

# Conserving Southern Ontario's Eastern Hemlock Forests

Opportunities to Save a Foundation Tree Species

Research Report No. 38

***Ancient Forest Exploration & Research***

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## EXECUTIVE SUMMARY

This document was developed to help inform a citizen-science approach to hemlock woolly adelgid (HWA) detection and is complementary to the HWA Plan for Canada that was released in 2018. HWA attacks and kills eastern hemlock (*Tsuga canadensis*), a long-lived shade-tolerant species that is commonly a dominant tree in old-growth forests of southern and central Ontario. The hemlock is considered a “foundation species” because of its strong influence on the environment and on other species including understory plants, forest animals, and aquatic organisms found in associated streams. In addition to a detailed literature review, this report provides a map and descriptions of 94 high-conservation value forests in southern Ontario that should be part of a network to monitor the health of eastern hemlock.

HWA has spread through more than half the entire North American range of eastern hemlock and can cause very high mortality, threatening the existence of many hemlock forests in the long-term. HWA colonizes new areas primarily by wind, birds, and humans, at an average rate of roughly 8.1 km/yr in the northern part of its range. Biocontrol of HWA using a suite of predators remains the best hope for conserving eastern hemlock populations. If biocontrol fails, the principal sources of protection are host resistance, which is likely very rare; or climatic refugia, which are likely to continue to shrink in the face of climate change. Chemical treatments will also be important in some situations, but associated environmental impacts need further research.

The effectiveness of silvicultural management (e.g., thinning, logging) is currently unknown, as are the ecological costs. Further research should include an evaluation of the ecosystem impacts of management. Best management guidelines should place an equal or greater weight on the do-nothing option, which may ultimately result in less ecosystem damage. Management should be explicitly discouraged in old-growth stands.

Citizen education and involvement in HWA monitoring is important. Detection of HWA in the early stages of infestation increases with search effort, and citizens have often been the first to detect and report HWA infestations. Tree branch surveys may be more useful than other sampling techniques for broad-scale public participation.

## INTRODUCTION

Hemlock woolly adelgid (*Adelges tsugae*; HWA) has invaded half of the North American range of eastern hemlock (*Tsuga canadensis*), frequently causing hemlock mortality exceeding 90%. HWA is now present in parts of northern New York State and Pennsylvania and has been detected in two southern Ontario locations. Because of the ecological importance of eastern hemlock as a foundation, shade-tolerant, old-growth tree (Foster et al. 2014) in Ontario, strong action is needed to avoid and mitigate the damage that will be caused by this insect.

This report is intended to inform a citizen-science response to the northward advancement of HWA towards Ontario and is complementary to the Hemlock Woolly Adelgid Management Plan for Canada (Emilson et al. 2018). We provide a review of the ecology and value of eastern hemlock forests, the biology and impacts of HWA, and management strategies used to counteract HWA. Based on these findings, we have produced two educational publications (Appendix 1). We encourage any form of non-commercial use or modification of these publications.



We have also identified 94 high conservation value forests with a significant eastern hemlock component. These forests are described in Appendix 2, which can be used to focus detection and conservation efforts, including seed collection, for hemlock forest restoration. A map of publicly accessible forests is available on our website at [www.ancientforest.org/hemlock](http://www.ancientforest.org/hemlock).

## THE VALUE OF EASTERN HEMLOCK

### A Long-lived Climax Species

Eastern hemlock is an old-growth forest species that tends to grow in very stable ecosystems that may persist for thousands of years between natural disturbance events such as catastrophic windstorms and fires (Bormann & Likens 1979, Frelich & Lorimer 1991, Frelich & Reich 1996, Foster 2000, Ziegler 2000). Eastern hemlock forests are known to persist for 8,000 years in Massachusetts despite periodic natural disturbance (Foster & Zebryk 1993). This tree species is often found in relatively undisturbed, mature and old-growth forests for several reasons.

Eastern hemlock is an extremely shade tolerant climax forest species that regenerates well on fallen logs and mineral soil exposed by windthrow (Rogers 1978; Burns & Honkala 1990, Goerlich & Nyland 1996). Logs and windthrow are characteristics of old-growth forests and are relatively rare in less mature forests. Human land use, which commonly changes and accelerates disturbance, is likely to reduce eastern hemlock in favour of hardwoods such as sugar maple and beech (Rogers 1978). Consequently, there has been a significant decline in eastern hemlock abundance in many parts of its range, particularly where land use is more intensive (Rogers 1978, Whitney 1990, Fuller et al. 1998, Evans 2002, Suffling et al. 2003). Thus, eastern hemlock could be considered an indicator of relatively undisturbed or at least less disturbed forest sites. Mladenoff (1996) estimated that eastern hemlock has been reduced to only 0.5% of its former abundance in the mesic forests of Wisconsin and Michigan.

### Old Growth

Eastern hemlock trees are an important component of old-growth forests in southern Ontario, particularly on ravine slopes. For example, almost one third of old-growth forests identified by Kershner (2004) in Ontario's Niagara Peninsula contained eastern hemlock. In the Long Point region, eastern hemlock is an important component on north- and east-facing slopes in the valleys of Big Creek, Big Otter Creek, and their tributaries (Lindsay 1981). However, the extent to which these forests are old growth is unknown.

In Toronto, eastern hemlock is also found on many ravine slopes and in multiple environmentally significant areas (ESA; North-South Environmental 2012). It is also an abundant tree species on the slopes of the Bronte Creek Valley, a Halton Region ESA that includes a provincial life science Area of Natural and Scientific Interest (ANSI; Halton Region and North-South Environmental 2005). Ring counts of cut trees along trails and ravine slopes at Bronte Creek show tree ages of at least 240 years (Henry & Quinby 2018b). To the east of the Greater Toronto Area (GTA), old-growth eastern hemlock forest occurs in the Wesleyville Ravines (Larson et al. 1999).

In central Ontario, eastern hemlock is a dominant tree in some of the highest quality old-growth forests including Mark S. Burnham Provincial Park and Clear Lake Conservation Reserve. The center of eastern hemlock abundance in Ontario is Algonquin Park (Henry & Quinby 2006), where it is often unusually old.

In Algonquin, 62.1% of forests estimated at over 180 years old on forest resource inventory maps are dominated by eastern hemlock, even though the eastern hemlock working group only occupies 6.6% of the forest area of the Park. In some of these forests, trees exceeding 400 years of age can be found (Vasiliauskas 1995, Henry & Quinby 2006, Henry & Quinby 2018d).

## A Foundation Species

Eastern hemlock is considered a “foundation species” because of its strong influence on the environment and on other species (Martin & Goebel 2013). Although eastern hemlock can decrease productivity of terrestrial ecosystems, the unique vegetation communities found in hemlock forest understories can increase landscape-level terrestrial diversity (Quimby 1996, Martin & Goebel 2013). Streams that run through these forests have greater diversity of fish species, and markedly different fish and aquatic invertebrate communities compared with streams in hardwood forests. Eastern hemlock is also important in regulating stream temperature and volume of flow, and in supporting cold-water fish species such as brook trout (Evans 2002, Snyder et al. 2002, Ross et al. 2003).

Numerous impacts resulting from the loss of eastern hemlock have been documented, including colonization by invasive species (Eschtruth et al. 2006), changes in invertebrate communities (Adkins & Rieske 2013), changes in carbon cycling (Nuckolls et al. 2009), and decline or loss of habitat specialist bird species such as Blackburnian warbler, black-throated green warbler, Acadian flycatcher, hermit thrush, solitary vireo, and northern goshawk (Quimby 1996; Foster et al. 2014). Loss of eastern hemlock also negatively affects the feeding and breeding habitat of the Louisiana Waterthrush, a bird species that is closely associated with eastern hemlock along clear, coldwater streams in southern Ontario. COSEWIC reassigned the status of Louisiana Waterthrush from special concern to threatened due in large part to the looming threat of HWA (COWESIC 2015a,b).

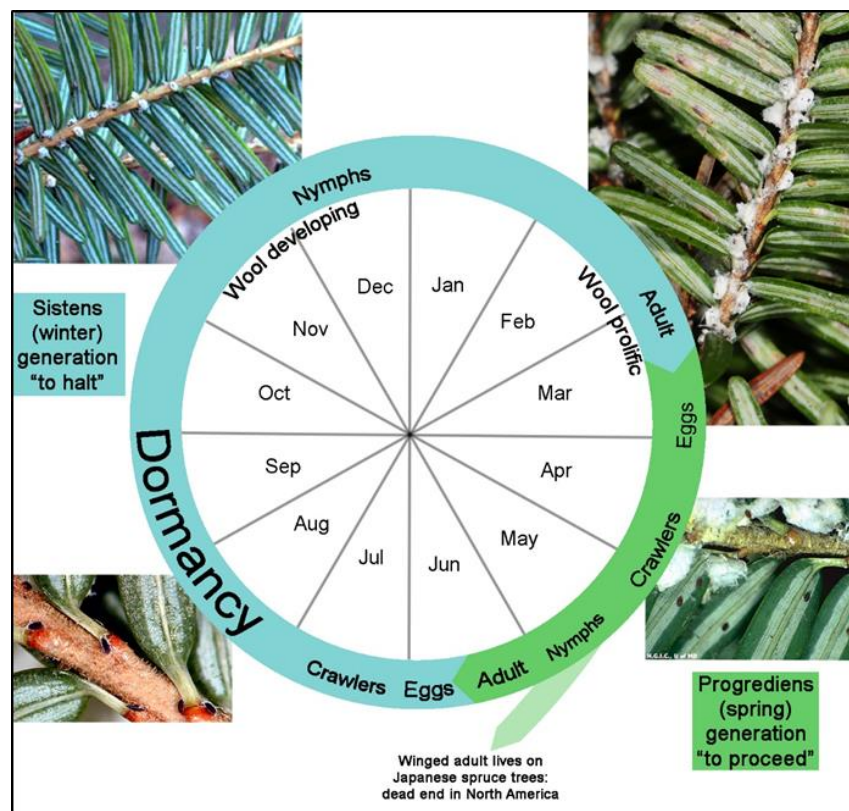
Eastern hemlock commonly grows in riparian areas, and on moderate to steep slopes in valleys and along lakeshores. Its removal from the ecosystem will likely result in increased erosion and permanent changes to stream hydrology (Ford & Vose 2007). Threats to this species other than HWA include browsing by deer and moose (Mladenoff & Stearns 1993, Vasiliauskas & Aarssen 1999), climate change (Davis 1989), and fire facilitated by climate change (He et al. 2002). Due to the lack of ecological surrogates to take its place, Evans (2002) suggested that the loss of eastern hemlock forests may be even more ecologically significant than the loss of American chestnut.

Evidence from the pollen record tells us that there was a major decline in eastern hemlock to less than 5% of pre-decline abundance approximately 5,000 years ago, probably due to a combination of climate change and defoliation by hemlock looper (Foster 2000, Foster et al. 2006, Day et al. 2013). Eastern hemlock did eventually recover on many sites over a period of 1,000 – 2,000 years. Faced with a similar coupling of climate change with a destructive pest, the action we take now to protect Ontario’s eastern hemlock populations will determine the extent of its current decline, including if or how quickly eastern hemlock will recover.

# INVASION OF HEMLOCK WOOLLY ADELGID

## History and Biology

HWA was introduced to the eastern United States prior to 1951 and has now spread through more than half of the geographic range of eastern hemlock, and through much of 20 U.S. states (Havill et al. 2014). The biology of HWA has been reviewed in numerous publications (McClure et al. 2001, Jones 2013, Havill et al. 2014, Preisser et al. 2014). Here we summarize the key features of the life cycle of North American populations of HWA.



Unlike the Japanese population from which it is descended, the North American HWA lacks a host tree for the sexual part of its life cycle. Therefore HWA in North America reproduces asexually, with two generations per year (Figure 1). The sistens (winter) generation hatches in early summer. After the crawlers find a suitable location to feed on a branch near the base of a needle, they enter a period of aestivation (summer dormancy), remaining invisible without a hand lens and inactive until autumn when they resume growing.

**FIGURE 1 - LIFE CYCLE OF HWA IN NORTH AMERICA FROM CHEAH ET AL. 2004)**

By late October or November, it is possible to see the protective waxy woolly covering forming on the nymphs, which grows through the winter. From 50 - 175 eggs representing the next generation (progreddiens) are laid in March and April, hatch into crawlers, settle on twigs and begin to feed. The progreddiens generation continues to grow, without dormancy, and completes its life cycle in June, laying fewer eggs than the sistens, depending on food quality, which hatch into the next sistens generation.

A portion of the progreddiens generation develops into sexuparae (winged form of *A. tsugae*), which are unable to develop in the absence of their Japanese host tree. There appears to be significant regional variation in the proportion of HWA that develop into sexuparae (Sussky & Elkinton 2014).

## Rates and Patterns of Spread

Short-range dispersal of HWA is commonly by wind and includes distances up to 300 m. However, the possibility of wind dispersal beyond 400 m exists (McClure 1990, Turner et al. 2011), and rare high-wind

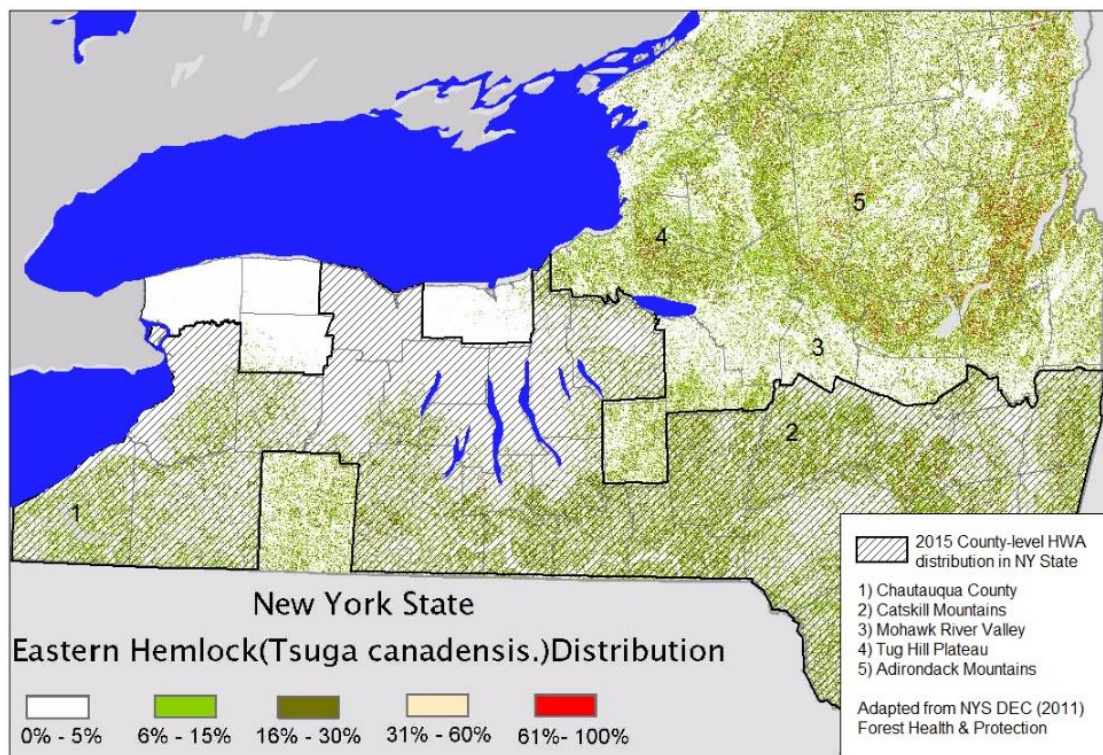
events likely disperse HWA many km (McClure 1990). Birds have also been shown to play a significant role in HWA dispersal over several km and it is generally assumed that much of the range expansion of HWA may be attributable to birds, however, maximum dispersal distances by birds are unknown (McClure 1990, Russo et al. 2016). Humans are responsible for rare long-distance dispersal, particularly through movement of infested nursery stock. To date, no models have been developed that can accurately predict the timing and extent of range expansion of HWA (Fitzpatrick et al. 2012).

HWA has shown a faster rate of range expansion in the south (15.6 km/yr) compared with the northern part of the current range of HWA where the rate of spread based on township records for Pennsylvania and areas to the north has been 8.1 km/yr (Evans and Gregoire 2007). This rate of range expansion was determined using 1990-2004 data.

HWA range expansion is anisotropic (Morin et al. 2009), which means that simple linear predictions of future range expansion will tend to have significant errors. Relatively slow range expansion in central New York (north of the Catskills) may be largely explained by climate, however (as discussed below) evolving cold tolerance of HWA and climate change are likely to affect future rates of range expansion.

Morin et al. (2009) concluded that much of the variation in the HWA dispersal rate is explained by the abundance and spatial distribution of eastern hemlock. In other words, HWA has spread more rapidly in landscapes with higher concentrations of eastern hemlock. When HWA enters the Adirondack Mountains it will find itself in a landscape where eastern hemlock is very abundant across a large area. Likewise, eastern hemlock abundance is much higher in Oswego County, particularly on the Tug Hill Plateau. Range expansion could be more rapid in these areas, though interactions with climate remain uncertain as HWA continues to test northern boundaries.

**FIGURE 2 – EASTERN HEMLOCK DISTRIBUTION IN NEW YORK STATE**



## Cold Tolerance

Cold winter temperatures are often considered to be a limiting factor in HWA distribution and some authors have suggested that, with its dispersal into New York State, HWA is nearing the limits of range expansion due to low winter temperatures. For example, Fitzpatrick et al. (2012) modeled HWA range expansion and concluded that, “In the case of HWA, there appears to be little potential for additional spread, at least under current climatic conditions”. However, in the years since the final year of their model, HWA continued to spread northward including into areas of Vermont, Maine, and Michigan that all have a near zero probability of infestation in the model. Morin et al. (2009), who found a negative correlation between January temperatures and rates of HWA expansion, nevertheless concluded that “it is possible that HWA is nearing the limits of potential range in most regions.” The question of cold tolerance is critical to predicting the future threat of HWA, particularly for Canada, but we do not yet have a good understanding of it.

Parker et al. (1999) studied HWA survival at low temperatures in the laboratory and found >98% mortality with exposure to -30°C, however, the study noted that “adelgids along the leading edge of the infestation may develop an ability to tolerate colder temperatures in the future.” This statement appears to have been prescient. Skinner et al. (2003) found that cold tolerance varied significantly between adelgids taken from different parts of the range in eastern North America, while Butin et al. (2005) used a common garden experiment to confirm the genetic basis of this cold tolerance and noted that HWA “...has long surpassed the population size needed to escape evolutionary constraints imposed by mutation limitation. Indeed, it is likely to be generating tremendous genetic variation within very small geographic areas.”

Whitmore (2014) examined HWA at Mine Kill State Park in the northern Catskills where instruments recorded minimum temperatures of -31°C and found HWA mortality of 72%. This is much lower mortality than Parker et al. (1999) measured in the laboratory, and also lower than mortality at another site in Taughannock State Park in the Finger Lakes region of New York State, where minimum measured temperature was 9°C warmer (-22°C) but mortality was higher (88%). Whitmore concluded that “The Mine Kill SP data suggests HWA populations in colder areas are indeed becoming more cold tolerant than those in warmer locations like Taughannock SP.”

These mortality rates may sound high, but Paradis et al. (2008) found that the threshold at which HWA populations are stable (mortality is balanced by fecundity) is 91% mortality – only 9% of HWA have to survive the winter to sustain the population. Trotter and Shields (2009) concluded that even lower survival rates (2 - 4.5%) could result in a stable population. Even with very low winter temperatures dropping below -30°C, the Mine Kill State Park population of HWA (with 28% survival) is still able to grow, and theoretically still able to spread to surrounding areas.

HWA appears likely to continue expanding its range northward, and it is impossible at this stage to predict an exact climatic limitation of its range due to their ongoing adaptation of cold tolerance. Trotter (2010), in an analysis of 49 years of weather data, found that “2.2 percent of the eastern hemlock population range in the continental United States occurs in regions in which none of the included 49 years were well suited for adelgid survival; these regions are found in northern Maine, New Hampshire, and Wisconsin.” However, he warned that even these refugia could be at risk due to climate change.

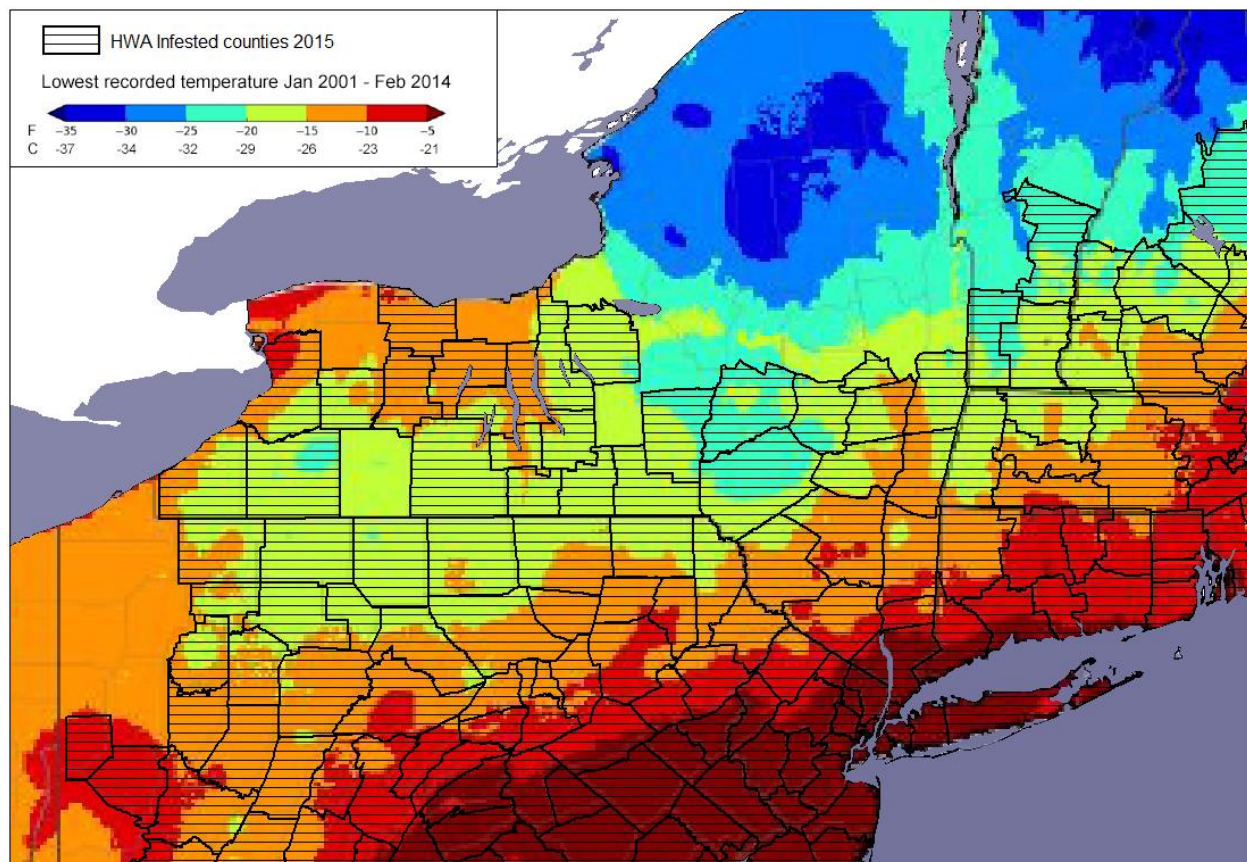
Paradis et al. (2008) found that conditions that limited HWA spread in Massachusetts included mean winter temperature of -5°C or lower, minimum winter temperature of -35°C or lower, or when there



are at least 79 days in which the average daily minimum temperature is below  $-10^{\circ}\text{C}$ . Figure 3 shows that, using the minimum temperature threshold, Tug Hill and much of the Adirondacks could be colonized by HWA under current climate conditions. However recent work by Mark Whitmore (personal communication 2019) indicates that it is not solely the minimum low temperature, but also the conditioning prior to the cold event that is responsible for cold mortality (i.e. a cold snap at the end of a warm winter can cause very high mortality).

In summary, much of the northern range of eastern hemlock may become at risk to HWA infestation during this century due to global warming (Paradis et al. 2008, Huntington et al. 2009, Trotter 2010, McAvoy et al. 2017) and/or by continued evolution of cold tolerance by HWA (Butin et al. 2005, Whitmore 2014).

**FIGURE 3 – JANUARY LOW TEMPERATURES IN HWA INFESTED COUNTIES IN NEW YORK STATE (ADAPTED FROM ACIS-NOAA REGIONAL CLIMATE CENTER)**



## Status and Risk Factors in Ontario

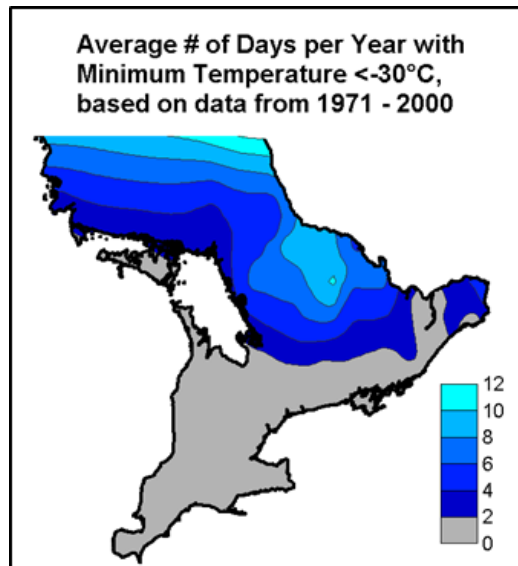
Although HWA is now established in Nova Scotia, it is currently thought to be eradicated in Ontario. In Canada, it was first detected in Etobicoke in 2012 on a planted tree in an urban area and was promptly eradicated. Later in 2013, HWA was detected in the Niagara Gorge; the infested tree was destroyed and delimitation surveys found no further infestations that year. However, HWA was again detected in 2014 and 2015 in the Niagara Gorge and the same protocols were followed; there were no detections in 2016 and 2017.



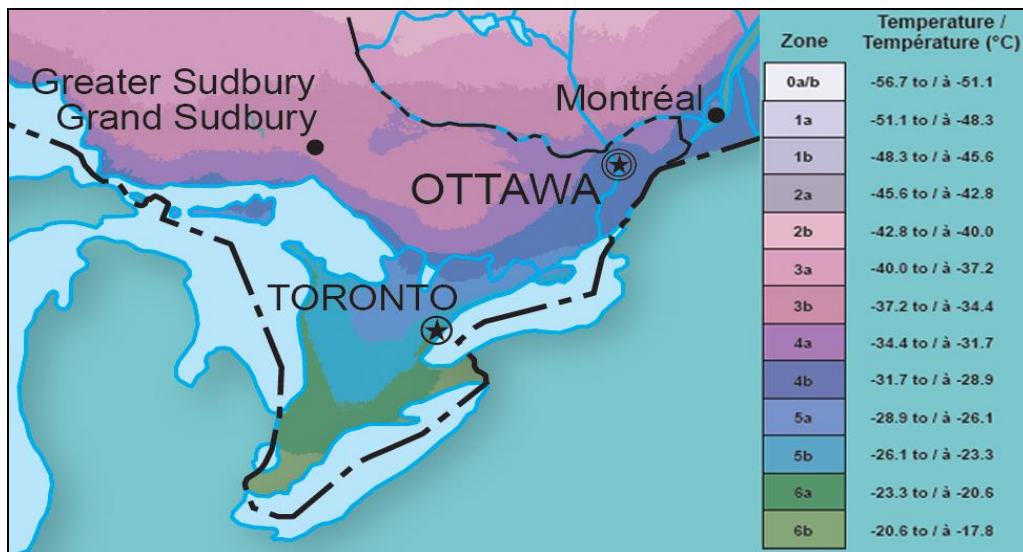
HWA might have been carried by birds across the border from New York to Ontario's Niagara Gorge. Populations of HWA have been present in the Buffalo and Rochester areas of New York since before 2008 and have spread into many natural areas in western New York (NYDEC 2016, Figure 3). Given that birds are an important vector for HWA movement, the U.S.-Canada border is likely to be very porous to HWA.

Climate is not likely to be a barrier to HWA movement anywhere in southern Ontario as shown on Figure 4. Most of the Southern Ontario region has 0-2 days below  $-30^{\circ}\text{C}$ , indicating the high likelihood that this region will be readily colonized by HWA. If we use plant hardiness zones as an indicator of extreme winter conditions (Figure 4), HWA is likely to spread through zone 5 and possibly into zone 4b (minimum temperature of  $-31.7^{\circ}\text{C}$ ), or even into 4a (minimum temperature  $-34.4^{\circ}\text{C}$ ). This places much of Ontario's eastern hemlock forest at risk, with much of the Algonquin Park highlands, and some areas further north, potentially being notable exceptions (Figure 5).

**FIGURE 4 - NUMBER OF DAYS BELOW  $-30^{\circ}\text{C}$  (ENVIRONMENT CANADA 2003)**



**FIGURE 5 - PLANT HARDINESS ZONES BY MINIMUM TEMPERATURE (NATURAL RESOURCES CANADA 2014)**



Making predictions of future HWA distribution is very difficult. It may move faster or slower than expected and infrequent long-range dispersal events, such as transport on nursery stock, can significantly alter its geographic range. However, it is highly likely that HWA will spread into the Niagara Peninsula in the coming decade. The primary barrier to its movement there (at a rate of 8+ km/year) is the discontinuous distribution of eastern hemlock in the region.

Ontarians will also want to keep a very close eye on HWA expansion into Oswego County and the Tug Hill area in New York State (Figure 3) because of the nearly continuous distribution of eastern hemlock around the east end of Lake Ontario. HWA may move very quickly through this area due to eastern hemlock abundance, or it may be slowed considerably by colder climate. When HWA crosses into Canada through the Thousand Islands at the east end of Lake Ontario it will meet a much more continuous eastern hemlock distribution than in southwestern Ontario and it will be much more difficult to control its spread.

## Long-distance Dispersal by Birds

Two important dispersal questions that have not been conclusively answered in the scientific literature are: (1) how important is spring migration for long-distance dispersal of HWA? and (2) is HWA likely to cross the Great Lakes attached to migratory birds? While it is impossible to provide definitive answers, there is sufficient evidence to raise concerns and to apply the precautionary principle (Kriebel et al. 2001) in planning for HWA invasion into Ontario.

The timing of the spring (progreddiens) emergence of HWA crawlers overlaps with spring bird migration. Fidgen et al. (2015) recorded crawler activity from the second week of May through June in upper New York State, with a peak of activity occurring on May 25. In Connecticut, Russo et al. (2016) reported a peak of crawler transfer to stationary birds on the first day of their experiment (May 14) and acknowledged that the true peak of crawler transfer may have been earlier. Fidgen (2016) reported that crawlers can begin emerging in mid-April and Whitmore (Personal Communication 2019) found HWA crawlers began emerging around April 10 in 2018, but is highly dependent on spring temperatures.

Song birds that have been found to be associated with eastern hemlock forest, and therefore, may represent a significant HWA risk, include black-throated green warbler, ovenbird, blackburnian warbler, black-capped chickadee, solitary vireo, winter wren and red-breasted nuthatch (Yamasaki et al. 1999). Four of these bird species (black-throated green warbler, ovenbird, blackburnian warbler, and black-capped chickadee) have been recorded with some regularity at Long Point Bird Observatory located on the north shore of Lake Erie during migration (Long Point Bird Observatory 2015).

However, dispersal of crawlers is not restricted to specialist bird species. In Connecticut, McClure (1990) reported finding eggs and crawlers of HWA on 13 species of birds with very diverse foraging, nesting and roosting behaviours (Table 1). It was not uncommon for one bird to carry multiple crawlers and eggs, and McClure (1990) found a single male robin that was carrying eight eggs and seven crawlers. From 50 to 70% of the crawlers on these birds were still alive up to 24 hours after the birds were captured and a significant number of eggs were being transported on the birds. These observations indicate that HWA could potentially be carried relatively long distances during spring migration. Monitoring priorities should include known bird migration areas and large natural areas near the shores of Lake Ontario and Lake Erie such as Bronte Creek, Rattray Marsh and Long Point.

The Long Point area is particularly notable as it has a relatively high regional abundance of eastern hemlock, and there have been detections of HWA across Lake Erie in Cattaraugus and Chautauqua Counties on the south shore of Lake Erie (Figure 3). The infestation at the SUNY Fredonia campus is 60 km from Long Point, and eastern hemlock is more abundant in the central and southern parts of western New York than it is in the vicinity of Niagara Falls, New York. The detections of HWA in western New York occurred in old-growth forest areas where people were looking for it. Other infestations may have gone unrecognized in lower profile hemlock forests. We should assume that HWA is established and continues to spread in western New York and that it could potentially be carried by birds and wind across Lake Erie to Ontario.

**TABLE 1 – BIRD SPECIES CARRYING HWA EGGS AND CRAWLERS (McCLURE 1990)**

Scientific name	Common name
<i>Cardinalis cardinalis</i>	Northern cardinal
<i>Dumetella carolinensis</i>	Catbird
<i>Helmitheros vermivorum</i>	Worm-eating warbler
<i>Hylocichla mustelina</i>	Wood thrush
<i>Megaceryle alcyon</i>	Belted kingfisher
<i>Mniotilta varia</i>	Black-and-white warbler
<i>Poecile atricapillus</i>	Black-capped chickadee
<i>Pheucticus ludovicianus</i>	Rose-breasted grosbeak
<i>Sayornis phoebe</i>	Eastern phoebe
<i>Seiurus aurocapilla</i>	Ovenbird
<i>Thryothorus ludovicianus</i>	Carolina wren
<i>Turdus migratorius</i>	American robin
<i>Vermivora cyanoptera</i>	Blue-winged warbler

## HWA MANAGEMENT

HWA management options are summarized in Emilson et al. (2018), however, additional details and recommendations are provided below.

### Current Management Practices in the Northeast, USA

The two main tools to combat HWA are chemical insecticides, primarily imidacloprid, and biological control. Imidacloprid is very effective at an individual tree level, but its use in forests is limited by cost and concerns over environmental impacts, primarily on aquatic ecosystems (Preisser et al. 2014, Emilson et al. 2018). While cost remains a significant obstacle, concerns about impacts on aquatic ecosystems may be overstated. Since the detection of HWA in Great Smokey Mountains National Park in 2002, over 250,000 eastern hemlock trees have been treated with imidacloprid soil drenches, many in riparian areas. Benton et al. (2017) assessed aquatic macroinvertebrate communities in streams where eastern hemlock had been treated with imidacloprid, comparing samples collected downstream of treatments to baseline (pre-treatment) and upstream samples, and concluded that “imidacloprid, when used within the limits of USEPA federal regulations, has not had detrimental impacts on aquatic macroinvertebrates.”

Biological control is currently the most promising avenue for broad scale protection of eastern hemlock from HWA, but successful control has not been demonstrated except in anecdotal cases. The most

promising predator for HWA to date is *Laricobius nigrinus*, a predator beetle native to the west coast of North America (Preisser et al. 2014, Forest Health Technology Enterprise Team undated).

*L. nigrinus* is a specialized predator that can only complete its life cycle on HWA and is active from October to May during the sistens generation. Adult *L. nigrinus* feed on sistens generation HWA, and females oviposit approximately 100 eggs singly into HWA ovisacs. Larvae emerge during oviposition of progrediens eggs from February to May and the larvae consume the eggs - each larval *L. nigrinus* may consume up to 250 eggs of HWA. The life cycle of *L. nigrinus* is highly synchronized to HWA and the minimum temperatures for complete development of both predator and prey are within 1°C (Kohler 2007).

Whitmore (2015) noted that *L. nigrinus* has spread over 30 miles since first introduced at Banner Elk, North Carolina in 2003. In just two weeks, over 12,000 beetles were collected there for re-release. Populations of *L. nigrinus* at Delaware Water Gap, New Jersey and in Pennsylvania have been growing since releases began in 2006. In New York, where the first releases were in 2009, *L. nigrinus* has established at three of the earliest release locations. The primary limitation of *L. nigrinus* is that it feeds only on nymphs and adults of the (sistens) generation and eggs of the early summer (progrediens) generation. The success of *L. nigrinus* population growth in northern climates is likely limited by frequent host HWA scarcity caused by winter mortality and points to the necessity to find predators that feed on the spring/summer progrediens generation (Whitmore, Pers. Com. 2019).

*Leucopis argenticollis* and *Leucopis piniperda* are two species of silver fly that are among the most important predators on all stages of the life cycle of HWA in the Pacific Northwest of North America. Kohler et al. (2016) found that *Leucopis* spp. larvae were present during both the progrediens and sistens egg stages of HWA and, depending on the sampling method, were collected 2.3 - 3.5 times more frequently than *L. nigrinus*. Since *Leucopis* spp. and *L. nigrinus* co-exist throughout the Pacific Northwest, it is believed they will complement each other rather than compete.

*Leucopis argenticollis* is already present in eastern North America where it feeds on other adelgid species, but it does not appear to feed on HWA (Kohler et al. 2008). Havill (pers.com. 2018) has found genetic markers proving that these geographically isolated populations are genetically distinct and may have different host preferences. *Leucopis argenticollis* collected in the Pacific Northwest were released in New York State in 2015, 2017, and 2018 (Whitmore, pers com. 2019) with hope that it will form an important part of the suite of predators that will more effectively control HWA in the northeast U.S.

Biological control of HWA works best when predators establish on a young, growing population of adelgids (Cheah et al. 2004). Given the limited number of predators available and the time it takes for predator populations to grow, it has been suggested that some mature high values trees might be treated with insecticides, while others are left untreated to host HWA while predator populations establish and grow (Havill et al. 2014).

Although it is often pointed out that biological control has had a poor track record for controlling balsam woolly adelgid (*Adelges piceae*), biocontrol has been successful for related *Pineus* spp. (pine woolly aphids) that have been successfully managed in four different countries using three different predators (Kohler 2007). Biological control remains one of the best hopes for preserving hemlock forest in Canada.

## Silvicultural Management

There is limited evidence, primarily from a single nursery experiment (Brantley et al. 2017), that silvicultural management could reduce mortality caused by HWA. Experimental thinning of stands appears to stimulate a small increase in live crown ratio, which may be beneficial while increased moose browse of hemlock regeneration is a potential risk (Fajvan 2017). Where silvicultural management practices are employed they should be considered experimental and include a study design plan for follow-up to evaluate results. Also, potential benefits from thinning stands should be considered against potential for loss of host resistance and negative ecological impacts due to increased light penetration, temperature changes, species invasions, and loss of large trees.

Silvicultural treatments should never target old-growth stands. This is of particular concern in Algonquin Park, Ontario where significant tracts of old-growth eastern hemlock in the recreation-utilization zone are available for logging, including unprotected hemlock stands reaching over 400 years in age (Henry and Quinby 2006, 2018a, 2018d). It is also a concern on crown and private land where old-growth hemlock stands may not be recognized since very old hemlock trees are commonly under 60 cm diameter (Henry and Quinby 2018a, 2018b, 2018c, 2018d).

The development of a best management practices brochure in the short term is not realistic due to a lack of research for developing prescriptions. Research needs include field trials of management prescription efficacies and evaluations of negative ecological impacts. Best management practice guidelines, when they are developed, should balance ecological impacts, encourage retention of large mature trees, discourage active management of old-growth forests and emphasize the option to “do nothing” (Foster & Orwig 2006).

Management recommendations that prioritize economic over ecological values should be avoided. For example, management guidelines for beech bark disease in Ontario (McLaughlin and Greifenhagen 2012) encourage removal of large and old-growth trees from forests on the advancing front. This recommendation is likely to result in the removal of many large disease-resistant trees that have a suite of values (Lutz et al. 2018), including their value as superior seed sources for restoration (Ingwell & Preisser 2011). Resistant trees found in old-growth forests commonly meet one or more of the criteria for removal given in these management guidelines (Henry and Quinby 2018b, Beech Bark Disease Resistance Project undated).

## Host Resistance

Eastern hemlock trees that are putatively resistant to HWA have been identified but they appear to be quite rare (Caswell et al. 2008, Ingwell & Preisser 2011, Oten et al. 2014). The rarity of resistance makes it especially imperative to preserve as many resistant individuals as possible, and Ingwell & Preisser (2011) conclude that, “The human intervention most likely to interfere with the identification and propagation of surviving individuals is pre-emptive logging.” Logging to control spread of HWA is not effective, and pre-emptive logging to recover economic value can cause more ecological damage than the pest itself, while also threatening the genetic diversity that may be the key to long-term conservation of eastern hemlock (Foster & Orwig 2006, Ingwell & Preisser 2011).

Oten et al. (2014) and Ingwell & Preisser (2011) describe a variety of approaches to locating resistant trees in aftermath forests using the expertise of resource management professionals and citizen scientists. Records of putatively resistant trees are being collected from the public using a web form

(Forest Restoration Alliance 2016), an approach that could potentially be applied in aftermath forests in Canada. Canadian strategies will need to be developed once HWA becomes well established, however we recommend including a proactive education and management component to preserve genetic diversity and discourage pre-emptive salvage logging.

## Importance of Early Detection Surveys

The High Allegheny Plateau Hemlock Conservation Project (Johnson et al. 2014) was in the process of identifying high value stands for conservation and was implementing monitoring when HWA was first detected in Cook Forest, Pennsylvania in 2013. This area is one of the most notable eastern hemlock old-growth forests in the eastern United States and was one of the top priority areas on the High Allegheny Plateau (Johnson et al. 2014). The Cook Forest infestation was detected because volunteers and staff were actively looking for it. With an intensified search effort, several other infestations were detected in 2013 in Pennsylvania along the Clarion River, the Allegheny River, Allegheny Reservoir, and in the Tionesta Scenic and Research Natural Area, another top priority area for conservation (Johnson et al. 2014).

It appears that detection of HWA in the early stages of infestation is positively correlated with search effort. The Allegheny experience is not unique in this way. While in western New York State, Mark Whitmore decided to visit the iconic Zoar Valley, and found an HWA-infested eastern hemlock tree within half an hour (personal communication 2015). Two other infested trees were subsequently found in the Valley, and 600 surrounding trees were treated with insecticides to control any infestations that may have spread but remained undetected in 2018. Also in western New York, HWA was detected in the Fredonia State University woodlot, an old-growth forest located on the university campus, where it was detected by faculty member Jonathan Titus (personal communication 2017).

## Strategies from Other U.S. Jurisdictions

The *Forest Health Technology Enterprise Team* (U.S. Forest Service undated) made the following recommendations for HWA management.

- Rearing and releasing of HWA predators should be continued to promote their natural spread.
- The number of field insectaries should be expanded to allow increased harvesting and redistribution of the climate-adapted “wild” individuals.
- A biological control program integrated into management programs with early detection surveys, monitoring of pest density throughout the management effort, and a combination of control methods should be consistently applied through time.
- A strategy of applying insecticide on a select number of large high-value eastern hemlocks and at the same time releasing and allowing the predators to become established on understory and non-treated trees should be applied.

The *New York State Hemlock Initiative* is pursuing the following steps (Whitmore 2015):

- identify and engage stakeholders,
- identify priority eastern hemlock stands,
- survey and map,
- develop and implement best management practices – assess management efficacy,
- establish eastern hemlock gene conservation strategies, and



- develop and implement biocontrol programs to grow and redistribute natural enemies – locate eastern hemlock hedges across the state.

## Strategies Identified in the Management Plan for Canada

The HWA management plan for Canada (Emilson et al. 2018), which is a comprehensive blueprint for the Canadian response to HWA, is by necessity an evolving document. The strategies in the management plan are listed below, followed by some areas where we feel improvements can be made.

- Continue to closely monitor hemlock stands for further HWA incursions
- Cut, remove, and monitor hemlock stands where HWA is found locally
- Treat high value trees with systemic insecticides
- Develop a biological control program for HWA in Canada
- Perform silvicultural management, including thinning, reduce hemlock in managed forests, and use physical barriers to reduce HWA dispersal
- Start collecting eastern hemlock seeds for preservation of genetic diversity and future restoration efforts
- 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
- Assess and document established HWA population dynamics and impacts on hemlock stands in southwestern Nova Scotia
- Continue to work on outreach and education to ensure constituency support

## Improving Management Strategies

### Phase out the removal of infested trees in the short term

Tree removal and incineration is currently employed for small, localized infestations. The HWA management plan for Canada (Emilson et al. 2018) correctly identifies that “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.”

HWA has been present in the Buffalo and Rochester areas of New York State since before 2008, has spread into natural areas in Western NY (NYDEC 2016), and may have been carried across the Canadian border to Ontario’s Niagara Gorge by birds (Emilson et al. 2018). There is no reason to believe that HWA will not spread into Ontario far more broadly, and for this reason, destruction of individual trees will have little effect even over the short- to medium-term.

Many of Ontario’s eastern hemlock resources are found in ecologically sensitive areas and have often been designated as ANSIs or as having high ecological, recreational and other values, and commonly meet the criteria for old-growth forest designation (Appendix 2). Continuing to cut down infested trees is not consistent with management goals in these areas, particularly if it is not the optimal strategy for other reasons. In the Niagara Gorge, for example, eastern hemlocks have been found up to 435 years old (Kershner 2004). In addition, a continued strategy of cutting infested trees would likely act as a disincentive for citizen volunteers to survey for HWA infestations. Public participation will be required if we are to maximize our response to this impending infestation.



Lessons learned in Nova Scotia should be applied to Ontario as early as possible, and when an HWA response framework is developed for new HWA incursions it should include options other than cutting and incineration, which should be applied in sensitive forests and those that possess ecological and cultural values.

### **Do-nothing option**

Management recommendations should include the option of “doing nothing”. In addition, these recommendations should be developed using peer-reviewed science including field trials. Currently, there is a lack of evidence to support definitive management prescriptions, thus, they should be avoided until research can confirm effectiveness, including evaluations of ecosystem impacts. Best management practices should place an equal or greater weight on the option of doing nothing, which may ultimately result in less ecosystem damage (Foster and Orwig 2006). Management should be

explicitly discouraged in old-growth stands. Recommendation #5 in the HWA management plan for Canada “Perform silvicultural management...” should read “**Research** silvicultural management...”

### **Prioritize development of field insectaries**

The Canada management plan states that, “The development of field insectaries for rearing in Nova Scotia could also be explored.” Whitmore has found that eastern hemlock hedges are excellent as field insectaries, and he recommends locating them or planting them ahead of the arrival of HWA (personal communication 2015). Since it takes time for hemlock hedges to become established, they should be planted or identified immediately in both Nova Scotia and Ontario.

### **Keep invasive species watch lists up to date**

Organizations should ensure that HWA is included on invasive species watch lists. At the time of writing, HWA is not identified as a watch list species on some invasive species websites in Ontario.

## **HEMLOCK DISTRIBUTION IN ONTARIO**

### **Existing Mapping**

Currently, there is no map showing the distribution of eastern hemlock abundance in southern Ontario. Forest Resource Inventory maps showing eastern hemlock abundance exist for the “area of the undertaking” (north of southern Ontario), however the most likely early infestations of HWA will be south of this area. The HWA working group for land managers, organized by Silv-Econ, is collecting

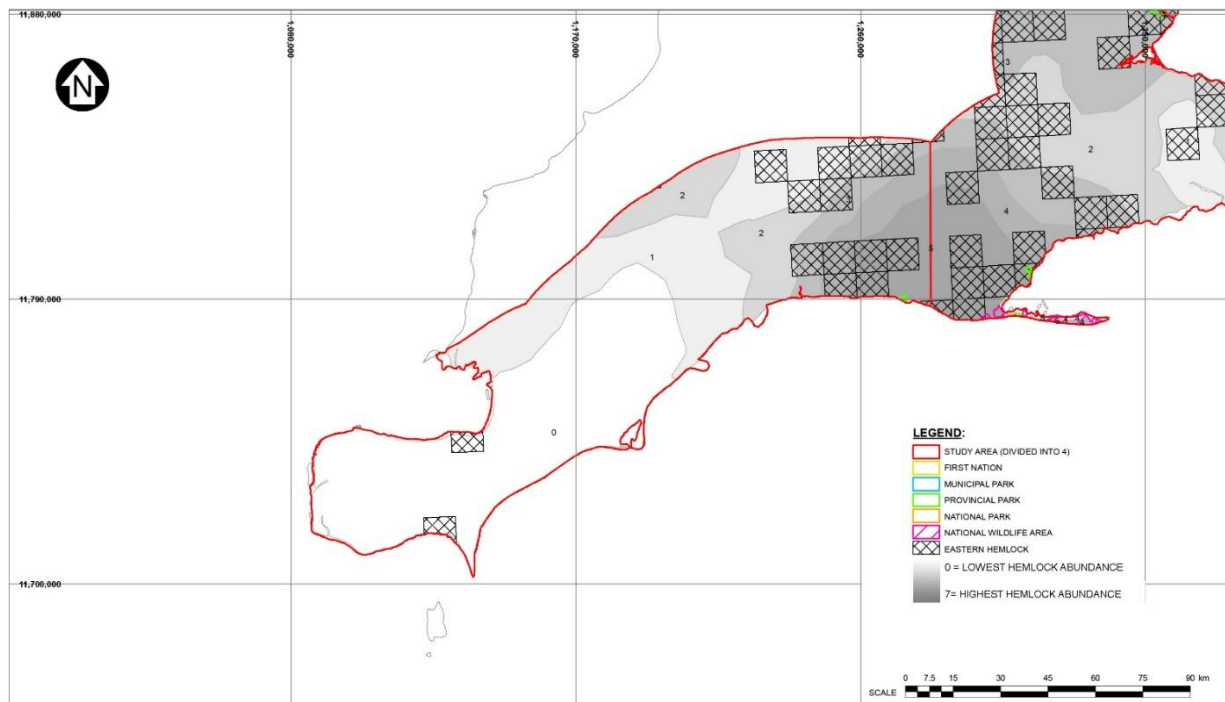
eastern hemlock data from land owners and managers - interested land managers can contact Kathleen Ryan (kathleen.ryan@silvecon.com) to share data.

There are some standardized provincial eastern hemlock data from the Ministry of Natural Resources and Forestry (State of the Forest data) and the University of Guelph Arboretum (Tree Atlas data), which we have combined in distribution maps for a 50 km wide study area in Ontario along Lakes Erie and Ontario (Figures 6 - 9). Due to its close proximity to the advancing northern edge of HWA, we consider this to be the highest risk area for initial infestation in Ontario.

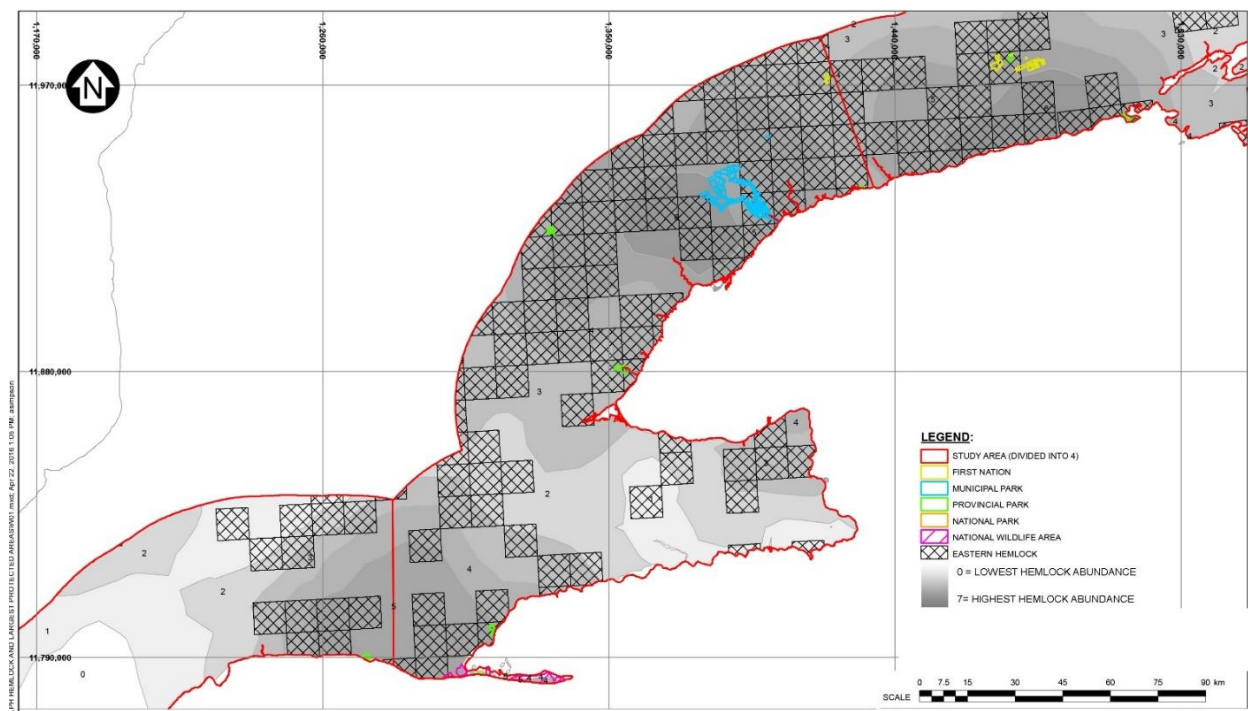
There is a semi-continuous distribution of eastern hemlock throughout most of the study area with the exception of the extreme southern portions, however there are significant variations in abundance. Areas with high eastern hemlock relative abundance are centered on Long Point (Figures 6 - 7), the City of Toronto (Figures 7 - 8), between Wesleyville and Colborne (Figures 7 - 8) and the Thousand Islands area (Figures 8 - 9).

Analysis of large protected areas intersecting with areas of high eastern hemlock abundance (Table 2) will be helpful in focusing HWA monitoring and management efforts. Many of these parks have no eastern hemlock stands that have been singled out for special designation (ANSI, etc.), thus, a process for identifying high conservation value eastern hemlock forests within these parks should be undertaken.

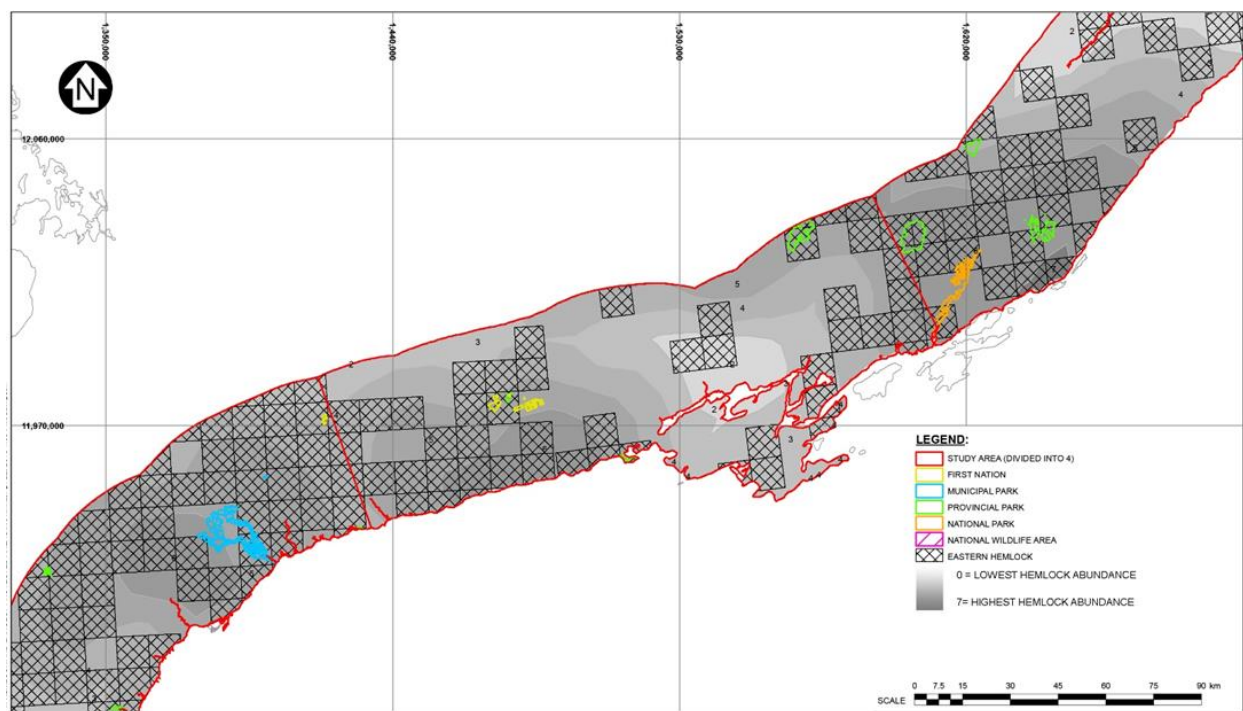
**FIGURE 6 - HEMLOCK ABUNDANCE IN THE WINDSOR-LONG POINT REGION OF ONTARIO (BLACK CROSS-HATCHING FROM U. GUELPH TREE ATLAS DATA (PRESENCE); 0 TO 7 HABITAT SUITABILITY SHADING FROM MNRF DATA)**



**FIGURE 7 - HEMLOCK ABUNDANCE IN THE LONG POINT-TORONTO REGION OF ONTARIO (BLACK CROSS-HATCHING FROM U. GUELPH TREE ATLAS DATA (PRESENCE); 0 TO 7 HABITAT SUITABILITY SHADING FROM MNRF DATA)**

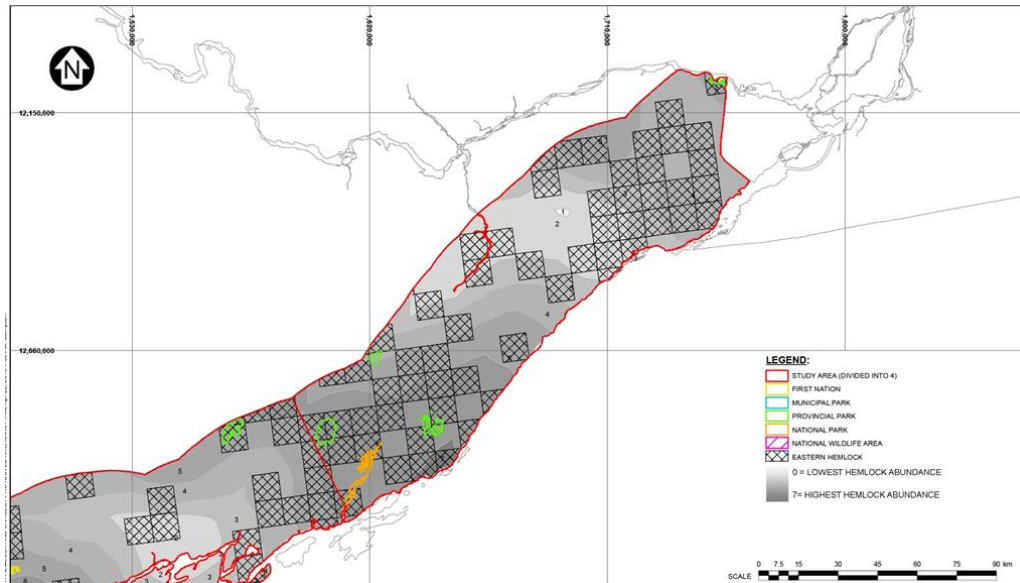


**FIGURE 8 - HEMLOCK ABUNDANCE IN THE WESLEYVILLE AND COLBORNE REGION OF ONTARIO (BLACK CROSS-HATCHING FROM U. GUELPH TREE ATLAS DATA (PRESENCE); 0 TO 7 HABITAT SUITABILITY SHADING FROM MNRF DATA)**





**FIGURE 9 - HEMLOCK ABUNDANCE IN THE THOUSAND ISLANDS REGION OF ONTARIO (BLACK CROSS-HATCHING FROM U. GUELPH TREE ATLAS DATA (PRESENCE); 0 TO 7 HABITAT SUITABILITY SHADING FROM MNRF DATA)**



**TABLE 2 - TOP 20 PROTECTED AREAS WITH HIGH HEMLOCK HABITAT SUITABILITY**

Protected Area Name	Size (ha)	Mean Habitat Suitability Class (4+) <sup>1</sup>
Potential Rouge National Park (North of Steeles)	6947	5.3
Frontenac Provincial Park	5283	5.5
Rideau Canal National Park	3437	6.0
Puzzle Lake Provincial Park	3406	5.0
Charleston Lake Provincial Park	2418	6.0
Existing Rouge National Park	2312	5.0
Long Point National Wildlife Area	1764	4.3
Murphy's Point Provincial Park	1323	4.5
Nonquon Provincial Wildlife Area	1126	4.0
Big Creek National Wildlife Area	929	5.0
Voyageur Provincial Park	685	5.0
Bronte Creek Provincial Park	677	4.0
Presqu'ile Provincial Park	540	5.0
Menzel Centennial Provincial Nature Reserve	399	4.0
Turkey Point Provincial Park	312	5.0
Forks of the Credit Provincial Park	282	4.5
Port Burwell Provincial Park	166	5.0
Serpent Mounds Provincial Park	141	5.0
Darlington Provincial Park	111	4.0
Stoco Fen Provincial Nature Reserve	100	5.0

**TABLE 2 NOTES:** 1 - from MNRF Hemlock Habitat Quality Mapping; habitat categories range from 0 to 7; only habitat categories greater than or equal to 4 are shown here; most protected areas are composed of multiple habitat polygons

## Topographic Predictors

*“Large aggregates of hemlock, though infrequent, are almost always associated with either (1) relatively steep, eroding slopes where rooting-zone soil is probably dependably moistened (by climate or presence of soil seepage) or (2) slightly elevated sandy areas that border certain wetlands (e.g., old beachlines, levees, banks washed of clay).”*  
(Rogers 1978)

Eastern hemlock has strong topographic habitat associations that vary regionally. In his literature review on topographic relationships of eastern hemlock, Marks (2012) noted that, in general, it tends to grow on slopes (often steep) with northerly aspects, and it is also often associated with east and west aspects depending on the region being studied. A GIS model using digital elevation, soil and other habitat variables, overlain with Southern Ontario Land Resource Information System (SOLRIS) conifer data, may provide a useful tool for predicting the spatial occurrence of eastern hemlock. Related work has already been done by Danijela Puric-Mladenovic (personal communication 2017).

## Identifying Priority Stands for Conservation

### Introduction

Due to limited resources, it is unlikely that we will be able to protect all of southern Ontario’s eastern hemlock forests from HWA. Thus, there is a need to prioritize monitoring and management to ensure that eastern hemlock resources with the highest conservation value are preserved. There is no generally accepted definition of conservation value, and the concept continues to evolve over time (e.g., Capmourteres & Anand 2016). However, there are some frameworks that should be considered in prioritizing eastern hemlock forests for conservation.

For example, the High Conservation Value (HCV) Resource Network identified the following six HCVs: species diversity, landscape-level ecosystems and mosaics, ecosystems and habitats, ecosystem services, community needs, and cultural values (Brown et al. 2013). Our objective for this report component was to compile a preliminary list of HCV eastern hemlock forests that should be priorities for early detection, seed harvesting, and future management. Only options for management that do not include removal and incineration of infested trees should be considered and planned for in HCV eastern hemlock forests.

### Methods

We used internet searches, searches of available literature including natural area inventories, the NHIC database, old-growth and heritage woodland reports, and personal communications to identify and describe potential HCV eastern hemlock forests in southern Ontario. The ecological and social values provided by eastern hemlock in Pennsylvania’s High Allegheny Plateau were identified by Johnson et al. (2014) as: high water quality, healthy riparian zones, presence of rare species and habitats (including old growth), general habitat provision (such as in unbroken core forest tracts), social values (recreation, aesthetic, spiritual), and connectivity of eastern hemlock forests.



Adapting this set of ecological and social values to southern Ontario, we applied the following criteria to evaluate the conservation value of eastern hemlock forests located within our study area.

- Old-growth forest
- Mature forest / entering old-growth stage
- Contiguous forest in large tracts or connected in a natural heritage network
- High scenic, recreational, or educational value
- Urban forest
- Representation value: ANSI, Nature Reserve, candidate reserve
- Important birding area (IBA)
- Recognized environmentally significant area, heritage woodland, or signature site
- Riparian, waterfront or wetland forest
- Slope stabilization
- Rare species

Highest priority should usually be assigned to old-growth forests, which have significant biodiversity, genetic diversity, ecosystem services, recreational, educational and scientific value (Buchert et al. 1997, Mosseler et al. 2003a, Mosseler et al. 2003b, Luyssaert et al. 2008, Shaffer 2009, Lutz et al. 2018, etc.). High priority should also be assigned to areas recognized as ANSIs, important birding areas (IBAs), Carolinian Canada signature sites, and heritage woodlands.

## Results

Our list of 94 sites (Figure 10, details in Appendix 2) is partial and is meant to serve as a starting point. These and other identified sites should be priorities for monitoring, seed collection, and enhanced / alternative management. We are also using this list of sites to help promote citizen monitoring in publicly accessible hemlock forests (AFER 2018).

A more thorough collaborative-based process to identify and prioritize HCV sites should be undertaken, as was done in the High Allegheny Plateau region (Johnson et al. 2014). The sites that we selected are plotted on a map of eastern hemlock relative abundance (Figure 10) and described in Appendix 2. Priority should be placed on regions with high concentrations of eastern hemlock forest, high conservation value, as well as high threat due to close proximity to the U.S. border, bird migratory routes, and human population centers. However, it is important to realize that HWA movement is unpredictable, emphasizing the need to carry out monitoring and public awareness efforts throughout Ontario.

The Long Point region shows a significant concentration of eastern hemlock (Figures 6 & 7), which is likely attributable in large part to the incised valleys of Big Creek, Big Otter Creek, Little Otter Creek, and their tributaries. These valleys include numerous ANSIs and IBAs and are likely the most important habitat in Ontario for Louisiana waterthrush. Access to these valleys is limited and their conservation value is significant, however, many of them are on private land.

The Dundas Valley contains a nationally significant community of forest birds, with breeding evidence for at least five nationally vulnerable, threatened or endangered species. Notably, two to four breeding pairs of Louisiana waterthrush have been documented annually (IBA Canada undated) that could be threatened by the loss of eastern hemlock. The Dundas Valley is also a very large and mature urban forest with significant areas of old-growth forest including Spencer Gorge (M. Henry 2017, unpublished field notes).

The Twelve Mile Creek headwater forests support the Louisiana waterthrush as well as a rich assemblage of species including red-shouldered hawk (nationally vulnerable), American woodcock, eastern screech-owl, ruby-throated hummingbird, red-bellied woodpecker, tufted titmouse, eastern wood-pewee, Carolina wren, wood thrush, yellow-throated vireo, blue-winged warbler, pine warbler, cerulean warbler (nationally vulnerable), scarlet tanager, eastern towhee, and field sparrow (IBA Canada undated). Numerous areas in the Twelve Mile Creek headwaters have been identified as old-growth forests (Kershner 2004).

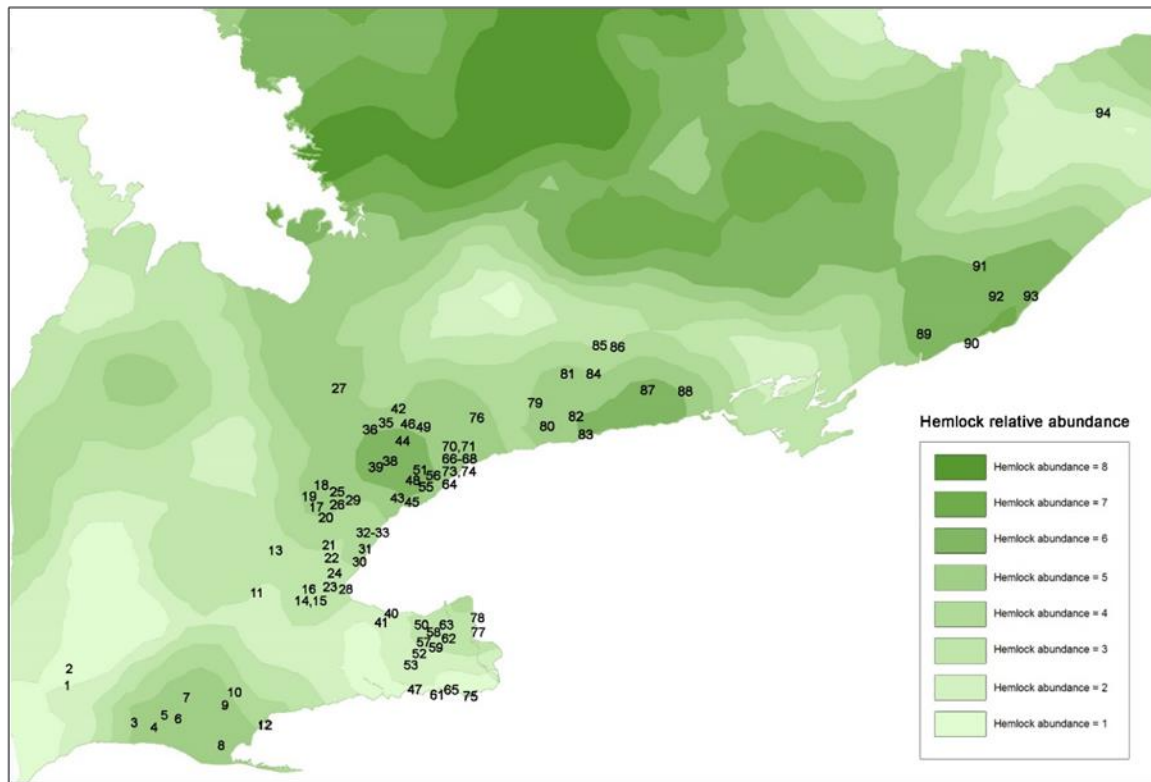
Bronte Creek Provincial Park is notable for its very significant eastern hemlock forests, which are relatively large, old, and natural. They are primarily distributed along the steep valley slopes and are readily viewed by the public. Thus, they have high scenic, recreational, and educational value as well.

The Greater Toronto Area (GTA) is a regional center of eastern hemlock abundance with significant concentrations in the major river valleys and their tributaries: Etobicoke/Mimico Creek, Humber River, Don River, Highland Creek and the Rouge River. Significant old-growth eastern hemlock forests occur in tributary ravines linked to the West Don Valley and Rouge River.

The Niagara Escarpment, which has numerous eastern hemlock forests and many unique sites with high conservation value, is designated as a biosphere reserve by the UNESCO Man and Biosphere Program. Once HWA arrives in southern Ontario, the Niagara Escarpment will likely act as a movement corridor for this forest pest.



**FIGURE 10. LOCATIONS FOR 94 HIGH CONSERVATION VALUE HEMLOCK FORESTS IN SOUTHERN ONTARIO**



- |  |   |                                       |
|--|---|---------------------------------------|
| 1 Delaware Woodlot                         | 40 Grimsby Point                              | 79 Long Sault Conservation Area       |
| 2 Kilworth Valleylands                     | 41 Beamers Falls Gorge                        | 80 Stephen's Gulch Conservation Area  |
| 3 Springwater Forest                       | 42 Glenville Hills                            | 81 Cavan Creek Headwaters             |
| 4 Mount Salem Forest                       | 43 Lambton Woods                              | 82 Osaca - Ganaraska River            |
| 5 Little Jerry Creek                       | 44 Maple Uplands & Kettles / McGill ESA       | 83 Wesleyville Ravines                |
| 6 Little Otter Creek                       | 45 High Park                                  | 84 Stewart's Woods                    |
| 7 Big Otter Creek                          | 46 White Rose West Forest                     | 85 Jackson Creek old-growth forest    |
| 8 Big Creek Floodplain                     | 47 Harold Mitchell Nature Reserve             | 86 Mark S. Burnham Provincial Park    |
| 9 Delhi Big Creek Valley                   | 48 Earl Bales Park                            | 87 Peter's Woods                      |
| 10 Delhi Wetland Nature Reserve            | 49 Simeon Lakes                               | 88 Goodrich-Loomis                    |
| 11 Pinehurst Lake Complex (Grand River)    | 50 Balls Falls Gorge (Twenty Valley)          | 89 Collins Lake                       |
| 12 Spooky Hollow                           | 51 East Branch Of Don River                   | 90 Thousand Islands                   |
| 13 Oil Well Bog Little Tract               | 52 Boye's Explosive's -Fenwick Forests        | 91 Phillipsville Cliff                |
| 14 Spring Creek                            | 53 Northwest Fenwick Forest                   | 92 Charleston Lake Provincial Park    |
| 15 Dundas Valley                           | 54 North Fenwick Foothlope Forest             | 93 Jones Creek Trails                 |
| 16 Spencer Gorge                           | 55 Wilket Creek / Sunnybrook Parks            | 94 North Castor River/Pana Road South |
| 17 Limehouse Conservation Area             | 56 Brookbanks Ravine                          |                                       |
| 18 Terra Cotta Woods                       | 57 Short Hills Wilderness Preserve            |                                       |
| 19 Silver Creek Valley / Scotsdale Farm    | 58 Rockway Falls Gorge                        |                                       |
| 20 Stewarttown Woods                       | 59 St. John's Conservation Area, East Ravines |                                       |
| 21 Crawford Lake - Rattlesnake Point       | 60 Hemlock Valley                             |                                       |
| 22 Lowville-Bronte Creek Escarpment Valley | 61 Sugar Loaf Hill                            |                                       |
| 23 Bridgeview Valley                       | 62 Terrace Creek Gorge                        |                                       |
| 24 Lake Medad and Medad Valley             | 63 Decew Falls and Gorge                      |                                       |
| 25 Georgetown Credit Valley                | 64 Hague Park                                 |                                       |
| 26 Hungry Hollow Ravine                    | 65 Nickel Beach Woods                         |                                       |
| 27 Beattie Pinery                          | 66 Highland Creek Swamp                       |                                       |
| 28 Lasalle Park                            | 67 Finch Avenue Meander Scar                  |                                       |
| 29 Huttonville Valley                      | 68 Momingside Tributary Ravine (Rouge)        |                                       |
| 30 Bronte Creek Provincial Park            | 69 Momingside Park                            |                                       |
| 31 Sixteen Mile Creek Valley               | 70 Meadowdale Woodlot A                       |                                       |
| 32 Roy Ivors Woodlot                       | 71 Little Rouge River (Woodland Trail)        |                                       |
| 33 Credit River At Erindale                | 72 Rouge Park                                 |                                       |
| 34 Rattray Marsh                           | 73 North Pickering / Seaton Hiking Trail      |                                       |
| 35 Happy Valley Forest                     | 74 Altona Forest                              |                                       |
| 36 Pottageville Southeast Upland           | 75 Marcy's Woods (Point Albino)               |                                       |
| 37 Winona Escarpment Slopes                | 76 Glen Major Forests                         |                                       |
| 38 Boyd Conservation Area / Adjacent Lands | 77 Niagara Gorge Steep Slope Forest           |                                       |
| 39 Kleinberg Woodlots                      | 78 Smeatons Ravine                            |                                       |

## Setting Priorities for Monitoring

HWA carried by birds is likely to continue to move into the Niagara Peninsula. Areas of high risk are the Niagara Gorge including Smeaton's Ravine, Twelve Mile Creek headwaters including Short Hills Provincial Park, Balls Falls Conservation Area, Marcy's Woods, Nickel Beach Woods, Sugar Loaf Hill, and Harold Mitchell Nature Reserve, among others.

In addition to risk of birds carrying HWA, both Dundas Valley and the GTA (and other areas near urban centers) could be at additional risk from eastern hemlock nursery stock. Since the 2012 infestation was found in Etobicoke, nearby areas such as Etobicoke Creek and the Humber River should be considered priority areas for monitoring. However, the whole GTA should also be considered as a priority area because of the elevated risk to HWA and the significant conservation value of the eastern hemlock forests found there. The magnitude of the risk from infested nursery stock is unknown.

The Long Point Region is an even greater unknown because the likelihood of birds carrying HWA across Lake Erie has not been determined, however because of the concentrations of eastern hemlock found there and the high conservation value of these forests, some monitoring and awareness efforts should be focussed on the region.

Even though HWA colonization appears unlikely in the short term, a close watch should be kept on the Thousand Islands region, particularly if HWA is seen to be moving into New York's Tug Hill area. A significant and far more continuous distribution of eastern hemlock is found north of the Thousand Islands area along the Frontenac Axis. Monitoring and management in this area should become a high priority if U.S. infestations move closer.

Although these five regions are among the highest risk areas, nearly all of Ontario's eastern hemlock range should be monitored due to the combined risk of birds and nursery stock carrying HWA.

## HWA DETECTION

### Detection Methods

#### Visual inspections of branches

The most common method of surveying for HWA is visual inspection of the underside of branches within reach during the winter/spring while wool is present. This may be either standardized sampling (Costa & Onken 2006) or more informal approaches, usually geared towards citizen science (e.g., New York State Hemlock Initiative undated). Until recently, HWA surveys using citizen science have been the most common type of survey and have detected the majority of infestations to date. Their primary limitation is that detection of low density infestations in the upper canopy is unlikely (Fidgen & Turgeon 2016).

Marked decline in eastern hemlock occurs at relatively high rates of HWA infestation. When 30% of new shoots on a tree are infested, noticeable crown decline usually occurs and the probability of successful control and tree survival may be lower (Fidgen et al. 2006). An infestation level of 30% should be easily observed with ground surveys or simple observation in winter and spring, however by the time decline is likely to be observed, infestations will be well advanced.

## Ball sampling

Launching Velcro-covered balls into the upper forest canopy can detect even light infestations of HWA higher in the tree with less than ten balls launched into each tree (~12 minutes sampling time/tree). For land managers, this is a valuable complement to ground-based surveys of branches and may be applicable in citizen monitoring efforts with motivated volunteers, if the equipment is made available.

## Crawler sampling

Sticky traps deployed under eastern hemlock trees during peak HWA crawler activity can detect infestations high in the tree, as crawlers are dislodged by wind or rain and caught on the sticky surface. This has the potential to be very effective as a monitoring tool but requires more effort and expertise. It might be used for monitoring in high risk HCV forests.

## Citizen Monitoring

*“All four HWA infestations identified here on the Allegheny National Forest were found by non-Forest Service individuals. In fact, they were detected by folks that had participated in our training efforts. Bottom line, the training sessions are very successful in getting more eyes out in the woods looking.”*

Andrea Hille  
US Forest Service

## Season (when to look)

The HWA survey season runs from late October to mid-July when the adelgid is actively growing and fresh wool is present (Costa & Onken 2006), however HWA is most visible in the winter and early spring (Kanoti et al. 2015). The New York State Hemlock Initiative Survey Protocol recommends surveying from late November to July (New York State Hemlock Initiative 2018).

When sampling with a ball in the upper canopy, the recommended detection season is Late April to early July, when HWA wool is most conspicuous and abundant (Fidgen & Turgeon 2016). When surveying for active crawlers, sticky traps should be set up before the hatch of progrediens crawlers in mid-April and taken down just after sistens crawlers have settled in mid-July (Fidgen & Turgeon 2016).

## Monitoring priorities (where to look)

The New York State Hemlock Initiative recommends prioritizing monitoring areas close to water or streams, or areas frequented by humans or birds. Costa & Onken (2006) suggest targeting sites that are at high risk for infestation to increase search effectiveness. Types of high risk areas include the following:

- sites that concentrate or attract wildlife such as game trails, feeding stations (birds, deer, and other wildlife), and water sources including vernal pools;
- sites that concentrate human activity such as trails, resting spots, and parking lots; and
- heat islands that reduce cold in the winter such as roadways, roofs, and large water bodies.

Lakeside surveys using boats have been used in New York State (Whitmore, personal Communication 2019) and may be an effective technique for citizen surveys. This technique also has the advantage that low branches often overhang waterbodies for ease of surveying.



## Promoting awareness and starting monitoring early

Volunteer surveys have proven to be highly effective in detecting HWA. For example, professional surveys for HWA have been ongoing on the Allegheny National Forest since 2004, however all survey results were negative, and HWA was only discovered there when volunteers became formally involved in 2013. At that time, HWA was discovered in several areas, discovered mainly through volunteers and unplanned detections (Johnson et al. 2014).

Since HWA has maintained a low public profile in Ontario until recently, it could be present here at relatively low abundances and remain un-noticed for some years. It is therefore imperative to mobilize volunteers in citizen monitoring as soon as possible. One of the best ways to do this is through citizen science training workshops.

We have also created a project that uses the *iNaturalist App* to collect data on eastern hemlock stand location and maturity, and encourages monitoring. Although the stand and site information will be limited, it provides precise locations and photos, and it harnesses citizen science to help us locate old-growth forests in particular (available at: <https://www.inaturalist.org/projects/eastern-hemlock-project>).

## Workshops

Andrea Hille (personal communication 2017) made the following suggestions for organizing citizen monitoring workshops.

- Schedule training in the evenings for volunteers with regular jobs.
- Provide coffee and light snacks - it just makes for a nicer meeting, especially after work for some folks.
- Volunteers don't need to adopt a specific conservation area that you want monitored. We have several volunteers who look for HWA when out enjoying their normal recreation activities.
- You will get many "HWA look alike". Which is okay, at least folks are looking.
- Make sure as part of the training to instruct volunteers to NOT move any eastern hemlock material they suspect has HWA. Have them leave it there, flag it, GPS it, and obtain a detailed enough description of how to relocate the tree.
- Make sure volunteers know where to report HWA.

## Survey protocols

The New York State Hemlock Initiative volunteer survey protocol (New York State Hemlock Initiative undated) is described below.

- Start your survey in an easily accessible location.
- Begin at a random eastern hemlock tree with branches within arm's reach.
- Examine the underside of branches closest to the tips for HWA's white woolly egg sacs.
- Check three branches per tree.
- Continue to survey by moving randomly from one eastern hemlock to the next, ideally selecting a tree 10 to 15 feet from the previous tree surveyed.
- Survey as many trees as time, weather, and safety permit. It is okay if there are not many eastern hemlock in the area you are surveying.
- Large stands should be surveyed in several locations.



- Eastern hemlock branches found on the ground provide a good way to check on what may be going on further up in the canopy.
- Check eastern hemlock bark for woolly masses after rain storms.
- Complete surveys by mid-April to reduce the chance of accidentally spreading HWA.

The following survey protocol is used for volunteer monitoring in the Allegheny National Forest (USDA undated).

- 1. Walk through the sample area in a random direction until you reach a tree to sample. Trees must have two branches that can be reached from the ground.
- 2. Select a branch and closely examine the underside of the terminal meter of foliage for the presence or absence of HWA nymphs or white woolly masses at the base of hemlock needles. If HWA are found, GPS and note the tree location, and go to step 4.
- 3. If no HWA are found on the first branch, select a second branch on the opposite side of the tree and examine as before.
- 4. Pace out approximately 10 to 15 single-step paces (in a stand with a goal of 100 sample trees) (50 single-step paces when a total of 25 trees will be sampled in the stand) in a random direction and select the closest tree with two branches that you can reach. Don't get carried away being too exact with your cardinal directions; it doesn't matter much, just shoot and go. The same goes for the distance to the next tree, though efforts should be made to sample across the entire stand. Arbitrarily select trees to examine.
- 5. Examine the tree for HWA as in steps 2 and 3.
- 6. If no HWA were found, repeat steps 4 to 5 until HWA are detected (go to 7 and REPORT find), or 25 trees (general forest stands) or 100 trees (stands with large influxes of recreation users) are sampled. Any time HWA is detected, go to 7 and REPORT find.
- 7. If the number of trees with HWA is less than 15 then repeat steps 4 to 5 until either 15 trees with HWA are detected or 25 trees in general forest stands or 100 trees in stands with large influxes of recreation users have been examined.
- 8. In all sample stands, when 25 trees in general forest stands or 100 trees in stands with large influxes of recreation users, have been examined, stop sampling.
- 9. In each stand sampled, keep a record of the number of trees examined and obtain a GPS point or map any trees with suspected HWA infestation. Photograph (if possible) and report potentially infested trees immediately.

## Other awareness efforts

- Probably the single greatest accomplishment on HWA awareness in Ontario is the work done by *Silvecon* to raise the profile of HWA among land managers and to create a working group modelled on the *High Allegheny Collaborative Hemlock Conservation Strategy*.
- Since 2015, *Ancient Forest Exploration & Research* has been promoting the issue to naturalists via social media, newsletters, an article in *Ontario Nature Magazine*, and via the website *ancientforest.org*. Presentations to naturalist groups and at parks have taken place and are scheduled.

- The *Canadian Food Inspection Agency* (CFIA) has made available HWA credit cards, temporary tattoos, and perhaps most importantly, trail signs.
- The *Early Detection and Rapid Response Project*, coordinated in Halton and Peel regions by *Ontario Invasive Plant Council*, has lead HWA detection workshops focused on ball monitoring.
- The *Ontario Federation of Anglers and Hunters*, through their existing programming, provides the most user-friendly means of reporting detections of HWA and all invasive species (*EDDMapS*).
- The *Canadian Forest Service*, *Ontario Ministry of Natural Resources and Forestry*, and the *Invasive Species Centre* provide information online and elsewhere.

Short-term goals for raising awareness should include the following:

- ensure that all trails through eastern hemlock forest from Niagara to GTA have HWA awareness signage,
- greater outreach to traditional media, and
- more detection workshops with a focus on the general public (prioritize ground-level branch surveys).

## Reporting HWA in Ontario

In Canada, any HWA sighting should be reported directly to the CFIA Plant Health Surveillance *Unit* (1-800-442-2342). Sightings in Ontario can be verified or reported on a smartphone using the EDDMapS Ontario app ([www.eddmaps.org/ontario](http://www.eddmaps.org/ontario)). HWA sightings reported to EDDMapS are shared with CFIA and verified, so this is an alternative to reporting to CFIA.

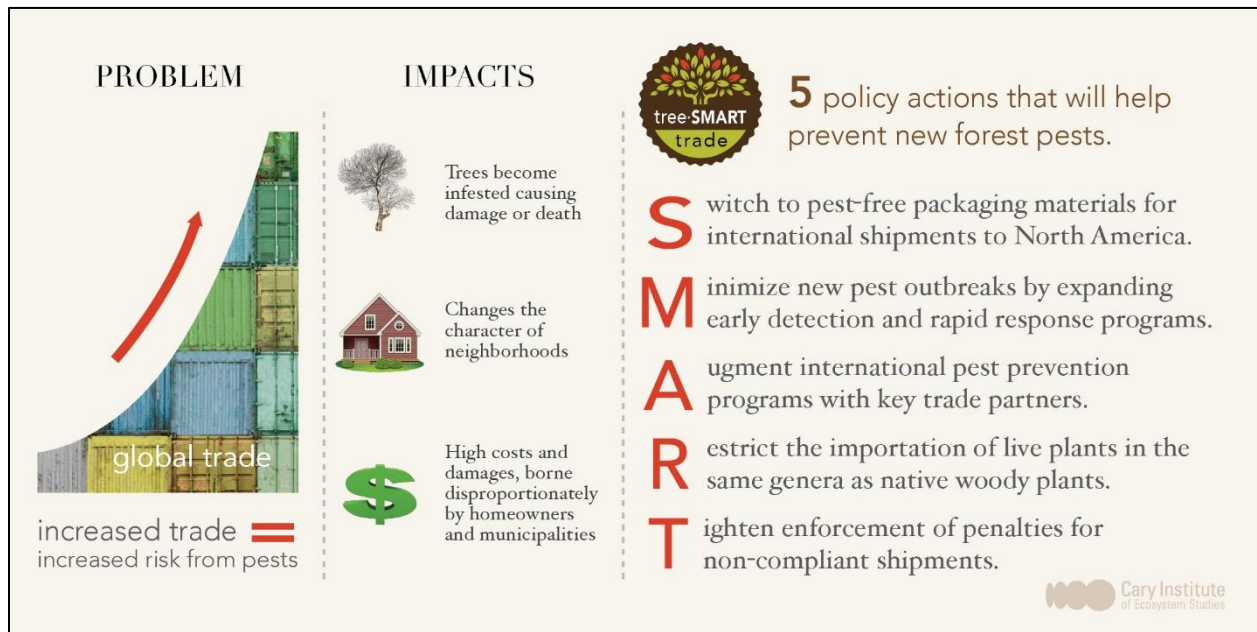
## The Larger Context of Invasive Species

There is a long historical trend of invasive tree pests and pathogens being introduced to Ontario including larch sawfly, white pine blister rust, chestnut blight, Dutch elm disease, beech bark disease, butternut canker, and emerald ash borer. Likely candidates for the next wave of infestations include oak wilt, thousand cankers disease, spotted lanternfly, and HWA (Invasive Species Centre undated). However, unknown new pests might arrive at any time, or could already be present. For example, emerald ash borer had been present in North America for up to a decade before being detected (Natural Resources Canada undated).

The need for much stricter control of imports of both live plant and wood packaging material has been widely noted (Liebhold et al. 2012, Strutt et al. 2013, Haack et al. 2014, Roy et al. 2014, Lovett et al. 2016). A meaningful framework for dealing with invasive forest pests, labelled Tree-SMART Trade, has been proposed by the Cary Institute of Ecosystem Studies (undated, Fig. 11). This approach or an equivalent made-in-Canada approach should be implemented as soon as possible.

More stable funding should also be made available for citizen-based early detection programs such as the EDRR program in Ontario, since early detection is essential for effective and cost-effective eradication of destructive invasive species (Brockerhoff et al. 2010, Haack et al. 2010).

FIGURE 5 – TREE-SMART TRADE INFOGRAPHIC



## Opportunities for Increased Stakeholder Involvement

### Environmental NGOs

As invasive species issues have become more critical, environmental NGOs are presented with often unrealized opportunities to promote greater citizen awareness and political activism geared to controlling these pests. Although the resources of eNGO's are typically thinly stretched, we urge these organizations to take invasive species seriously as a leading cause of biodiversity decline in North America and globally (Clavero and Garcia-Berthou 2005, Bellard et al. 2015, Downey and Richardson 2016). Furthermore, invasive species interact with climate change and habitat loss to cause cumulative impacts that are greater than the sum of individual impacts (Smith et al. 2012, Bellard et al. 2015). This has implications for policy and for public awareness/education campaigns. ENGOS can offer different perspectives and reach different audiences than government agencies.

Activities could include helping to promote existing initiatives (e.g., EddMapS, EDRR, grow me instead), addressing the larger context of pathways of colonization (e.g., Tree-SMART Trade), and developing new initiatives. There are significant opportunities to promote greater citizen involvement in detection efforts. Duplication of efforts should be avoided where possible, however different materials and approaches may be needed to reach different audiences.

### Municipalities

Municipalities are necessarily involved in invasive species management because direct economic impacts can not be avoided and tend to fall disproportionately on municipalities and homeowners (Lovett et al. 2016). Reports prepared for the Invasive Species Centre (Vyn 2017, 2018) found that Ontario municipalities spend an estimated \$38.8 million annually to manage invasive species, whereas the potential economic costs of invasive species in Ontario are as high as \$3.6 billion.

Associations that represent municipalities could take a greater leadership role on invasive species, much as they have with climate change. The Federation of Canadian Municipalities recognizes the challenges of invasive species (Federation of Canadian Municipalities 2017) but could work more with other levels of government to attempt to reduce invasion pathways. The Association of Municipalities of Ontario has no invasive species policy, considering it a regional issue (Jessica Schmidt, personal communication, 2016).

## **ACKNOWLEDGEMENTS**

Funding for this study was provided by the Plymouth Hill Foundation, the Helen McCrea Peacock Foundation and the ECHO Foundation. We thank these foundations for their generous support. We also thank Amanda Simpson for her assistance with mapping.

## **AFER's MISSION AND GUIDING PRINCIPLES**

AFER is a non-profit scientific organization with a mission to carry out research and education that lead to the identification, description and protection of ancient (pristine) forested landscapes, including old-growth forests. The earth-stewardship principles that guide our work include the following.

- Many forest ecosystem types are now endangered. We consider these ecosystems and other ancient forests to be non-renewable resources, which is not consistent with the practice of mining or logging them.
- We consider biodiversity conservation needs at local, provincial, federal and international scales.
- We support the Government of Canada's official commitment to increase protected areas to 17% of the Canadian land base (Government of Canada 2018).
- We support the New York Declaration on Forests to end natural forest loss by 2030 (Climate Focus 2015).
- We support the Tree-SMART Trade policy initiatives proposed by the Cary Institute of Ecosystem Studies (2017) to eliminate the importation of invasive insects and pathogens and to prevent tree species declines.

## **REFERENCES**

- Adkins, J. K. & L. K. Rieske. 2013. Loss of a foundation forest species due to an exotic invader impacts terrestrial arthropod communities. *Forest Ecology and Management* 295:126-135.
- Ancient Forest Exploration & Research (AFER). 2018. *The Eastern Hemlock Project*. [www.ancientforest.org/hemlock/](http://www.ancientforest.org/hemlock/).
- Bellard, C., C. Leclerc & F. Courchamp. 2015. Combined impacts of global changes on biodiversity across the USA. *Scientific Reports* 5:1-11.
- Benton, E.P. et al. 2017. Risk assessment of imidacloprid use in forest settings on the aquatic macroinvertebrate community. *Environmental Toxicology and Chemistry* 36:3108–3119. <https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/f/7151/files/2017/08/BENTON-2017-Risk-Assessment-Imidacloprid-Aquatic-Community-1gu1yxh.pdf> [accessed January 10, 2019].
- Brantley, S. T. et al. 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.

- Brockerhoff, E. G. et al. 2010. Eradication of invasive forest insects: Concepts, methods, costs and benefits. **New Zealand Journal of Forestry Science** 40(SUPPL.):117-135.
- Brown, E. et al. 2013. **Common Guidance for the Identification of High Conservation Values**. HCV Resource Network. [www.hcvnetwork.org/resources/folder.2006-09-29.6584228415/cg-for-hcv-identification](http://www.hcvnetwork.org/resources/folder.2006-09-29.6584228415/cg-for-hcv-identification).
- Brown, J. E. 2017. **Flies Released to Attack Hemlock-Killing Pest**. University of Vermont. <http://www.uvm.edu/~uvmpr/?Page=news&storyID=21026>.
- Buchert, G. P. et al. 1997. Effects of Harvesting on Genetic Diversity in Old-Growth Eastern White Pine in Ontario, Canada. **Conservation Biology** 11:747-758.
- Burns, R. M. & B. H. Honkala. 1990. Silvics of North America. **Agriculture Handbook 654**, Vol. 2, p.877. [http://www.na.fs.fed.us/spfo/pubs/silvics\\_manual/table\\_of\\_contents.htm](http://www.na.fs.fed.us/spfo/pubs/silvics_manual/table_of_contents.htm).
- Butin E. et al. 2005. Adaptation during biological invasions and the case of *Adelges tsugae*. **Evolutionary Ecology Research** 7:887–900.
- Capmourteres, V. & M. Anand. 2016. “Conservation value”: A review of the concept and its quantification. **Ecosphere** 7(10).
- Cary Institute of Ecosystem Studies. 2017. **Tree-SMART Trade**. <http://www.caryinstitute.org/science-program/research-projects/tree-smart-trade>.
- Caswell, T. et al. 2008. Production and evaluation of eastern hemlocks (*Tsuga canadensis*) potentially resistant to the hemlock woolly adelgid (*Adelges tsugae*). **Proceedings of the Fourth Symposium on Hemlock Woolly Adelgid in the Eastern United States**. pp. 124-134.
- Cheah, C. et al. 2004. **Biological Control of Hemlock Woolly Adelgid**. U.S. Forest Service. <http://www.fs.fed.us/na/morgantown/fhp/hwa> [accessed February 9, 2017].
- Clavero, M. & E. García-Berthou. 2005. Invasive species are a leading cause of animal extinctions. **Trends in Ecology and Evolution** 20:110.
- Climate Focus. 2015. **Progress on the New York Declaration on Forests – An Assessment Framework and Initial Report: Technical Annexes**. Goal 1: At least halve the rate of loss of natural forests globally by 2020 and strive to end natural forest loss by 2030. Prepared by Climate Focus, in collaboration with Environmental Defense Fund, Forest Trends, Global Alliance for Clean Cookstoves, Global Canopy Program and The Sustainability Consortium.
- COSEWIC. 2015a. **COSEWIC Assessment and Status Report on the Louisiana Waterthrush (*Parkesia motacilla*) in Canada**. Government of Canada, Ottawa. [http://www.registrelep-sararegistry.gc.ca/virtual\\_sara/files/cosewic/sr\\_Louisiana\\_Waterthrush\\_2015\\_e.pdf](http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_Louisiana_Waterthrush_2015_e.pdf) [accessed March 8, 2017].
- COWESIC. 2015b. **Committee on the Status of Endangered Wildlife in Canada (COSEWIC)**. Press Release, November 30, 2015. <http://www.cosewic.gc.ca/default.asp?lang=En&n=8313C380-1> [accessed March 7, 2017].
- Costa, S. & B. Onken. 2006. **Standardized Sampling for Detection and Monitoring of Hemlock Woolly Adelgid in Eastern Hemlock Forests**. U.S. Forest Service, Forest Health Technology Enterprise Team, University of Vermont, Burlington, Vermont and Northeastern Area State and Private Forestry, Morgantown, West Virginia. [http://www.cornellbotanicgardens.org/sites/default/files/hwa\\_sampling.pdf](http://www.cornellbotanicgardens.org/sites/default/files/hwa_sampling.pdf).
- Dalusky, M. 2017. **Status of Hemlocks, HWA and Biocontrol in Georgia**. Georgia ForestWatch. <http://gafw.org/status-of-hemlocks-hwa-and-biocontrol-in-georgia/>.
- Day, L. T. et al. 2013. Analysis of hemlock pollen size in Holocene lake sediments from New England. **Quaternary Research** 79:362-365.
- Downey, P. O. & D. M. Richardson. 2016. Alien plant invasions and native plant extinctions: a six-threshold framework. **AoB Plants** 8:1-21.
- Dyer, J. M. & J. M. Dyer. 2009. Assessing topographic patterns in moisture use and stress using a water balance approach. **Landscape Ecology** 24:391-393.



- Emilson, C. et al. 2018. Hemlock Woolly Adelgid Management Plan for Canada. **Canadian Forest Service Information Report GLC-X-21**, Natural Resources Canada.
- Environment Canada. 2003a. **National Climate Data and Information Archive**. [http://acer-acre.ca/wp-content/uploads/2011/12/dayswith-30C\\_ON.png](http://acer-acre.ca/wp-content/uploads/2011/12/dayswith-30C_ON.png).
- Eschtruth, A. K. et al. 2006. Vegetation dynamics in declining eastern hemlock stands: 9 years of forest response to hemlock woolly adelgid infestation. **Canadian Journal of Forest Research** 36:1435-1450.
- Evans, A. M. & T. G. Gregoire. 2007. A geographically variable model of hemlock woolly adelgid spread. **Biological Invasions** 9:369-382.
- Evans, R. A. 2002. Hemlock Woolly Adelgid Proceedings - 2002. In: **Hemlock Woolly Adelgid in Eastern North America Symposium**, R. R. B. Onken & and J. Lashomb, eds., Feb. 5-7. USDA Forest Service and State Univ. of N.J. Rutgers, East Brunswick, N.J. pp. 23-33.
- Fajvan, M. A. 2017. **Management Strategies for Eastern North American Forests Threatened by Hemlock Woolly Adelgid (*Adelges tsugae*)**. CIF/IFC Electronic Lectures. [https://cif-ifc.adobeconnect.com/\\_a1112870713/p3n64kepaidu/?launcher=false&fcsContent=true&pbMode=normal](https://cif-ifc.adobeconnect.com/_a1112870713/p3n64kepaidu/?launcher=false&fcsContent=true&pbMode=normal).
- Federation of Canadian Municipalities. 2017. **Policy Statement Environmental Issues and Sustainable Development**. [https://fcm.ca/Documents/corporate-resources/policy-statements/Environmental\\_Issues\\_and\\_Sustainable\\_Development\\_Policy\\_Statement\\_EN.pdf](https://fcm.ca/Documents/corporate-resources/policy-statements/Environmental_Issues_and_Sustainable_Development_Policy_Statement_EN.pdf) [accessed June 22, 2018].
- Fidgen, J. 2018. **Personal communication, Canadian Forest Service**. September 30 2016.
- Fidgen, J. & J. Turgeon. 2016. **Detection tools for an invasive adelgid**. Canadian Forest Service, Frontline, Technical Note No. 116. [http://publications.gc.ca/collections/collection\\_2016/rncan-nrcan/Fo123-1-116-eng.pdf](http://publications.gc.ca/collections/collection_2016/rncan-nrcan/Fo123-1-116-eng.pdf) [accessed February 14, 2017].
- Fidgen, J. et al. 2015. Detection of Hemlock Woolly Adelgid (*Hemiptera: Adelgidae*) infestations with sticky traps. **The Great Lakes Entomologist** 48:125-131.
- Fidgen, J. et al. 2006. Binomial sequential sampling plan for hemlock woolly adelgid (*Hemiptera: Adelgidae*) sistens infesting individual eastern hemlock trees. **Journal of Economic Entomology** 99:1500-1508.
- Fitzpatrick, M. C. et al. 2012. Modeling range dynamics in heterogeneous landscapes: Invasion of the hemlock woolly adelgid in eastern North America. **Ecological Applications** 22:472-486.
- Ford, C. R. & J. M. Vose. 2007. *Tsuga canadensis* (L.) Carr. mortality will impact hydrologic processes in southern Appalachian forest ecosystems. **Ecological Applications** 17:1156-1167.
- Forest Health Technology Enterprise Team. 2017. **Hemlock Woolly Adelgid Biological Control**. U.S. Forest Service. <http://www.fs.fed.us/foresthealth/technology>.
- Forest Restoration Alliance. 2016. **Locate a Survivor Project**. <http://threatenedforests.com/locate-a-survivor/> [accessed June 19, 2018].
- Foster, D. R. 2000. Hemlock's Future in the Context of its History: An Ecological Perspective. In: **Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America**, eds: K. Shields and D. R. Souto, Gen. Tech. Rep. 267, June 22-24, USDA, Forest Service, Newtown Square, PA. pp. 1-4.
- Foster, D. R. & D. A. Orwig. 2006. Preemptive and salvage harvesting of New England forests: When doing nothing is a viable alternative. **Conservation Biology** 20:959-970.
- Foster, D. R. et al. 2006. A climatic driver for abrupt mid-Holocene vegetation dynamics and the hemlock decline in New England. **Ecology** 87:2959-2966.
- Foster, D. R. et al. 2014. **Hemlock: A Forest Giant on the Edge**. Yale University Press, New Haven, CT.

- Fuller, J. L. et al. 1998. Impact of Human Activity on Regional Forest Composition and Dynamics in Central New England. *Ecosystems* 1:76–95. <http://link.springer.com/10.1007/s100219900007> [accessed February 4, 2017].
- Goerlich, D. L. & R. D. Nyland. 1996. Natural Regeneration of Eastern Hemlock: A Review of Silvical Characteristics of Eastern Hemlock. In: *Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America*, eds: K. Shields and D. R. Souto, Gen. Tech. Rep. 267, June 22-24, USDA, Forest Service, Newtown Square, PA.
- Government of Canada. 2018. *Canada Biodiversity Targets 2020*. [http://publications.gc.ca/collections/collection\\_2016/eccc/CW66-524-2016-eng.pdf](http://publications.gc.ca/collections/collection_2016/eccc/CW66-524-2016-eng.pdf).
- Grubin, S. M. et al. 2011. Prey Suitability and Phenology of *Leucopis* spp. (Diptera: Chamaemyiidae) Associated With Hemlock Woolly Adelgid (Hemiptera: Adelgidae) in the Pacific Northwest. *Environmental Entomology* 40:1410-1416.
- Haack, R. A. et al. 2010. Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: a worldwide perspective. *Annual Review of Entomology* 55:521-546.
- Haack, R. A. et al. 2014. Effectiveness of the international phytosanitary standard ISPM No. 15 on reducing wood borer infestation rates in wood packaging material entering the United States. *PLoS ONE* 9(5):e96611.
- Halton Region and North-South Environmental Inc. 2005. *Halton Region Environmentally Sensitive Areas Consolidation Report*. Unpublished report prepared by Halton Region Planning and Public Works Department in conjunction with North - South Environmental Inc., Oakville, ON.
- Havill, N. P. et al. 2014. *Biology and Control of Hemlock Woolly Adelgid*. USDA Forest Service Publication FHTET-2014-05, [June].
- Henry, M. et al. 2018. The Cayuga Lake Old-growth Forest Landscape: An Endangered Old-growth Forest Landscape in Algonquin Provincial Park, Ontario. *Preliminary Results Bulletin No. 6*, Ancient Forest Exploration & Research, Powassan, ON.
- Henry, M. & P. Quinby. 2006. A Preliminary Survey of Old-Growth Forest Landscapes on the West Side of Algonquin Provincial Park, Ontario. *Research Report No. 32*, Ancient Forest Exploration & Research, Powassan, ON.
- Henry, M. & P. Quinby. 2018a. The Hurdman Creek Old-Growth Forest: An Unprotected Endangered Old-Growth Forest in Algonquin Provincial Park, Ontario. *Preliminary Results Bulletin No. 2*, Ancient Forest Exploration & Research, Powassan, ON.
- Henry, M. & P. Quinby. 2018b. The Old-Growth Forests of Bronte Creek Provincial Park, Ontario. *Preliminary Results Bulletin No. 4*, Ancient Forest Exploration & Research, Powassan, ON.
- Henry, M. & P. Quinby. 2018c. Oakview Woods: An Old-growth Forest in Wasaga Beach Provincial Park, Ontario. *Preliminary Results Bulletin No. 5*, Ancient Forest Exploration & Research, Powassan, ON.
- Hille, A. 2017. *Personal Communication, Allegheny National Forest*. Feb 17, 2017.
- IBA Canada. 2017a. *IBA Site Summary ON005 Dundas Valley and Dundas Marsh Dundas, Ontario*. <http://www.ibacanada.ca/site.jsp?siteID=ON005>.
- IBA Canada. 2017b. *IBA Site Summary ON021 Twelve Mile Creek Headwaters Fonthill, Ontario*. <http://www.ibacanada.com/site.jsp?siteID=ON021>.
- iNaturalist. 2018. *Beech Bark Disease Resistance Project*. <https://www.inaturalist.org/projects/beech-bark-disease-resistance>.
- Ingwell, L. L. & E. L. Preisser. 2011. Using Citizen Science Programs to Identify Host Resistance in Pest-Invaded Forests. *Conservation Biology* 25:182-188.
- Invasive Species Centre. 2017. *Forest Invasives Canada*. <http://forestinvasives.ca/>.

- Johnson, S. et al. 2014. **A Collaborative Approach to Prioritizing High Allegheny Hemlock for Conservation in Light of Impending Impact by Hemlock Woolly Adelgid**. Friends of Allegheny Wilderness. <http://www.pawild.org/pdfs/TNCUSFSFinalreportHighAlleghenyHWA18march2014.pdf> [accessed February 28, 2017].
- Jones, A. C. 2013. **Fitness and Physiology of the Hemlock Woolly Adelgid, *Adelges tsugae*, in Relation to the Health of the Eastern Hemlock, *Tsuga canadensis***. Virginia Polytechnic Institute and State University. [https://vtechworks.lib.vt.edu/bitstream/handle/10919/53700/Jones\\_A\\_T\\_2013.pdf?sequence=1](https://vtechworks.lib.vt.edu/bitstream/handle/10919/53700/Jones_A_T_2013.pdf?sequence=1) [accessed March 7, 2017].
- Kanoti, A. et al. 2015. **Managing Hemlock in Northern New England Forests Threatened by Hemlock Woolly Adelgid and Elongate Hemlock Scale**. U.S. Forest Service, Northeastern Area State and Private Forestry, Newtown Square, PA.
- Kershner, B. 2004. **Old Growth Forest Survey of Eastern Niagara Peninsula Phase 2**. <http://www.nativetreesociety.org> [accessed March 1, 2017].
- Kohler, G. R. et al. 2008. Predators associated with the hemlock woolly adelgid (Hemiptera: Adelgidae) in the Pacific Northwest. *Environmental Entomology* 37:494-504.
- Kohler, G. R. 2007. **Predators Associated with Hemlock Woolly Adelgid (Hemiptera: Adelgidae) Infested Western Hemlock in the Pacific Northwest**. Oregon State University. [https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/4600/Kohler\\_Thesis.pdf;sequence=1](https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/4600/Kohler_Thesis.pdf;sequence=1) [accessed February 9, 2017].
- Kohler, G. R. et al. 2016. Seasonal phenology and abundance of *Leucopis argenticollis*, *Leucopis piniperda* (Diptera: Chamaemyiidae), *Laricobius nigrinus* (Coleoptera: Derodontidae) and *Adelges tsugae* (Hemiptera: Adelgidae) in the Pacific Northwest USA. *Bulletin of Entomological Research* 106:546-550.
- Kriebel, D. et al. 2001. The Precautionary Principle in Environmental Science. *Environmental Health Perspectives* 109:871-876.
- Larson, B. M. et al. 1999. **The Woodland Heritage of Southern Ontario: A Study of Ecological Change, Distribution and Significance**. Federation of Ontario Naturalists. <https://books.google.ca/books?id=YA4JAQAAMAAJ>.
- Liebholt, A. M. et al. 2012. Live Plant Imports: The Major Pathway for Forest Insect and Pathogen Invasions of the U.S. *Frontiers in Ecology and the Environment* 10:135-143.
- Lindsay, K. M. 1981. **An Identification and Evaluation of Life Science Candidate Nature Reserves in Site District 7-2 West of Haldimand Clay Plain**. Long Point Biosphere Reserve. <http://longpointbiosphere.com/download/Environment/An-Identification-and-Evaluation-of-Life-Science-Candidate-Nature-Reserves-In-Site-District-7-2-West-of-Haldimand-Clay-Plain-by-K.M.-Lindsay.pdf> [accessed March 1, 2017].
- Long Point Bird Observatory. 2005. **Migration Monitoring Protocol**, 4<sup>th</sup> edition. <http://www.bsc-eoc.org/download/LPBOMigrationProtocol.pdf>.
- Lovett, G. M. et al. 2016. Nonnative forest insects and pathogens in the United States: Impacts and policy options. *Ecological Applications* 26:1437-1455.
- Lutz, J. A. et al. 2018. Global importance of large-diameter trees. *Global Ecology and Biogeography*:1-16. DOI: 10.1111/geb.12747.
- Luyssaert, S. et al. 2008. Old-growth forests as global carbon sinks. *Nature* 455:213-215.
- Marks, T. 2012. **Analysis of Hemlock - Topography Relationships in Southwest Wisconsin**. M.A. Thesis, Western Illinois University. <http://pqdtopen.proquest.com/doc/1022050244.html?FMT=ABS>.
- Martin, K. L. & P. C. Goebel. 2013. The foundation species influence of eastern hemlock (*Tsuga canadensis*) on biodiversity and ecosystem function on the Unglaciaded Allegheny Plateau. *Forest Ecology and Management* 289:143-152.

McAvoy, T. J. et al. 2017. Mortality and recovery of hemlockwoolly adelgid (*Adelges tsugae*) in response to winter temperatures and predictions for the future. **Forests** 8(12). <https://vtechworks.lib.vt.edu/bitstream/handle/10919/82548/forests-08-00497.pdf> [accessed June 22, 2018].

McClure, M. S. 1990. Role of Wind, Birds, Deer, and Humans in the Dispersal of Hemlock Woolly Adelgid (*Homoptera: Adelgidae*). **Environmental Entomology** 19:36-43.

McClure, M. S. et al. 2001. **Hemlock Woolly Adelgid**. United States Department of Agriculture Forest Service. Pest Aert NA-PR-09-05.

McLaughlin, J. & S. Greifenhagen. 2012. Beech Bark Disease in Ontario: A Primer and Management Recommendations. Ontario Forest Research Institute, **Forest Research Note No. 71**. <https://dr6j45jk9xcmk.cloudfront.net/documents/2851/stdprod-096009.pdf> [accessed June 14, 2018].

Mladenoff, D. J. & F. Stearns. 1993. Eastern hemlock regeneration and deer browsing in the northern Great Lakes region: A re-examination and model simulation. **Conservation Biology** 7:889-900.

Mladenoff, D. J. 1996. **The role of eastern hemlock across scales in the northern lake states**. Proceedings of the Hemlock Ecology and Management Conference, 27-28 September, Mroz, G. and J. Martin (eds.), Iron Mountain Michigan. University of Wisconsin, Madison.

Morin, R. S. et al. 2009. Anisotropic spread of hemlock woolly adelgid in the eastern United States. **Biological Invasions** 11:2341-2350.

Mosseler, A. et al. 2003a. Old-growth red spruce forests as reservoirs of genetic diversity and reproductive fitness. **Theoretical and Applied Genetics** 106:931-937.

Mosseler, A. et al. 2003b. Overview of old-growth forests in Canada from a science perspective. **Environmental Reviews** 11(S1):S1-S7.

Natural Resources Canada. 2017. **Emerald Ash Borer**. Factsheet, Natural Resources Canada. <http://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13395>.

New York State Department of Environmental Conservation. 2016. **Hemlock Woolly Adelgid New York State**. <http://www.dec.ny.gov/animals/86382.html>.

New York State Hemlock Initiative. 2018. **Hemlock Woolly Adelgid Survey Protocol**. [http://www.sleloinvasives.org/wp-content/uploads/2018/02/NYSHI\\_HWA\\_SurveyProtocol-17ztig7.pdf](http://www.sleloinvasives.org/wp-content/uploads/2018/02/NYSHI_HWA_SurveyProtocol-17ztig7.pdf).

North-South Environmental. 2012. **Environmentally Significant Areas in the City of Toronto**. City of Toronto Planning Department, Toronto, ON.

Nuckolls, A. E. et al. 2009. Hemlock declines rapidly with hemlock woolly adelgid infestation: Impacts on the carbon cycle of southern appalachian forests. **Ecosystems** 12:179-190.

Paradis, A. et al. 2008. Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. **Mitigation and Adaptation Strategies for Global Change** 13:541-554.

Parker, B. L. et al. 1999. Low lethal temperature for hemlock woolly adelgid (*Homoptera: Adelgidae*). **Environmental Entomology** 28:1085-1091.

Preisser, E. L. et al. 2014. Hemlock woolly adelgid in the eastern United States: What have we learned? **Southeastern Naturalist** 13:1-15.

Puric-Mladenovic, D. 2017. **Personal Communication, University of Toronto**. January 24, 2017.

Quimby, J. 1996. Value and Importance of Hemlock Ecosystems in the Eastern United States. In: **Proceedings of the First Hemlock Woolly Adelgid Review**. Forest Health Technology Enterprise Team, USDA Forest Service, Charlottesville, Virginia, 12 October 1995. pp. 1-8.

- Roberts, E. S. 2015. ***Evaluating Seedlings of Eastern Hemlock Resistant to Hemlock Woolly Adelgid (*Adelges tsugae*)***. Master's Thesis, Department of Biological Sciences, University of Rhode Island. <http://digitalcommons.uri.edu/theses/634>.
- Rogers, R. S. 1978. Forests dominated by hemlock (*Tsuga canadensis*): Distribution as related to site and postsettlement history. ***Canadian Journal of Botany*** 56:843–854.
- Ross, R. M. et al. 2003. Influence of eastern hemlock (*Tsuga canadensis* L.) on fish community structure and function in headwater streams of the Delaware River basin. ***Ecology of Freshwater Fish*** 12:60–65.
- Roy, B. A. et al. 2014. Increasing forest loss worldwide from invasive pests requires new trade regulations. ***Frontiers in Ecology and the Environment*** 12:457–465.
- Russo, N. 2015. Avian Dispersal of the Hemlock Woolly Adelgid (*Adelges tsugae* Annand). ***Holster Scholar Projects***, Paper No. 20. [http://digitalcommons.uconn.edu/srhonors\\_holster/20](http://digitalcommons.uconn.edu/srhonors_holster/20).
- Russo, N. J. et al. 2016. Experimental Evidence for Branch-to-Bird Transfer as a Mechanism for Avian Dispersal of the Hemlock Woolly Adelgid (Hemiptera: Adelgidae). ***Environmental Entomology*** 45:1107–1114.
- Schmidt, J. 2016. ***Personal Communication, Association of Municipalities of Ontario***. October 26, 2016.
- Shaffer, J. 2009. ***Prioritization of Old-Growth Forest Conservation on the Pisgah National Forest***. Duke University, Durham, NC. <http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=AEBDC7B35E252BEF20DF233E0A1494F0?doi=10.1.1.515.1703&rep=rep1&type=pdf> [accessed March 25, 2017].
- Skinner, M. et al. 2003. Regional responses of hemlock woolly adelgid (Homoptera; Adelgidae) to low temperatures. ***Environmental Entomology*** 32:523–528.
- Smith, A. L. et al. 2012. Effects of climate change on the distribution of invasive alien species in Canada: A knowledge synthesis of range change projections in a warming world. ***Environmental Reviews*** 20:1–16.
- Snyder, C. D. et al. 2002. Influence of eastern hemlock (*Tsuga canadensis*) forests on aquatic invertebrate assemblages in headwater streams. ***Canadian Journal of Fisheries and Aquatic Sciences*** 59:262–275.
- Strutt, A. et al. 2013. Evaluating the impacts of an international phytosanitary standard for wood packaging material: Global and United States trade implications. ***Forest Policy and Economics*** 27:54–64.
- Suffling, R. et al. 2003. Presettlement forest in southern Ontario: Ecosystems measured through a cultural prism. ***Forestry Chronicle*** 79:485–501.
- Sussky, E. M. & J. S. Elkinton. 2014. Density-dependent survival and fecundity of hemlock woolly adelgid (Hemiptera: Adelgidae). ***Environmental Entomology*** 43:1157–67.
- Titus, J. 2017. ***Personal Communication, Fredonia State University***. February 14, 2017.
- Trotter, R. T. 2010. ***Long-term weather variability and shifting distribution limits of the invasive hemlock woolly adelgid (*Adelges tsugae* Annand)***. USDA Research Forum on Invasive Species, GTR-NRS-P-75. pp. 136-137.
- Trotter, R. T. & K. S. Shields. 2009. Variation in Winter Survival of the Invasive Hemlock Woolly Adelgid (Hemiptera: Adelgidae) across the Eastern United States. ***Environmental Entomology*** 38:577–587.
- Turner, J. L. et al. 2011. Simulating the dispersal of hemlock woolly adelgid in the temperate forest understory. ***Entomologia Experimentalis et Applicata*** 141:216–223.
- USDA Forest Service. undated. Allegheny National Forest Hemlock Woolly Adelgid Survey Protocol.
- Vasiliauskas, S. A. 1995. ***Interpretation of Age-structure Gaps in Hemlock (*Tsuga canadensis*) Populations of Algonquin Park***. Ph.D. Thesis, Department of Biology, Queen's University, Kingston, ON.
- Vyn, R. 2017. ***An Assessment of Costs and Economic Impacts of Invasive Species in Ontario***. Invasive Species Centre, Sault Ste. Marie, ON.



- Vyn, R. 2018. **Updated Expenditure Estimates on Invasive Species in Ontario: 2018 Survey Results**. Invasive Species Centre, Sault Ste. Marie, ON. <https://www.invasivespeciescentre.ca/Portals/0/Final%20Report%20-%202018%20Survey%20Results.pdf?ver=2018-05-31-182438-190>.
- Whitmore, M. 2015. Managing Hemlock Wolly Adelgid & Emerald Ash Borer. **New York State Conference on the Environment**, Presentation slide notes. <http://www.nysaccny.org/wp-uploads/Managing-Hemlock-Wolly-Adelgid-Emerald-Ash-Borer-Mark-Whitmore.pdf>.
- Whitmore, M. 2015. **Personal communication, New York State Hemlock Initiative**. March 23 2015.
- Whitmore, M. 2019. **Personal communication, New York State Hemlock Initiative**. January 3 2019.
- Whitney, G. G. 1990. The history and status of the hemlock-hardwood forests of the Allegheny Plateau. **Journal of Ecology** 78:443-458.
- Yamasaki, M. et al. 1999. Wildlife habitat associations in eastern hemlock: Birds, smaller mammals, and forest carnivores. **Proceedings of the Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America**, U.S. Forest Service, GTR-NE-267. pp. 135-143.





In old-growth forests of Algonquin Park, like the one at Kenneth Lake pictured above, hemlock trees commonly reach over 300 years in age.

In the photo below, at Great Smokey Mountain National Park, many of the old-growth hemlock trees were killed by hemlock woolly adelgid in less than 10 years. Because we can draw on decades of management experience in the US, the situation in Ontario is more hopeful.



## Eastern hemlock: an ecologically important species

Hemlock is a very long-lived tree that is common in many of Ontario's old-growth forests. It often grows on steep ravine slopes, on lakeshores and along creek-sides where it casts very deep shade, cooling streams so that cold-water fish such as brook trout can live there.

Louisiana waterthrush feeds on bottom-dwelling insects and crustaceans in cold-water streams of southern Ontario, and was recently reassessed from *Special Concern* to *Threatened* status because of the growing threat to eastern hemlock. Louisiana waterthrush is known to breed in hemlock ravines near Long Point and in the Dundas Valley.



## Hemlock Woolly Adelgid

Hemlock woolly adelgid (HWA) was introduced from Japan and has spread through more than half of the geographic range of hemlock, and through much of 20 US states. It was first detected in Ontario in 2012.



HWA is a serious threat to Ontario's hemlock forests, and is moved on nursery stock or by birds. So far it has been detected in Niagara Falls (where it was probably carried by birds), and in Etobicoke (where it was likely introduced on nursery stock).

It's not hopeless! HWA can be managed using a combination of systemic insecticides and biological control. A species of beetle (*Laricobius nigrinus*) and two kinds of silver fly (*Leucopis* spp.), all from western North America, are showing promise for control of HWA. In order to manage it, however, we need to know where it is. You can help by participating in citizen monitoring for hemlock woolly adelgid.

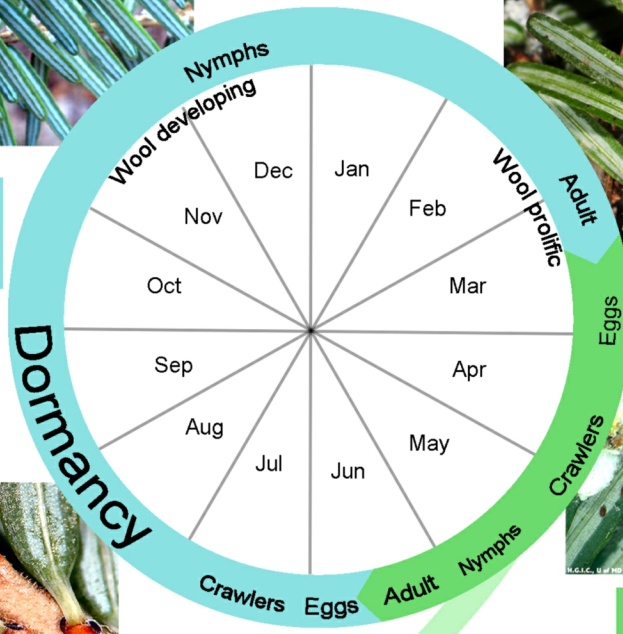




Sistens  
(winter)  
generation  
"to halt"



Progrediens  
(spring)  
generation  
"to proceed"



Winged adult lives on  
Japanese spruce trees:  
dead end in North America

## Hemlock Woolly Adelgid Biology

HWA has two asexual generations per year, and adults lay 25-175 eggs in each generation. This tremendous fecundity means that even small populations of the insect can expand rapidly, and recover quickly from high rates of winter mortality.

After eggs hatch there is a brief crawler stage, then the insects embed themselves in the twig at the base of a needle, and suck juices from the tree. HWA undergoes a period of dormancy in the summer, and is very hard to see.

In winter HWA develops a woolly coating, which is easily observed as small balls on the underside of the branches - consequently winter and spring are the best times for surveys.

It can take several years for HWA populations to grow and be noticed at ground level. It may take 10 years or more for trees to die, although HWA in combination with drought may kill infested trees much more rapidly.

Marv Elliott



## How HWA moves around

- Wind can move adelgid crawlers 300 m or more
- Birds commonly move crawlers several km or more
- HWA can be moved 100's of km on hemlock nursery stock
- Hikers may sometimes move HWA

The areas of Ontario at highest risk include the Niagara Peninsula and the Greater Toronto Area, however it could potentially be found almost anywhere in the province where hemlock grows.

Report HWA sightings to  
CFIA: 1-800-442-2342 or use  
the EDDMapS Ontario app:  
[www.eddmaps.org/ontario](http://www.eddmaps.org/ontario)

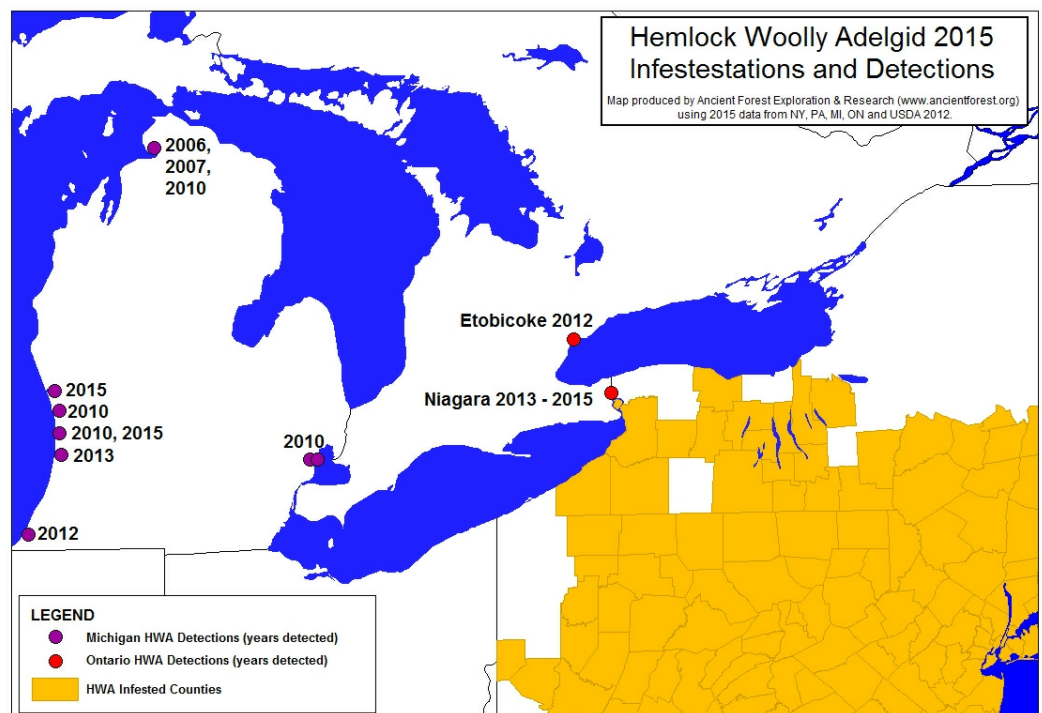
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# A Citizen's Guide to Hemlock Woolly Adelgid Detection in Ontario

## When to Look

Hemlock woolly adelgid (HWA) is visible anytime from November to May. The woolly balls become more prominent later in the winter. HWA is inactive and very hard to see for most of the summer. If you'll be moving between forests plan to complete surveys by mid-April to reduce the chance of accidentally spreading HWA. If you're out hiking in May and would like to check trees, please do so, however you may want to limit your survey to one forest area.



Jason Michael Crockwell

## What to look for

During winter and spring, look for white woolly balls on the underside of twigs at the base of needles. Hemlock woolly adelgid has the following characteristics that differentiate it from look-alikes:

- It is permanently attached to the branch and immobile during the winter/early spring.
- The balls of wool are attached to the twig not the needle.
- The “wool” is waxy, not silky or stretchy and is wispy (like a cotton ball), not fabric-like.
- There are separate distinct balls of wool.
- It doesn't look painted on (like pine sap).

## How to look

- Start your survey in an accessible location, choose a hemlock tree with branches within arm's reach.
- Examine the underside of branches - closest to the tips - for HWA's white woolly egg sacs.
- Check 3 branches per tree, about the lower 1 m of each branch. Look closely at the twigs.
- Continue to survey by moving randomly from one hemlock to the next, ideally selecting a tree at least 10-15 feet from the previous tree surveyed.
- Survey 15-25 trees, or as many trees as time, weather, and safety permit. It's fine if there are not many hemlock in the area you are surveying, and it's ok to only check a few trees if time is limited.
- Large stands should be surveyed in several locations.
- Hemlock branches found on the ground provide a good way to check on what may be going on higher in the tree.
- Check hemlock bark for signs of wool after spring rain storms.
- Complete surveys by mid-April to reduce the chance of accidentally spreading HWA, or limit survey to one forest/day.
- Photograph and record GPS locations of any suspected sightings, and report them (see below).

## Where to look

Prioritize lakeshores and streamsides, or areas near bird feeders. Given the option it's usually best to start by inspecting a number of trees near water, then randomly move inland.

## If you find it

If you think you've found hemlock woolly adelgid, *leave it where it is - take photos and record the GPS location*. Mark it with flagging tape if you have some, and note down directions that someone else could follow if need be.



Jonathan Carpenter

In Ontario you can verify and report your finding on your smartphone using the EDDMapS Ontario app ([www.eddmaps.org/ontario](http://www.eddmaps.org/ontario)), or email: [Erin.Bullas-Appleton@inspection.gc.ca](mailto:Erin.Bullas-Appleton@inspection.gc.ca), phone: 1-800-442-2342



## Hemlock Woolly Adelgid Photos

Are you monitoring?

Let us know by email at  
[info@ancientforest.org](mailto:info@ancientforest.org).

Tell us where, when and  
how many trees.



### Bring with you

GPS, compass, map, pen  
and paper, camera, hand  
lens, flagging tape, warm  
clothes, food and water.



## **Appendix 2 – Site Descriptions for 94 High Conservation Value Eastern Hemlock Forests in Ontario within 50 km of Lakes Erie and Ontario**



**Values Definitions:**

OG - Old-growth forest

MF - Mature forest / entering old-growth stage

CF - Contiguous forest tracts or connected to natural heritage network

SRE - High scenic, recreational, or educational value

UF - Urban forest

REP - Representation value: ANSI, Nature Reserve, candidate reserve

IBA - Important birding area (IBA)

ESA - Recognized environmentally significant area, heritage woodland, signature site, or

RW - Riparian, waterfront or wetland forest

SL - Slope stabilization

RS - Rare species

Name	Lat	Long	Ha	Land Use Designation	Values	Public Access 1=best 4=worst	References	Description
Altona Forest	43.8286	-79.1379	53	TRCA land	MF,UF,ESA	1	Wake 1997	This is a mature woodland, including communities dominated by white cedar and sugar maple-hemlock communities.
Balls Falls Gorge (Twenty Valley)	43.1340	-79.3810	20	Conservation Area	OG,SRE,RW,SL,RS	1	Bert Miller Nature Club 2003, Kershner 2004	Hemlock-northern hardwood forest, with inspiring pristine forest in a spectacular gorge. Kershner (2004) reports ring counts of hemlocks up to 330 years. Red mulberry occurs.
Beamers Falls Gorge	43.1866	-79.5702	<1	Conservation Area	OG,SRE,IBA,RW,SL	2-3	Bert Miller Nature Club 2003, Kershner 2004	Only a small pocket of old-growth forest remains in the gorge due to aggressive logging in the early 1900s. This and the old-growth hardwood forest above it at Grimsby Point, complement cliff-face ancient cedars, and spectacular views, making this one of Ontario's premier scenic treasures
Beattie Pinery	44.123	-79.860	80	Provincial Nature Reserve	MF,REP,ESA		Larson et al. 1999	The most mature, least disturbed woodland remaining in the Alliston Sand Plain. Trees reach 100+ years. Hemlocks are mostly small-mid diameter.
Big Creek Floodplain	42.6413	-80.5406	455	ANSI, Carolinian Canada Signature Site	MF,CF,REP,ESA,RW,SL	4	Lindsay 1981, Carolinian Canada 2017	The north-facing valley slopes and tributary ravines support mixed forests of hemlock with white pine, yellow birch, red maple and beech in good condition. The south and east-facing slopes are wooded with sugar maple and some beech and hemlock.

Big Otter Creek	42.8333	-80.7447	647	ANSI	MF,CF, REP,RW ,SL,RS	4	Lindsay 1981, IBA Canada 2017	A large, relatively intact, natural corridor follows the deeply incised, meandering valley of Big Otter Creek for about 7 km south from Tillsonburg. The east and north-facing slopes and tributary ravines tend to be dominated by hemlock with some yellow birch and red maple. The valleys of two tributaries South Creek and Moore's Creek-are included. Hemlock slopes which contain some sugar maple, beech and yellow birch; mixed deciduous-hemlock forests, and sycamore-willow-aspen floodplains are examples of the vegetation. It is estimated that more than 20 pairs of Louisiana waterthrush (nationally vulnerable) are nesting in the upper Big Otter Creek valley, from just south of Tillsonburg upstream to Otterville.
Bolton resource management Tract (Humber Valley)	43.8855	-79.7878	973	TRCA Land	OG,CF, SRE,RW ,SL	1	Henry and Quinby 2019	Several pockets of old-growth hemlock occur within and adjacent to the Bolton Resource Management Tract, along the Humber Valley Heritage Trail. Visual characteristics suggest the hemlocks are commonly 130-200 years old, but some have characteristics of older trees, one is estimated at 250-300 years old.
Boyd Conservation Area And Adjacent Lands	43.8188	-79.5823	57	Life Science ANSI, Provincial	MF,UF, REP,RW ,SL	3-4	NHIC 2016, TRCA 2012	This site includes the northeast corner of Boyd Conservation Area and the uplands immediately adjacent to its east side. It is characterized by flat uplands flanking a steep-sided flat bottomland valley. Dense, semi-mature to mature hemlock forests occurs (NHIC). Fresh-Moist Hemlock Coniferous Forest (FOC3-1) occurs on the northeast aspect of the East Humber River Valley, at 43.806, -79.584, while Fresh Moist Hemlock – Hardwood Mixed Forest (FOM6-2) occurs on floodplain terraces south of Langstaff Rd (43.802, -79.582 and 43.798, -79.580). TRCA 2012
Boye's Explosive's - Fenwick Forests	43.0364	-79.3757	120	Mostly private	OG,ESA, RW	4	NPCA 2010	Mixed Swamp habitat in this study area is characterized by a species rich hemlock ( <i>Tsuga canadensis</i> ) - Yellow birch ( <i>Betula alleghaniensis</i> ) community which grades into Red Maple ( <i>Acer rubrum</i> ) swamp on some upland edges.
Bridgeview Valley	43.3009	-79.8952	67	Life Science site, ESA	MF,UF, ESA,RW ,SL	4	NHIC 2016, Halton Region and North-South Environmental 2005	Bridgview Valley is a deep, narrow, steep-sided ravine which runs south from the Escarpment, and contains a tributary to Grindstone Creek. The east bank supports a good quality maturing forest of maple, oak and hickory in the south and hemlock to the north

Bronte Creek Provincial Park Nature Reserve Zone	43.4111	-79.7585	196	Life Science ANSI, Provincial, Provincial Park	OG,CF, SRE,UF, REP,ESA ,RW,SL	2	NHIC 2016, Halton Region and North-South Environmental 2005	A narrow deep winding gorge cut through shale and till plain characterizes Bronte Creek area. The parks 30 m high steep slopes are vegetated with hemlock-white birch-white cedar, sugar maple and yellow oak-red oak-white oak.
Brookbanks Ravine	43.751	-79.330	17	ESA, Municipal Park	MF,SRE, UF,ESA, RW	2	North-South Environmental 2012; AFER 2016	Deciduous forest dominated by sugar maple, American beech and hemlock along the steep slopes of a ravine, to a bottomland dominated by lowland forest. Access is via Deerlick Creek Trail. Much of the hemlock is off-trail (but accessed by commonly used informal trails). Ring counts of cut tree gives a minimum age of 140.
Cavan Creek Headwaters	44.1926	-78.5347	1601	Candidate Life Science ANSI, Regional	CF,RW	3-4	NHIC 2016	Primary headwaters (714 ha (1765 acres)) of Cavan Creek. Open pond, cattail-alder-grasses marsh, alder-willow-cedar scrub swamp, cedar-hemlock-white birch-trembling aspen-cedar-white pine upland woodland. Good coldwater trout stream (brown trout).
Charleston Lake Provincial Park	44.5066	-76.028		Provincial Park	MF,CF, SRE,RW	1	AFER 2017, Friends of Charleston Lake Park 2017	Sugar maple, beech, paper birch, hemlock, red oak and white pine are the most abundant tree species in the park. The Hemlock Ridge Trail leads through rock crevices, and dense hemlock and white pine forest with views over wetlands and hemlock trees up to 120 years old.
Collins Lake	44.3584	-76.4515	70	Private. Life Science ANSI, Provincial	OG,CF, REP,RW	3	White 1990, NHIC 2016, Lindsay, 1986	"This is the least disturbed old forest stand seen in Eastern Region in this study or in the author's previous field experience of nearly 20 years. Its large size, location along an undisturbed marshy shoreline of Collins Lake, and range of moisture and composition, add to its representative value." White, 1990. A mature example of maple-beech -hemlock upland forest on a mesic, sandy loam site. Other vegetation and site types present. [Lindsay, 1986]
Crawford Lake - Rattlesnake Point Escarpment Woods	43.471	-79.927	664	Private / public - HRCA Conservation Area	CF, ESA, REP, RS, SRE, MF, OG	1-2	Halton Region and North-South Environmental 2005	The Escarpment forests in this area are mature hardwoods and hemlock, situated on shallow loam soils overlying fissured dolomite bedrock. Ancient cedar forests occur on the escarpment. Includes a provincially significant Life Science ANSI, Crawford Lake - Milton Outlier Valley.
Credit River At Erindale	43.5532	-79.6618	248	Life Science ANSI, Regional,	MF,CF, UF,REP, RW	1	NHIC, Wake 1997	Steep, wooded river valley and floodplain stretching 6 km in length, south of Streetsville. River floodplain Manitoba maple-willow-black maple, valley slope sugar maple-hemlock-beech and sugar maple-red oak-black cherry and

				Municipal Park				tableland white oak-white pine. Eastern hemlock and white cedar occurs on the east-facing slopes
Decew Falls and Gorge	43.109	-79.264	11	Privately owned? But a priority for acquisition to add to Short Hills Provincial Park	OG,SRE, IBA,RW, SL,RS	3	Cheskey 2003, Kershner 2004	Decew Falls and Gorge "includes one kilometre of spectacular gorge that cuts north through the escarpment. At times the gorge walls are over 40 metres in depth. To the south, above the 20 metre waterfall, are the Fonthill Kame uplands and valleys. The slopes are heavily forested with hemlock, maple, and oak" (Cheskey 2003). Kershner (2004) aged a variety of trees including hemlock to over 260 years.
Delaware Woodlot	42.9038	-81.4164	35	Life Science ANSI, Regional. Private land?	REP,ESA ,RW,RS	2	NHIC 2016	Fifty ha of steep ridges adjacent to Thames River floodplain. Hardwood uplands dominated by beech-sugar maple-ash and red oak-white oak-basswood-witch hazel with black walnut-black maple-blue beech. Flowering dogwood and blue ash occur here. Hemlock-yellow birch forest occurs. Area can be access via Thames Valley Trail (access at Pleasant St turnaround)
Delhi Big Creek Valley	42.815	-80.507	259	ANSI, Carolinian Canada Signature site. Largely private	MF,CF, REP,RW ,RS	4	Eagles & Beechey 1985, Ambrose and Kirk 2010	Eastern hemlock grows on the drier slopes. The best example of this type of forest occurs on the west side of the river where a large spring-fed creek flows into the main river by a small waterfall. It is unclear if this area includes old-growth forest, but it seems likely. Cucumber tree occurs and is regenerating.
Delhi Wetland Nature Reserve	42.858	-80.494	5	Private Nature Reserve	MF,CF, RW,SL	3	LPBLT 2016	Nestled in a deep valley alongside Big Creek north of Delhi, the property is as diverse ecologically as it is varied topographically. Despite its relatively small size (12 acres), the property includes a diversity of habitat types, including: mature hemlock and hardwood forests on the ravine slopes and uplands; a small stream flowing through the narrow valley; a perched grass and sedge wetland; and, a cedar-fringed ox-bow pond at the property's lowest elevations. Access by permission only
Dundas Valley	43.2385	-79.9919	2698	Mixed land use	OG,MF, CF,SRE, UF,REP, IBA,ESA ,RW,SL, RS	1	IBA Canada 2017, Carolinian Canada 2017, Eagles & Beechey 1985	Hemlock often dominates, along with Sugar maple, on valley slopes with a northerly aspect. The Dundas Valley contains a nationally significant community of forest birds, with breeding evidence for at least five nationally vulnerable, threatened or endangered species. Notably, Louisiana waterthrush has two to four breeding pairs annually that could be threatened by loss of hemlock.

Spencer Gorge (Dundas Valley)	43.2746	-79.9799	56	Conservation area, ANSI, IBA	OG,CF, SRE,UF, REP,IBA ,RW,SL, RS	3	Eagles & Beechey 1985, AFER 2017	Old growth begins upstream of the fork with Logie's Creek. A ring count of a typical hemlock in the gorge yielded 180 rings, for an approximate age of 200. Visual characteristics of old sugar maples near the creek suggest ages of 300+ (M. Henry unpublished field notes).
Spring Creek (Dundas Valley)	43.2460	-79.9953		Conservation area	MF,CF, SRE,IBA ,RW	1	AFER 2017	Groves of hemlock occur along the trail
Earl Bales Park	43.7481	-79.4229	51	Municipal Park	SRE,UF, ESA,RW	1	City of Toronto 2016	The upper slopes of this section of the West Don River valley have good examples of Mixed Forests of sugar maple, eastern white pine, American beech, red oak and eastern hemlock.
East Branch Of Don River	43.7846	-79.378	104	Candidate Life Science ANSI, Provincial	CF,UF, REP,RW	3	NHIC 2016	This site along the east branch of the Don River, south of Finch Avenue contains: cedar swamp; alder swale with open sedge meadows and scattered clumps of tamarack; a hemlock-yellow birch seepage slope and cattail-burreed marsh.
Finch Avenue Meander Scar	43.8269	-79.1965	2	Life Science site	CF,UF, REP,RW		NHIC 2016	Floodplain, ravine and slope terraces along meander scar of Rouge River north of Metro Zoo in Toronto. Upland forest of red oak-sugar maple-hemlock-white birch. Provincially rare sycamore; regionally rare black maple. [Hanna 1984]
George G. Newton Nature Reserve	43.6595	81.6613	32	Private nature reserve	MF,CF, RW	1	Wake 1997, Ontario Nature 2017	The river valley and slopes are mostly covered with a native stand of white cedar and mature forest of maple, beech, hemlock, elm, ash, butternut and other hardwoods. Abundance of hemlock may be limited.
Georgetown Credit Valley	43.6555	-79.8775	267	Life Science ANSI, Regional. 90% private, 10% public (CVC)	MF,CF, UF,REP, ESA,RW ,RS		NHIC 2016, Credit River Watershed and Region of Peel Natural Areas Inventory Project 2011	A large wooded valley of Credit River. The slopes are covered in forests of white cedar and sugar maple-eastern hemlock-beech-red Oak. Other communities include red oak-sugar maple forest, white cedar-Ash swamp, sugar maple-Manitoba maple-poplar-basswood. Hemlock communities cover 12.6 ha (about 5% of the area), mostly adjacent to the river. Fresh-moist sugar maple-hemlock mixed forest is regionally rare.
Gillies Grove	45.4430	-76.3620	25	Private nature reserve	OG,SRE, UF,ESA	1	Larson et al. 1999	Hemlock to 70+ cm. An impressive, relatively undisturbed old-growth forest. Minimum age is 250 years.
Glen Major Forests	44.005	-79.0789	300	Life Science site	MF,CF, SRE,REP		NHIC 2016	A variety of vegetation types are found at this (ca. 300 ha) site on strongly dissected moraine: maple-beech uplands, hemlock slopes, old fields with natural regeneration, swamp



								cedar lowlands (headwaters for Duffin Creek) and some coniferous plantation.
Glenville Hills	44.0270	-79.5192	345	Conservation area	MF,CF,REP,SL		Wake 1997	Old-growth forests of sugar maple, beech on mid-slopes; sugar maple-eastern hemlock on cooler slopes; white cedar-eastern hemlock-yellow birch on extensive seepage slopes near the slope bases.
Goodrich-Loomis Conservation Area	44.1167	-77.8379	179	Conservation Area	MF,SRE,RW	2	LTCA 2019	The conservation area includes short-grass prairie, one of Ontario's largest eskers, and wet hemlock forest along Cold Creek.
Grimsby Point	43.1878	-79.5717	4	Conservation area, IBA	OG,SRE,IBA	1	Kershner 2004	Identified by Kershner 2004 as an old growth Carolinian forest. Some hemlock occurs with ages reported up to 275 years.
Hague Park	43.7496	-79.2384	9.3	Municipal Park, ESA	MF,CF,SRE,UF,ESA,RW,SL	1	City of Toronto 2016	The Hague Park ESA (#76) is located south of Lawrence Avenue East between McCowan Road and Bellamy Road North. The ESA at this site includes mature mixed forest on the ravine slopes that features sugar maple, American beech, eastern hemlock, eastern white cedar, white birch, and basswood. Especially relevant is a healthy stand of trees dominated by black cherry, a typical Carolinian species. Also present is the regionally rare American hazelnut.
Happy Valley Forest	43.9631	-79.6100	648	Life science ANSI, Provincial. Private nature reserve (NCC)	CF,SRE,REP	1	Larson et al. 1999	Forest is dominated by sugar maple and beech, but hemlocks under 30 cm occur, and abundant hemlock regeneration was recorded found by Larson et al. 1999.
Harold Mitchell Nature Reserve	42.888	-79.4246	19	Non-Government Organization - Natural Heritage Property	MF,RW	2	NHIC 2016	The area is comprised of a mature woodlot dominated by Hemlock, with Maple, Beech and Yellow birch. The area has a slough-ridge terrain with many ponds and open marshes. This woodlot contains the last remaining stand of hemlock on the Lake Erie shoreline
Hemlock Valley	43.0858	-79.2804	5	Provincial Park, IBA	OG,SRE,IBA,SL	2	Kershner 2003	Hemlock and hardwood forest clings to steep ravine slopes, the hemlocks were aged by Bruce Kershner in 2003 as being 280 years-old.
Highland Creek Swamp	43.7819	-79.1979	201	Candidate Life Science	MF,CF,UF,REP,ESA,RW	3	NHIC 2016	A relatively large natural area remains along Highland Creek in Scarborough. It includes cedar-tamarack swamp, hemlock-cedar-bottomland forests, sedge-graminoid marsh and sugar

				ANSI, Provincial				maple-red oak-beech slopes. Twelve regionally rare plants are reported.
High Park	43.648	-79.460	160	Municipal Park, ANSI, ESA	OG,SRE, UF,REP, ESA,RW ,SL	2	Varga 1989	Included in High Park are regionally rare examples of moist red oak and hemlock forests . Mixed forests in High Park are confined to three small stands along the eastern slopes of Spring Road Ravine. The tree layer is dominated by hemlock, with such strong secondary species as red oak, black oak, red maple and white pine.
Hungry Hollow Ravine	43.6408	-79.8768	193	Majority private, and Municipal Park	OG,ESA, RW,SRE ,SL	2	Halton Region and North-South Environment al 2005	The valley walls support a mature mixed forest of sugar maple, beech, eastern hemlock and white cedar. The wooded areas of the Hungry Hollow Ravine are of very high quality. There are excellent examples of mature sugar maple forests and mixed forests.
Huttonville Valley	43.6474	-79.7909	20	Life Science ANSI, Regional	?	?	NHIC 2016	Terrace sugar maple-beech-hemlock woods and floodplain willow-Manitoba maple-basswood totalling 20 h in size, east of Huttonville and Credit River. Relatively undisturbed; surrounded mainly by agricultural lands. Several rare plant species. [Hanna 1984]
Jackson Creek old-growth forest	44.313	-78.342	5	Municipal park	OG,CF, SRE,UF, RW,SL	1	Henry et al. 2016	The north-east facing slopes and valley bottom create ecological conditions that favour White cedar and Eastern hemlock, and historically discouraged land clearing and development; which has allowed an old-growth forest to persist here on the hilltop, slopes, and valley bottom. Tall white pines, predominantly found on the hilltop and slopes, reach 168 years old. White cedar reaches 256 years, and hemlock 204+ years old.
Jones Creek Trails	44.495	-75.828	n/a	Thousand Islands National Park	MF,CF, SRE,RW .	1	Parks Canada 2017	A picturesque trail through hemlock forest and past rare pitch pine trees to a rocky outcrop 14 metres above the Mud and Jones Creek wetlands. Difficulty: Easy to moderate Trail length: 1.0 km Loop hiking time: 25 minutes
Kilworth Valleylands	42.9642	-81.3984	50	Life Science ANSI, Regional	REP,RW ,SL	3	NHIC 2016	Small section along Oxbow Creek near its outlet into Thames River with uplands, slope forests, and floodplains. Upland of red oak-white oak-sugar maple-witch hazel. Hemlock-cedar slope. Basswood-cedar-hemlock-black maple-blue beech
Kleinberg Woodlots	43.832	-79.5791	53	Life Science ANSI, Regional	CF,UF,		NHIC 2016	Four woodlots totalling 50 h situated parallel to one another, 3 km southeast of Kleinburg. Surrounded by farmland and adjacent to concession road. Young to semi-mature upland mesic sugar maple-ash-hemlock-white pine and lowland ash-red maple-dogwood. A

Lake Medad and Medad Valley	43.361	-79.893	261	Private (includes ANSI)	ESA, REP, RW		Halton Region and North-South Environmental 2005	A large variety of flora and fauna is found in this heavily forested valley which has been identified as one of the top botanical sites within the Region. A provincially significant wetland complex extends into Hamilton Wentworth Region. This site is a provincially significant Life Science ANSI. The west uplands support deciduous forests of maple, oak, beech and cherry, while the valley floor is a mixed swamp of eastern white cedar, white birch, tamarack, maple and hemlock. Along the north margin of the lake is a cattail marsh which extends northward into the valley basin.
Lambton Woods	43.6645	-79.5143	19	Municipal Park, ESA	MF,SRE, UF,ESA	2	City of Toronto 2016	"The upland Mixed Forests of sugar maple, eastern hemlock and white birch on the steep slopes in Lambton Woods grade into lowland forests of balsam poplar, tamarack and yellow birch in the floodplains in the southern part of the park" Hemlock is not a major component of the park as a whole.
Lasalle Park	43.3026	-79.8438	20	Municipal Park	SRE,UF	1	Wake, 1997	Forests of sugar maple, red oak, white pine and hemlock.
Limehouse Conservation Area	43.637	-79.969		Conservation Area	ESA,MF, SRE	1-3	Krick and Forsyth 2012	Undisturbed sections of the property include a mature mixed hemlock forest on the north side of Black Creek
Little Jerry Creek	42.7722	-80.8480	130	Private	MF,CF, RW,SL	4	Lindsay 1981	Immediately north of Bayham, this area features about 130 ha of a river valley habitats with natural vegetation intact. Little Jerry Creek empties in Big Otter Creek near Bayham. Mixed woods of sugar maple, basswood, ironwood, blue beech, black maple, hemlock, hawthorn and red oak cover the steep valley slopes and adjacent uplands. Floodplains support willow, black walnut, oak and aspen
Little Otter Creek	42.758	-80.796	900	IBA	MF,CF, IBA,RW, SL,RS	4	IBA Canada 2017	The Little Otter Creek Complex is comprised of three closely linked forests known as Howes Woods, as well as a ten kilometre stretch of the creek and its ravines, centred roughly on these forests. The site is located fifteen kilometres south of Tillsonburg, near the town of Strathroy. Highway 19 cuts across the midpoint of the site, which extends five kilometres up and down the Little Otter Creek. The woods are mainly deciduous with an obvious element of White Pine on the uplands, and Eastern hemlock on the cooler slopes. It is not known how many Louisiana Waterthrushes are present in the section of Little Otter Creek within this site, perhaps 10 pairs, but this site

								certainly covers some of the prime Louisiana Waterthrush habitat in Canada.
Little Rouge River (Woodland Trail)	43.843	-79.1864	50	Provincial park	MF,CF, SRE,UF, ESA,RW	2	M. Henry unpublished field notes	Small groves of mature hemlock occur near the Little Rouge River, along with scattered trees showing signs of advanced age (hemlock, sugar maple, cedar). Access is via Woodland Trail, and informal trails that continue along the river. Some of the oldest hemlocks appear to be south of the parking area, near Reesor Rd (43.8469,-79.1983) (M. Henry unpublished field notes). Other groves are likely to occur in nearby areas.
Long Sault Conservation Area	44.0583	-78.7490	286	Conservation area	MF,CF, SRE	1	Wake 1997	White cedar-eastern hemlock swamp occurs here. There are groves of hemlock in the north-central part of the conservation area.
Lowville-Bronte Creek Escarpment Valley	43.428	-79.914	373	Private	ESA, REP, RW, RS, SRE	1-3	Halton Region and North-South Environmental 2005	The valley walls are densely vegetated with good quality broadleaf and mixed forests, and the area has been designated a provincially significant life science ANSI (Bronte Creek Escarpment Valley) by the OMNR. A second provincially significant life science ANSI has also been designated within the ESA (Bronte Creek Escarpment Valley). Includes hemlock swamp and hemlock-mixed hardwood forest. Rare species include Louisiana waterthrush. Access via Bruce Trail / River and Ruin Side Trail.
Maple Uplands & Kettles / McGill ESA / Maple Nature Reserve	43.9032	-79.4931	588	Candidate Life Science ANSI, Provincial	OG,CF, SRE,UF, REP,ESA ,RW		NHIC 2016, TRCA 2009	Upland forests, scattered kettle wetlands, old fields with shrub thickets and the headwaters of the Little Don comprise this ca. 250 ha site. The woodlots are younger, cut-over, maple-beech-birch-hemlock and white pine. Dry-Fresh Hardwood-Hemlock Mixed Forest (FOM3-1) is largely within the McGill ESA. The McGill Area Environmentally Significant Area - ESA covers most of the same area as the Maple Uplands and Kettles ANSI and Maple Spur ANSI (TRCA 2009). The adjacent / overlapping Maple Nature reserve has hemlocks reaching over 173 years old based on ring counts (Henry, unpublished field notes 2018)
Marcy's Woods (Point Albino)	42.859	-79.112	285	Private land, ANSI, IBA	OG,REP, IBA,ESA ,RW,SL	3	Larson et al. 1999 Kershner 2004,2005	An old-growth hemlock stand occurs here, and hemlock is a minor understory tree more generally (Larson et al. 1999). Rare example of eastern hemlock growing on sand dunes (Kershner 2005). Moist intraridge basins support deciduous forests of silver maple, yellow birch, red maple and others, or coniferous groves of eastern hemlock and Canada Yew.

							Eagles & Beechey 1985	Nowhere else in the region are the sand hill landforms and associated community patterns better developed. Access is granted by request.
Mark S. Burnham Provincial Park	44.3001	-78.2664	40	Provincial Park - Recreational Class	OG,SRE, RW	1	NHIC 2016, Henry and Quinby 2010,	Majestic stands of maple, beech, elm and hemlock - among the oldest in Ontario. In the middle of the Peterborough Drumlin Field, which contains more than 3,000 of these glacial remnants (Ontario Parks website, June 2015). Numerous very old trees have been cored in this forest, including an eastern hemlock with a 439-year ring count, and a sugar maple with a 330-year ring count.
Meadowvale Woodlot A	43.847	-79.187	4.2	City of Toronto ESA	MF,ESA	3	North-South Environmental 2012	Mature hemlock-sugar maple forest woodlot on the east facing slope of a valley.
Morningside Park	43.7824	-79.1901	240	Municipal Park, ESA, ANSI	MF,CF, SRE,UF, ESA,RW ,SL	2	City of Toronto 2016	North of the main entrance, along Morningside Avenue there is an excellent example of a white cedar swamp with one of the few stands of tamarack in the city. East of Morningside, the cedar swamp grades into a stand of eastern hemlock and balsam fir with a shrub layer of Canada yew.
Morningside Tributary Ravine (Rouge Park)	43.8106	-79.1908	10	Life Science site	OG,CF, UF,REP, ESA,RW ,SL	3	NHIC 2016	Sharply incised, heavily wooded 10 ha ravine south of Rouge River in Toronto. Cedar-hemlock slopes, immature maple, seasonal swamp, white birch woods and remnant white pine stand approximately RS0-120 years old (Hanna 1984) – now 140+ years old. Hemlock on the slopes appear to be 250+ years-old. Access to the site is only via an informal (but well used) trail.
Mount Salem Forest	42.7199	-80.9144	421	Life Science ANSI, Regional	REP,RW ,RS	4	NHIC 2016	North and east of Mount Salem is a ca. 240 ha block of forest on gently undulating sand plain. Sugar maple, beech, hemlock and yellow birch grow on the low ridges. Linear-shaped swamps of silver maple with some ash and elm lie between the ridges. This is the only location known in Canada for the small whorled pogonia ( <i>Isotria medeoloides</i> ), one of Ontario's endangered species.
Niagara Gorge First Growth Steep Slope Forest	43.115	-79.065	16	Regional Park, Slope of Niagara Gorge	OG,CF, RW,SL	4	Bert Miller Nature Club 2003, Kershner 2004	Very steep, unstable slopes of Niagara Gorge were inaccessible and never logged but still deceptively contain young "First-growth" woods of Manitoba and Norway maple, paper birch, white ash, and cottonwood, because of collapsing soil, landslides, and tree toppling. Still, old-growth hemlock, white cedar, and hop hornbeam survive. Kershner reported that he cored one hemlock in the Niagara Gorge,

								midway between the Whirlpool and the Whirlpool Bridge, at 435 years (personal communication, Sept 16 2004), making it among the oldest in Ontario. Nevertheless hemlock is rare here.
Nickel Beach Woods	42.8769	-79.2350	197	Mostly private land	OG,SRE, RW,SL	2	NPCA 2010	A very rich sugar maple ( <i>Acer saccharum</i> ssp. <i>saccharum</i> ). Hemlock ( <i>Tsuga canadensis</i> ) forest covered cool, north facing slopes in parts of the study area. Also noted here were scattered old growth (balding bark) bitternut hickory ( <i>Carya cordiformis</i> ) trees with bladdernut ( <i>Staphylea trifolia</i> ) in understory layer. Occasional large diameter (in sheltered interdune valleys) or tortured, wind-swept (on dune ridges) old growth individual trees were recorded. Several large diameter but short wind-swept Red Oaks (1 m+ dbh) in the mature rich section were documented as well.
North Castor River/Pana Road South	45.2735	-75.428	3.5	Life Science site	MF,RW		NHIC 2016	This small natural area was not examined in the field, but data from the RMOC (Regional Municipality of Ottawa-Carleton) Geographic Information System database indicates that it is a 50-100 year old, hemlock dominated forest on non-acidic sand plain.
North Fenwick Footslope Forest	43.0407	-79.3573	12	Life Science ANSI, Regional	REP,RS	4	NHIC 2016, Ambrose and Kirk 2010	Private gently rolling sandplain slope; deciduous and hemlock wet mesic forests present; general disturbance of cutting, drainage and development; a sample station of P.F. Maycock. [Macdonald 1980]. Cucumber tree occurs here.
North Pickering / Seaton Hiking Trail	43.8898	-79.1648	250	Mixed	OG,MF, CF,SRE, UF,RW, SL	1	Wake 1997	Sugar maple and beech are reported by Wake (1997) to be 300-400 years old. A sugar maple dominated forest with a hemlock component is 180+ years old. Stands of hemlock and cedar in the valley reach at least 130 years-old (by ring count of cut logs). Seaton is a popular hiking trail.
Northwest Fenwick Forest	43.0358	-79.3735	RS8	Life Science ANSI, Regional	REP,RW ,RS	4	NHIC 2016, Ambrose and Kirk 2010	Broadly rolling sandy clay plain with broad slough landform development; deciduous and hemlock forests of sub-intermediate to young age present; several district significant flora present; increasing impact of cutting and agriculture. [Macdonald 1980]. Cucumber tree occurs and is regenerating well.
Oil Well Bog Little Tract	43.4559	-80.2459	453	Life Science ANSI, Regional	CF,REP, RW	2	NHIC 2016	A 336 ha late stage heath and black spruce bog supporting 4 bog forms (leatherleaf-sphagnum; spruce-tamarack), swamp (aspen-red maple-elm; willow thickets), upland woods (sugar maple-beech-hemlock), old fields, marsh and ponds. A network of walking/mountain biking trails allows access.



Osaca - Ganaraska River	44.020	-78.4535	396	Life Science ANSI, Regional PSW	CF,REP, RW	4	NHIC 2016	404 ha (999 acre) river valley complex consists of cedar with hemlock-crack willow floodplain forest. Patches of mesic, deciduous sugar maple-ironwood valley wall woods. Borders on town of Osaca. Surrounded by agricultural fields.
Peter's Woods Provincial Park	44.1230	-78.044	102	Provincial Park, ANSI	OG, CF, SRE,REP RW	1	OMNR 2009	Old-growth hemlock occurs at the east end of the Park
Phillipsville Cliff	44.6359	-76.1287	12	Candidate Life Science ANSI, Provincial	OG,REP, SL		NHIC 2016	This site is a striking west-facing cliff that supports a mixed forest of red and white oak, white birch, and old stunted cedar and hemlock. The gnarled and deformed cedar and hemlock trees of the cliff and boulder talus have probably never been cut.
Pinehurst Lake Complex; part of the Grand River Valley Forests	43.2807	-80.3395	676	Conservation Area, ANSI	MF,CF, SRE,REP ,RW	2	Eagles & Beechey 1985	A series of linear morainic ridges are the most notable features of this complex... Communities include Forest (oak-hickory; hard maple-red oak-beech; hard maple-oak-hickory-ash; pine-oak; hemlock-northern hardwoods; poplar-maple; floodplains. The two sphagnum bogs within the study area are unique in the county. A pure stand of hemlock near Spottiswood Lake is also unusual.
Pottageville Southeast Upland	43.9812	-79.6096	90	Life Science ANSI, Regional	MF,CF, REP,RW		NHIC 2016	A high quality, upland forest (maple-beech-hemlock) broken by several creek valleys holding tributaries of the Holland River. On north-facing slope of Oak Ridges Moraine. Just north of the Happy Valley Forests candidate nature reserve.
Ratray Marsh	43.5175	-79.6135	95	Conservation area	MF,SRE, UF,RW	1	AFER 2017	From the Meadow Wood entrance hike east through mature sugar maple, beech and oak forest. As you continue east the forest is increasingly dominated by hemlock and pine. Ring counts of fallen logs show that pine and hemlock reach at least 150 years old in this small but beautiful urban forest. After the trail crosses Sheridan Creek you will enter a floodplain forest and green ash swamp.
Rockway Falls Gorge	43.112	-79.3221	2.4	Conservation Authority	OG,CF, SRE,IBA ,RW,SL, RS	2	Bert Miller Nature Club 2003, Kershner 2004	Seven species of old-growth trees populate the gorge bottom including black walnut, basswood, hemlock, ash, sugar and red maple, white ash, and sycamore; ages up to 250 years. Includes hemlock to 240 years, and a mature butternut, estimated at 170 years!
Rouge Park	43.8205	-79.1666	7910	Provincial Park	OG,MF, CF,SRE, UF,REP,	1	Hanna 1984 in Eagles & Beechey, 1985	Rouge River Central Woodland Valley Complex: Typical vegetation types are willow-Manitoba maple- cedar bottomland, red oak-hemlock-white cedar slopes and hemlock-white pine-sugar maple-beech-black cherry-red oak

					ESA,RW,SL			tableland. The Lower Rouge River Nature Reserve Zones (Varga, 1984 in Eagles & Beechey, 1985): hemlock forests are essentially confined to northfacing slopes and adjacent tablelands, while beech prefers dependably moist southern aspects. An excessively drained but cool tributary valley supports a white pine-hemlock-white cedar forest, more typical of stands on the Canadian Shield.
Roy Ivors Woodlot	43.5432	-79.6720		Municipal Park	MF,UF,ESA,RW	1	Credit River Watershed and Region of Peel Natural Areas Inventory Project 2011	Hemlock occurs mixed with sugar maple along sawmill creek, and in a fairly pure grove west of the Collegeway. Forest is mature, possibly old-growth.
Scotsdale Farm	43.682	-79.990	215	Ontario Heritage Trust property	OG,CF,SRE,RW	1	Henry and Quinby 2019	The property has sugar maple forest which estimated to be 150-200+ years-old, old and a cedar-hemlock swamp with trees that are over 250 years old. The swamp is extensive, greater than 50 ha in size, and has trees with old age characteristics at numerous points. Since ages of 250+ were obtained with little effort, and trees in the swamp have little commercial value, maximum ages could be higher.
Seneca College King Campus	43.9581	-79.515	276	Private (Seneca College)	OG,CF,SRE,RW	1	Henry and Quinby 2019, TRCA 2012	Old hemlock forest occurs near the lake west of Eaton Hall, and can be accessed from the Woodland Passage Trailhead. The cedars and hemlocks in the wetland are often older than they look – though they are small they are likely 150-200 years old or more. As you continue onto the ridge again you'll walk through a grove of old hemlocks that are over 150 years old. Invasive species in the forest include goutweed and periwinkle.
Short Hills Wilderness Preserve	43.062	-79.329	12	Non-profit reserve	OG,CF,IBA	2	Bert Miller Nature Club 2003	Carolinian old-growth forest including sugar maple, tulip tree, oaks, beech, and hemlock with tree ages up to 275 years. Access by permission
Simeon Lakes	43.9692	-79.3855	137	Candidate Life Science ANSI, Regional	UF,REP,RW		NHIC 2016	Intermediate-aged forests of sugar maple with some beech, hemlock and white birch cover the rolling uplands of this ca. 100 ha site on the south slope of the Oak Ridges Moraine. Scattered small wetland pockets.
Silver Creek Valley	43.692	-79.965	501	Private / public	OG,ESA,REP,CF,RW,RS,SRE	1-2	Halton Region and North-South Environment	Contains hemlock-hardwood forest and white pine-hemlock forest. The Credit Valley Conservation Authority owns the Silver Creek Education Centre within the boundaries of this

							al 2005, CVC 2008	ESA, and the area is utilized by one of the local school boards as an outdoor education centre. Bruce Trail passes through.
Sixteen Mile Creek Valley	43.456	-79.728	1104	Mostly private and some public (HRCA)	ESA, REP, RW, CF, RS, SL, UF	1-3	Halton Region and North-South Environmental 2005	The valley floor contains good lowland and floodplain associations, while the valley walls contain patches of prairie species on the dry south-facing slopes and moist hemlock communities on adjacent north-facing slopes
Smeatons Ravine	43.1506	-79.0461	2	Regional Park, Rim of Niagara Gorge	OG,CF,SRE,ESA, RW,SL, RS	3	Bert Miller Nature Club 2003, Kershner 2004	Little known, hidden, dramatically deep gorge cut into the side of Niagara Gorge with 40 ft. falls; unusual mix of old-growth chinkapin oak, tulip tree, and basswood, and hemlock; includes cliff-hanging white cedars and hemlocks, also hemlocks in the gorge. Hemlocks estimated by Bruce Kershner to be 300+. Significantly, four tree-sized individuals of nationally rare red mulberry were discovered. The largest is a two-trunked, 8.5-inch diam. tree with a remarkable height of 42 feet.
Spooky Hollow	42.7257	-80.3150	67	Life Science ANSI, Mixed land use including private nature reserve (HNC)	MF,CF, REP,RW, RS	2	Lindsay 1980	Spooky Hollow was identified as a candidate nature reserve, and has been designated as a life science ANSI. Part of the tract (~67 ha) is a private nature reserve owned by the Hamilton Naturalists Club. Diverse habitats and rare and unusual species occur here, including the endangered American Chestnut. The valley bottom supports a wet mesic forest of hemlock, yellow birch, oak, maple and white pine. Other forest types include Carolinian forest, oak savannah, and a small tamarack-white pine swamp. Access by permission of Hamilton Naturalists Club.
Springwater Forest	42.7425	-81.0243	150	Life Science site	OG,CF, SRE,REP, IBA,ESA, RW, RS	1	NHIC 2016, IBA Canada 2017; AFER 2017	This site is a predominantly deciduous forest with pockets of eastern hemlock ( <i>Tsuga canadensis</i> ) and white pine ( <i>Pinus strobus</i> ) on an undulating sand plain. The site is dissected by a creek system. Springwater forest provides habitat for both acadian flycatchers (nationally endangered), and hooded warblers (nationally threatened). It is an exceptional example of old-growth Carolinian forest.
St. John's Conservation Area, East Ravines	43.0628	-79.2845	48	Conservation Area	OG,CF, SRE,IBA, RW,RS	1	Bert Miller Nature Club 2003, Kershner 2004, Cheskey 2003	Mature and some old-growth Carolinian forest. Hemlock is a minor component, but occurs in the older forest. the old growth extends to the east over two secluded sand ravines and ridges... the forest is notably tall, with tulip tree, hemlock, sugar maple, pignut and bitternut hickories, red oak, and beech.

Stephen's Gulch Conservation Area	43.9665	-78.6763	106	Conservation Area	MF,CF, SRE,RW	1	NHIC 2016, AFER 2017	This property offers a unique variety of settings from wet hemlock forest and groundwater springs to dry sandy ridges with butternut trees. Protecting a large area of deciduous forest and coniferous forest/swamp along the Soper Creek valley system. From the parking area, the right fork will lead you into the cedar swamp with hemlock becoming more abundant as you go. As you climb back into a more upland forest the ages of the trees increase, and despite some historical disturbance there is a fairly nice old-growth sugar maple and hemlock forest here. Ring counts of trees cut from the trail indicate the forest is 130-140 years old, with some trees possibly older.
Stewart's Woods	44.201	-78.344	27	Conservation authority land	OG,CF, ESA	3	Larson et al. 1999	Larson et al. (1999) reported that it is "one of the best conifer woodlands examined during this study." Hemlock occurs in all diameter classes up to 69 cm. White pine supercanopy and dense hemlock regeneration. The area suffered significant windthrow.
Stewarttown Woods	43.624	-79.936	32	Private	MF/OG, SL,RW, ESA		Halton Region and North-South Environmental 2005	The vegetation of Stewarttown Woods consists of several plant associations including young sugar maple - white ash - white birch, mature hemlock - beech - sugar maple, and a white cedar - hemlock - mountain maple swamp. Meadows and open floodplain areas are located along the creek within the ESA.
Sugar Loaf Hill	42.8731	-79.2801	2	Private	OG,RW, SL	2-3	Bert Miller Nature Club 2003, Kershner 2004,	Sugar Loaf Hill is one of only three Lake Erie coastal dunes known to be covered by Old Growth. The 100-foot tall sand peak is also one of its steepest and most cone-shaped dunes. Ancient Hemlocks grow on the protected north slope. It is extremely rare for this old- growth hemlock to be found on sand dunes. Trees are small for their age: hemlock with a diameter of 14 inches had an age range of 170 to over 200 years old.
Terra Cotta Woods	43.722	-79.967	336	Public	OG,CF, RS,SRE, SL	1-2	Halton Region and North-South Environmental 2005, CVC 2008	The valleys have slope forests of pine, hemlock and maple, and a deeply entrenched stream valley runs through the western end. The ESA contains a provincially significant Life Science ANSI, Terra Cotta Forests. The area is owned almost entirely by public agencies. Some forested communities in the Terra Cotta-Silver Creek complex are considered near-old growth, with fourteen areas of forest between 100 -125 years old, and two forest stands greater than 125 years old.

Terrace Creek Gorge	43.0950	-79.2775	2	Provincial Park, Short Hills	OG,CF, SRE,IBA ,RW,SL	1-2	Bert Miller Nature Club 2003	Narrow corridor of ancient sugar maple, hemlock, beech, red oak, basswood, red maple, hardwoods lining 75 ft.-deep gorge with 3 cascades
Thousand Islands	44.2965	-76.1928	n/a	Mix of private and crown land	MF,SRE, RW,SL	2	Frontenac Arch Biosphere Reserve 2017	Lake Fleet Islands: the rugged islands of wind-swept white pine and rich hemlock gullies are reminiscent of our northern forests. Admiralty Islands: hemlock is noted on Aubrey and Mermaid Islands. Kingston Isles: Milton Island ( 44.2449, - 76.3987) hosts a mature mixed forest of white pine and red oak, interspersed with hemlock. Summer access by boat is good, but is limited in spring/late autumn.
Wesleyville Ravines	43.94	-78.4	138	Private (Ontario Hydro)	OG,CF, ESA,RW SL		Larson et al. 1999, AFER 2017	Hemlock is dominant in all diameter classes up to 69 cm. Hemlocks are at least 160 years old. This is reported to be the least disturbed forest in the site district, and it definitely feels old and undisturbed except for extensive ATV and dirt bike trails. The oldest trees are 160-212 years old; this is a significant old-growth area and should be managed as such.
White Rose West Forest	43.9745	-79.4414	80	Life Science site	?	?	NHIC 2016	*This ANSI was considerably reduced in size by residential development and a golf course and is no longer considered a regional ANSI (Varga and Mewa, 1998).Relatively mature, maple-beech-hemlock forests characterize this ca. 80 ha site.
Willet Creek / Sunnybrook / Serena Gundy Parks	43.7250	-79.3512	44	Municipal park	OG,MF, CF,SRE, UF,RW	1	AFER 2017, TRCA 2017, TRCA 2010	With the Bata Trail running its entire length, Wilket Creek Park is known for its mature coniferous and deciduous forest communities. Depending on soil moisture, light and orientation of the ravine slopes, mature stands of Eastern hemlock, Sugar maple and American Beech thrive along the valley walls, as do several tall Black Cherry trees. The park includes 15 ha of Fresh - Moist Hemlock Mixed Forest (roughly one third of the park). Access to hemlock is primarily from Sunnybrook trails. Some of the hardwoods in particular have characteristics of trees 160-200 years old. Sunnybrook Park, Serena Gundy Park and Glendon Forest have nearly continuous hemlock forests with maximum ages commonly up to 160, and occasionally to 180 years old.
Winona Escarpment Slopes / Winona Conservation Area			36.5	ANSI, Conservation Area	OG,CF, REP,SL		Eagles & Beechey 1985	This area contains some of the most mature, best developed and most diverse representative vegetation patterns of the Niagara Section of the escarpment... on the western end of the area there is a very well developed terrace ridge and valley pattern consisting of dry mesic Quercus-Pinus-Acer forests on the narrow sand and shale ridges... and more common Tsuga dominated canopies in the valleys.

**NOTE:** Some other important areas were identified but were not included in the above table because they: 1) didn't meet the minimum criteria, 2) had little hemlock, or 3) lacked information. These areas should also be considered for management including the following: Lynde Shores Conservation Area, Crothers Woods, Uxbridge Pine-Maple Uplands ANSI, Warsaw Caves Conservation Area, Waterfall Woods, Fallingbrook Woods, Chatsworth Ravine ESA and Cedarvale Ravine.

## References for Appendix 2

- AFER. 2017. **Brookbanks Ravine - Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=87>.
- AFER. 2017. **Charleston Lake Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=92>.
- AFER. 2017. **Rattray Marsh - Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=86>.
- AFER. 2017. **Spencer Gorge - Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=91>.
- AFER. 2017. **Spring Creek Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=99>.
- AFER. 2017. **Springwater Conservation Area Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=20>.
- AFER. 2017. **Stephen's Gulch Conservation Area Forest Information** - Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=RS1>.
- AFER. 2017. **Wesleyville Ravines Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=66>.
- AFER. 2017. **Wilket Creek Forest Information**. Ancient Forest Exploration & Research. <http://www.ancientforest.org/forest-info/?Num=135>.
- Ambrose, J. & D. Kirk. 2010. **Recovery Strategy for the Cucumber Tree (*Magnolia acuminata*) in Ontario**. Ontario Recovery Strategy Series. Prepared for the Ontario Ministry of Natural Resources, Peterborough, Ontario.
- Bert Miller Nature Club. 2003. **Old Growth Forest Survey of Niagara Peninsula Project of Bert Miller Nature Club First Phase Report to Trillium Foundation**. <http://www.bertmillernatureclub.org/assets/docs/library/OLD%20GROWTH%20FOREST%20SURVEY%20OCTOBER%202003.pdf>.
- Carolinian Canada. 2017. **What Is the Big Picture?** [https://caroliniancanada.ca/legacy/ConservationPrograms\\_BigPicture.htm](https://caroliniancanada.ca/legacy/ConservationPrograms_BigPicture.htm).
- Carolinian Canada. 2017. **Big Creek Valley - South Walsingham Sand Ridges Area ID17683**. [https://caroliniancanada.ca/legacy/CarolinianSites\\_BigCreek.htm](https://caroliniancanada.ca/legacy/CarolinianSites_BigCreek.htm).
- Cheskey. 2003. **Twelve Mile Creek Headwaters Important Bird Area**. The 12 Mile Creek Headwaters IBA Steering Committee. 27 pp. <http://www.ibacanada.ca/documents/conservationplans/ontwelveilecreekheadwater.pdf>.
- City of Toronto. 2016. **Trees, Shrubs and Vines of Toronto: A Guide to their Remarkable World**. City of Toronto Biodiversity Series. 85 pp. <https://www1.toronto.ca/City%20Of%20Toronto/City%20Planning/Environment/Files/pdf/B/Trees,%20Shrubs%20&%20Vines%20of%20Toronto.pdf>.
- City of Toronto. 2017. **How are Environmentally Significant Areas protected?** <http://www.toronto.ca/legdocs/mmis/2015/pg/bgrd/backgroundfile-80449.pdf>.



Credit River Watershed and Region of Peel Natural Areas Inventory Project. 2011. ***Credit River Watershed and Region of Peel Natural Areas Inventory - Volume 1***. <https://www.peelregion.ca/planning/pdc/data/monitoring/watersheds/maps.htm>.

Credit Valley Conservation (CVC). 2008. ***Credit Valley Conservation Terra Cotta-Silver Creek Complex***. <https://cvc.ca/wp-content/uploads/2011/11/tcscweb.pdf> [accessed June 21, 2018].

Eagles, P. F. J. & T. J. Beechey (eds.). 1985. ***Critical Unprotected Natural Areas in the Carolinian Life Zone of Canada***. Final Report, Identification Subcommittee, Carolinian Canada. The Nature Conservancy of Canada, The Ontario Heritage Foundation and World Wildlife Fund (Canada).

Friends of Charleston Lake Park. 2017. <http://www.friendsofcharlestonlakepark.com/about-the-park.html>.

Frontenac Arch Biosphere Reserve. 2017. ***1000 Islands Water Trail***. [http://www.frontenacarchbiosphere.ca/sites/frontenacarchbiosphere.ca/files/All Thousand Islands Routes\\_0.pdf](http://www.frontenacarchbiosphere.ca/sites/frontenacarchbiosphere.ca/files/All%20Thousand%20Islands%20Routes_0.pdf).

Halton Region & North-South Environmental Inc. 2005. ***Halton Region Environmentally Sensitive Areas Consolidation Report***. Unpublished report prepared by Halton Region Planning and Public Works Department in conjunction with North - South Environmental Inc.

Henry, M., P. Quinby & M. McMurtry. 2016. ***The Jackson Creek Old-Growth Forest: Core Area of the Jackson Creek Significant Woodland In Peterborough, Ontario***. Research Report No. 33. <http://www.ancientforest.org/wp-content/uploads/RR33-Jackson-Creek-OGF.pdf> [accessed March 14, 2017].

Henry, M. and P. Quinby. 2019. ***Eastern Hemlock Forests in The Greater Toronto Area: Rapid Surveys to Identify Urban Old-Growth Hemlock Forests***. Preliminary Results Bulletin #7. 10 pp.

IBA Canada. 2017. ***Little Otter Creek Complex (ON044)***. <http://www.ibacanada.ca/site.jsp?siteID=ON044>.

IBA Canada. 2017. ***Springwater Conservation Area (ON028)***. <http://www.ibacanada.ca/mobile/site.jsp?siteID=ON028>.

Kershner, B. 2004. ***Old growth Forest Survey of Eastern Niagara Peninsula. Phase 2 report to Trillium Foundation Oct 2004***. <http://www.bertmillernatureclub.org/assets/docs/library/OLD%20GROWTH%20FOREST%20SURVEY%20OCTOBER%202003.pdf>.

Kershner, B. 2005. ***The Last on Earth: Marcy Woods - Ontario's Endangered Treasure***. Report Prepared for Friends of Marcy Woods, October, 2005. [http://www.nativetreesociety.org/specialreports/marcywoods/marcy\\_woods\\_final.pdf](http://www.nativetreesociety.org/specialreports/marcywoods/marcy_woods_final.pdf).

Krick, R. & F. Forsyth. 2012. ***Credit Valley Conservation Invasive Species Program Year End Report 2011***. <https://cvc.ca/wp-content/uploads/2012/07/12-069-invasives-programreport-2011-web.pdf>.

Larson, B. M., J. L. Riley, E. A. Snell & H. G. Godschalk. 1999. ***The Woodland Heritage of Southern Ontario: A Study of Ecological Change, Distribution and Significance***. Federation of Ontario Naturalists, Don Mills, Ontario.

Lindsay, K. M. 1981. ***An identification and evaluation of life science candidate nature reserves in site district 7-2 west of the Haldimand clay plain***. Parks and Recreation Section, Ontario Ministry of Natural Resources, Central Region, Richmond Hill, ON and Southwestern Region, London, ON.

<http://longpointbiosphere.com/download/Environment/An-Identification-and-Evaluation-of-Life-Science-Candidate-Nature-Reserves-In-Site-District-7-2-West-of-Haldimand-Clay-Plain-by-K.M.-Lindsay.pdf>.

Lower Trent Conservation Authority (LTCA). 2019. **Goodrich-Loomis**. <http://www.ltc.on.ca/conservation/ca/gl/>.

Natural Heritage Information Centre (NHIC). 2016. **Natural areas shapefile**. [http://www.sse.gov.on.ca/sites/MNR-PublicDocs/EN/ProvincialServices/NADb\\_Pts\\_Oct2013.zip](http://www.sse.gov.on.ca/sites/MNR-PublicDocs/EN/ProvincialServices/NADb_Pts_Oct2013.zip).

Niagara Peninsula Conservation Authority. 2010. **NATURAL AREAS INVENTORY 2006–2009 Volume 1**. [https://npca.ca/sites/default/files/NAI-Vol-1\\_web.pdf](https://npca.ca/sites/default/files/NAI-Vol-1_web.pdf).

North-South Environmental. 2012. **Environmentally Significant Areas (ESAs) in the City of Toronto**. Toronto City Planning Department, [https://www.researchgate.net/profile/Vladimir\\_Kricsfalussy/publication/316256779\\_Environmentally\\_Significant\\_Areas\\_ESAs\\_in\\_the\\_city\\_of\\_Toronto/links/58f7d782a6fdcc86f8123506/Environmentally-Significant-Areas-ESAs-in-the-city-of-Toronto.pdf](https://www.researchgate.net/profile/Vladimir_Kricsfalussy/publication/316256779_Environmentally_Significant_Areas_ESAs_in_the_city_of_Toronto/links/58f7d782a6fdcc86f8123506/Environmentally-Significant-Areas-ESAs-in-the-city-of-Toronto.pdf).

Ontario Ministry of Natural Resources. 2009. **Peter's Woods Provincial Park Management Plan**. <https://www.ontario.ca/page/peters-woods-provincial-park-management-plan> [accessed January 16, 2019].

Ontario Nature. 2017. **George G. Newton Nature Reserve**. [https://www.ontarionature.org/protect/habitat/PDFs/George G Newton Nature Reserve.pdf](https://www.ontarionature.org/protect/habitat/PDFs/George%20G%20Newton%20Nature%20Reserve.pdf).

Parks Canada. 2017. **Thousand Island National Park**. [http://www.pc.gc.ca/eng/pn-np/on/lawren/visit/visit4/~media/pn-np/on/lawren/cartes-maps/carte\\_map\\_jones\\_en.ashx](http://www.pc.gc.ca/eng/pn-np/on/lawren/visit/visit4/~media/pn-np/on/lawren/cartes-maps/carte_map_jones_en.ashx).

Toronto and Region Conservation Authority (TRCA). 2017. **Wilket Creek Rehabilitation Project - Toronto and Region Conservation**. <https://trca.ca/conservation/erosion-management/restore/wilket-creek-rehabilitation-project/>.

TRCA. 2012. **Seneca College King Campus Terrestrial Biological Inventory and Assessment**. <https://trca.ca/app/uploads/2016/02/SenecaCollegeKingCampusMarch2012.pdf>.

TRCA. 2012. **William Granger Greenway - Pine Grove to Boyd Terrestrial Biological Inventory and Assessment**. <https://trca.ca/wp-content/uploads/2016/02/WilliamGrangerGreenwayNovember2012.pdf>.

TRCA. 2010. **Walk the Don: Wilket Creek Walk**. <http://www.trca.on.ca/dotAsset/93715.pdf> [accessed March 10, 2017].

TRCA. 2009. **Don River Watershed Plan Terrestrial Natural Heritage – Report on Current Conditions and Refinement of a Target System**. <http://trca.on.ca/dotAsset/55397.pdf> [accessed March 13, 2017].

Varga, S. 1989. **A Botanical Inventory and Evaluation of the High Park Oak Woodlands Area of Natural and Scientific Interest**. <http://highparknature.org/wiki/uploads/Resources/Varga-Report-1989-s.pdf> [Accessed March 10, 2017].

Wake, W. 1997. **A Nature Guide to Ontario**. University of Toronto Press.

White, D. J. 1990. **Preliminary Definitions and Evaluation of Old-Growth Forest in Eastern Ontario**. OMNRF, Kemptville, Ontario.