of upper-canopy trees creates gaps that allow sunlight to reach the forest floor. As these gaps enlarge, hemlocks are gradually replaced by shade intolerant hardwood tree species and shrubs.

In mixed stands, tree species associated with hemlock become more abundant. These changes lead to an increase in species richness and abundance as dying hemlocks give way to a wider array of plants, fungi and animals. However, these changes also lead to a significant reduction in the flora and fauna associated with distinctive hemlock-dominated ecosystems.

Figure 5b. Adult hemlock borer (Photo: Pennsylvania Department of Conservation and Natural Resources).

Dr. Mark Whitmore, Cornell University

Figure 6. Healthy stand of eastern hemlock in Pennsylvania. (Photo: thischanginglife.wordpress.com/2012/09/02/tiny-insect-continues-to-take-down-hemlock-forests-across-eastern-us/).
Photo: Dr. Mark Whitmore, Cornell University

At the landscape level, a decreasing abundance of hemlock in pure stands leads to higher soil respiration, faster nutrient cycling, greater variation in stream flows and higher water temperatures.

CONTROL

Role of natural enemies

A few natural enemies native to the eastern U.S. have been found eating HWA, which highlights the need to understand the potential complex of native natural enemies that may begin attacking HWA in Canada. Biological control programs for HWA using natural enemies from the native range of HWA in Asia and from western North America have been developed in the U.S.

For example, one of the predators found on HWA in western North America, *Laricobius nigrinus* Fender (Coleoptera: Derodontidae), has been released and has successfully established as a biological control agent in the eastern U.S. A second species of *Laricobius* from Japan, *L. osakensis* Montgomery & Shiyake, and two ladybird beetles (Coleoptera: Coccinellidae), *Sasajiscymnus tsugae* Sasaji from Japan and *Scymnus sinuanodulus* Yu & Yao, have also been recently released in the U.S. Research continues in evaluation and release of other candidate biological control agents.

Other management techniques

A number of insecticides and application methods have been shown to be effective against HWA. For example, insecticides with the active ingredients imidacloprid, emamectin benzoate and dinetofuran are commonly used for control of *A. tsugae* in the U.S. Of the various application methods, soil and stem injections and basal bark sprays are popular. Stem injections would limit effects on non-target organisms, especially for hemlocks close to moving water. The application of fertilizer speeds tree recovery following treatment with insecticides. Selective logging and salvage seem effective at removing heavily infested trees and recovering merchantable wood volume but research has shown that in stands with a high percentage of hemlocks, the impact of such practices on stand structure and ecosystem function can be worse than the gradual removal of hemlocks by HWA.

DISPERSAL

The current distribution of HWA in eastern North America is the result of a combination of natural dispersal modes such as rain, wind, birds and forest-dwelling animals and unintentional dispersal by humans. Crawlers spread during periods of high wind and rain; this mode of transport typically results in local dispersal, from a few centimetres to 8 km or more per year. Transport of crawlers and ovisacs by humans, birds and other animals, however, can result in dispersal over much longer distances. Ovisacs are sticky and can adhere to unsuspecting animals or humans as they move throughout the forest. The transport of infested seedlings or ornamental trees is one of the most significant means of long distance spread of HWA.

DETECTION OF INFESTATIONS

One of the basic requirements for effective management and mitigation of pests is sampling tools to detect populations, assess the abundance or the size of infestations and evaluate the success of management efforts. Currently, there is no attractant or trapping device that could be used to detect HWA.

In 2007, the CFIA implemented a presence/absence survey for HWA. This survey protocol, modified from an existing sampling method, consists of examining two branches from the lower crown of each tree until an infested tree is found or 100 un-infested trees have been examined in the stand, whichever occurs first.

Implementation of this survey in 2013 led to the detection of HWA on a single tree in the Niagara Gorge. This tree was growing beneath the crowns of several much larger hemlocks. Research in the U.S. has shown that small infestations may begin in the upper crown of tall, dominant trees. Because crawlers tend to spread rapidly down to subordinate trees in the stand, we suspect the infested tree detected in the gorge was likely infested by HWA crawlers becoming dislodged from the crowns of nearby overstory trees. However, these trees, suspected to be infested by HWA at low densities, are 25 to 30 metres tall, making sampling the middle and upper crown very difficult. Indeed, a follow-up visual survey of the lower crown of these trees did not reveal the presence of HWA. Currently, there are no tools that can be used to reliably survey the middle and upper crown of large hemlock trees.

GREAT LAKES FORESTRY CENTRE RESEARCH

The two discoveries of HWA in Ontario stress the need to prepare for its eventual establishment in eastern Canada. Once an inventory of the tools and techniques currently available to manage this alien, invasive species is completed, it will be necessary to distinguish between those that can be used or implemented immediately from those that must be adapted or modified.

Thus research efforts within the Canadian Forest Service will likely begin with a risk analysis. This analysis could help identify likely points of entry – sites that require increased surveillance and may help determine the long-term costs and benefits of early detection of, and intervention against, new invasions.

Such an analysis would likely benefit from field studies that will inventory the biota at risk of being displaced by an invasion of HWA. Additional research efforts will focus on the development or improvement of early detection tools and delimitation protocols for this pest so the rate of spread and impact can be more accurately measured.

It may also be prudent to initiate laboratory studies as soon as possible to assess the efficacy of various technologies for HWA control that could be used in Canada, potentially including pesticides, natural enemies or tree resistance, because they will likely differ from what is being used in the U.S. Finally, best practices will need to be developed for the management of hemlock stands.

CONCLUSION

Although the range of eastern hemlock in Canada is relatively small when compared to that in the U.S. (Fig.1), this species is nonetheless an important component of Canada's forests. With predictions of warmer climates, Canada's hemlock forest could be at a higher risk of arrival, establishment and spread of HWA and the eventual large-scale mortality of trees that has already been observed in the U.S.

We assume that additional finds of HWA will occur more frequently as HWA continues to spread from the northeastern U.S. into Canada. Hemlock's status as a foundational species to riparian forest land and to wildlife provides the motivation to preserve and protect this resource through scientific research and responsible forest management.

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ADDITIONAL RESOURCES

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