Risk Assessment from Emerald Ash Borer and Other Forest Pests Upon Commonly Harvested Forest Trees (Ash, Balsam, Birch, Maple and Oak) in the Ojibwe Ceded Territories

by

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Project Report 13-03
September 2013

In partial fulfillment of requirements for
Administration for Native Americans, ACF,
US Department of Health and Human Services,
Grant # 90NR0280

Contents

EXECUTIVE SUMMARY 3
NOTES 5
ACKNOWLEDGEMENTS 5
INTRODUCTION 6
The Treaty-Reserved Right to Hunt, Fish and Gather 6
History of Forest Pest Introduction and Damage in North America 7
OAK AND OAK WILT 9
Taxonomy, Distribution and Significance of Oaks 9
Environmental role 9
Economic value 10
The Oak Wilt Fungus 10
History and distribution 10
Life cycle 15
Impact on oaks 16
Vectors for spread 17
Potential pathways of spread 18
Detection 18
Control 18
Other pests of oak 19
ASH AND THE EMERALD ASH BORER 21
Taxonomy, Distribution and Significance of Ash 21
Environmental role 21
Economic value 25
The Emerald Ash Borer 25
History and distribution 25
The City of Superior infestation 28
Life cycle 30
Impact on ash 30
Vectors for spread 32
Potential pathways 32
Detection 33
Control 35
The Slow Ash Mortality Project 37
National and state control strategies 37
MAPLE AND THE ASIAN LONGHORNED BEETLE 39
Taxonomy, Distribution and Significance of Maples 39
Environmental role 39
The sugarbush 39
Economic value 44
The Asian Longhorned Beetle 44
History and distribution 44
Life cycle 46
Vectors for spread 48
Potential pathways 48

Detection ... 49
Control ... 50
Economic impacts ... 51
BALSAM FIR AND THE BALSAM WOOLLY ADELGID ... 52
Taxonomy, Distribution and Significance of Balsam Fir ... 52
Environmental role ... 52
Economic value ... 52
The Balsam Woolly Adelgid ... 54
History and distribution ... 54
Life cycle ... 55
Impact on balsam fir ... 57
Vectors and potential pathways for spread ... 58
Detection ... 59
Control ... 59
National and state control strategies ... 59
EASTERN HEMLOCK AND THE HEMLOCK WOOLLY ADELGID ... 60
Taxonomy, Distribution and Significance of Hemlock ... 60
Environmental role ... 60
Economic value ... 62
The Hemlock Woolly Adelgid ... 62
History and distribution ... 62
The HWA reaches Lower Michigan (temporarily) ... 62
Life cycle ... 64
Impact on hemlock ... 64
Vectors for Spread ... 65
Potential pathways for spread ... 66
Detection ... 66
Control ... 66
BEECH AND BEECH BARK DISEASE ... 68
Taxonomy, Distribution and Abundance of American Beech ... 68
Environmental role ... 68
Economic value ... 68
Beech Bark Disease ... 70
History and taxonomy ... 70
Life cycle of beech scale ... 71
Impact on beech ... 72
Vectors and pathways for spread ... 74
Control ... 74
Effects on the forest ... 74
The future of American beech ... 75
White birch ... 76
A NOTE ON THE JAPANESE CEDAR LONGHORNED BEETLE ... 78
REFERENCES ... 81

EXECUTIVE SUMMARY

The forests of North America and the ceded territory are under threat like never before (Frelich and Reich 2010; also see Felich's powerpoint at http://www.slideshare.net/maeeconference/lee-frelichs-climate-change-forests-presentation). European earthworm invasions and high populations of native white-tailed deer are already inhibiting the establishment of tree seedlings, including those of sugar maple. Freed from their natural pests and diseases and often adapted to living with earthworms, introduced, invasive plants continue to invade natural habitats, displacing native plants. Human population growth and the corresponding demand for resources place increasing pressure on shrinking forest lands. The warming climate will lead to greater frequency of droughts, fires, major windstorms, and outbreaks of native and exotic insect pests and diseases. Adult trees will be lost at a greater rate than they can be replaced. Boreal and northern hardwood forest ecosystems will be pushed north, to be replaced by savannas of native trees, shrubs and forbs from further south, as well as aggressive invasive species such as Eurasian bush honeysuckles (*Lonicera* spp.) and buckthorns (*Rhamnus cathartica* and *Frangula alnus*).

This report is aimed at assessing one of these threats: the risk of forest pests to five groups of trees used by Ojibwe tribal members in the ceded territories of 1836, 1837, and 1842. These five groups of trees are oaks, ash, maple, balsam, and birch. Additionally, sections are included for hemlock and beech, with a short section on cedar.

Oaks are one group of trees that may be able to withstand some climate warming. They are likely to become increasingly important components of forest and savanna ecosystems in the northern ceded territory, as they currently are in the southern ceded territory and southward. The most destructive disease currently facing oaks in the ceded territory is oak wilt. This fungal disease is widespread but still localized in the ceded territory. Recently discovered infestations in northern Wisconsin have been clearly linked to landowners who damaged oak trees while building vacation homes, and who also brought wilt-infested firewood from southern Wisconsin. The oak wilt fungus spreads underground through root grafts between trees and is also carried by sap beetles from infested trees to uninfested, injured trees. The spread of oak wilt is potentially very controllable, provided people do not move infested firewood to uninfested areas.

North American **Ash** are threatened with virtual extinction in the wild by the emerald ash borer (EAB). The EAB is the most destructive forest pest ever introduced to North America. First detected in Detroit in 2002, it has devastated ash in southern Lower Michigan, Ohio and Indiana, and is now established in 21 states and two Canadian provinces. The EAB is found in and around the ceded territory in northern Lower Michigan and eastern Upper Michigan, and is also established in Houghton, Michigan, Minneapolis, Minnesota, near Green Bay, Wisconsin, and now in Superior, Wisconsin.

Heroic efforts are being made to slow the spread of this insect and save some of eastern North America's ash trees. A new systemic insecticide called TREE-age® appears to provide long-lasting (at least 2 years), highly effective protection from the EAB. This pesticide is derived from a soil bacterium and appears to be safe for people, animals, and even insects that may simply land on ash trees. Three tiny parasitoid wasps have passed testing for host-specificity by the US Department of Agriculture, and are being released across the introduced range of the EAB, and additional insects (particularly those that can better survive cold winters) are being searched for in the EAB's native range. The SLAM project being conducted in Upper Michigan aims to use these and other tools to try and lower the EAB population enough so that native ash trees can survive on the landscape. The EAB usually only spreads about ½ mile per year on its own, so if people avoided moving ash firewood, it would be decades before the EAB could reach all the ash stands in the ceded territory. Slowing the spread of the EAB and other forest pests buys time to find solutions to slow the spread and mitigate the effects of these destructive forest pests.

Maples are potentially under threat from the Asian longhorned beetle (ALB). The ALB is a large wood-boring beetle from China. It first became established in the New York City area in 1997. This original infestation and subsequent ones in Chicago, Toronto, and New Jersey have been eradicated. Four infestations, including ones in suburban Massachusetts and semi-rural southern Ohio are still being eradicated. Unlike earlier infestations, which occurred in urban areas, these last two infestations include areas of natural forest.

In its native range the ALB attacks a wide variety of trees, including maple, horse chestnut, elm, birch, aspen and willow. In North America though, the ALB has so far almost exclusively attacked any and all available maple trees. Unlike the EAB, though, the ALB is a relatively easily detectible beetle that normally does not fly any farther than it has to in order to find a suitable tree. Though eradication efforts have been costly in terms of time, effort, trees and money, they have shown that the ALB can be eradicated.

Hemlock and **balsam fir** are both under attack in New England and the Appalachian region by introduced relatives of aphids (plant lice) called adelgids. These adelgids build to huge numbers, extracting stored food reserves from their respective hosts and starving them of reserves they need for winter. While cold winter temperatures traditionally experienced in the ceded territory may rid the forests of a large portion of these insects in some years, their ability to survive under the snow and rapidly multiply again in the spring means that if and when they arrive, they will always be a threat to these two conifers. The states of Michigan and Wisconsin (hemlock barely reaches Minnesota, where it is very rare) both have quarantines on the movement of infested hemlock nursery trees, boughs, logs and other materials into the state, and Michigan is preparing to implement a quarantine on fir tree materials from infested areas as well. Still, the awareness and cooperation of the public is needed to keep these destructive insects from showing up in the ceded territory.

The benefits of public awareness and early detection were illustrated when the hemlock woolly adelgid recently showed up at several sites in Lower Michigan. The adelgid arrived on infested nursery trees that had been shipped from the eastern US. One infestation was caught a Michigan nursery inspector, and several others were reported by local citizens. Prompt action was taken, and Michigan officials now believe these infestations have all been eradicated.

The **Beech** scale, an introduced insect from Europe, has now invaded Michigan and Wisconsin. Spread of this insect has been linked to the movement of firewood by campers. Another aphid relative, the beech scale pierces the outer bark of the tree and feeds on the sap, slightly damaging the bark in the process. This allows entry of one or more fungi that cause beech bark disease. Beech bark disease kills the trunks of the trees, whereupon the roots send up numerous suckers, creating “beech thickets”. These thickets (and thus the trees) eventually may be crowded out as other trees overtop them. The good news is that about 1-2% of the beech trees appear to have significant resistance to infestation by the beech scale, and a small percentage of these may be completely immune. Thus the American beech is down but not out. Forestry practices can play a major role in promoting the eventual recovery of beech, by watching for resistant trees and leaving them in the woods.

Birch decline is of great concern to tribal members, in part because of the importance of birch trees and birch bark to Ojibwe culture. Changes in land use practices and forest management appear to be primarily responsible for the decrease in birch in the ceded territory. These changes include fire suppression and perhaps excessive logging of birch. White birch is a fairly short-lived tree, and stands that were initiated 60-75 years ago may experience decline simply due to old age. White birch is also sensitive to severe drought and to elevated soil temperatures, problems that a warming climate will likely make worse.

White birch and most other native birch species are sometimes hosts for a close relative of the EAB called the bronze birch borer. This native insect generally only attacks stressed and dying trees, though, so while it may contribute to birch decline it is rarely the primary cause.

This scientific review of the threat posed to the forests of the ceded territory by introduced forest pests is the first of three to be produced during the course of this project. By the end of the 24th month, GLIFWC will have completed a risk assessment of threats to treaty resources from EAB and 4 other forest pests, that integrates Traditional Ecological Knowledge (TEK) on ash use and ash quality needed for baskets, wood fuel harvest patterns, and TEK information related to tribal use of balsam, birch, maple, oak and perhaps other species.

NOTES

Ojibwemowin

Ojibwe names generally follow Meeker et al. (1993). Other references consulted included the online Ojibwe People's Dictionary of the University of Minnesota (http://ojibwe.lib.umn.edu/about) and the Freelang Ojibwe-English dictionary (http://www.freelang.net/dictionary/ojibwe.php).

Biological Nomenclature

Unless otherwise indicated, plant nomenclature follows Voss and Reznicek (2012). Insect and fungal nomenclature was gleaned from the numerous paper reviewed and cited for this report.

ACKNOWLEDGEMENTS

Thanks to Language Specialist Wesley Ballinger of GLIFWC for advice on Ojibwemowin. His expertise and patience are greatly appreciated. Thanks also to member of GLIFWC staff who took time to review parts or all of this report, including Jonathan Gilbert, Neil Kmiecik, and Miles Falck.

Photos not credited are by the author.

INTRODUCTION

The Treaty-Reserved Right to Hunt, Fish and Gather

Since time immemorial, the Lake Superior Ojibwe Tribes have traditionally harvested certain plants and other resources to meet subsistence, religious, cultural, medicinal and commercial needs (MOU 1999). The culture and lifeway of these federally recognized Tribes depends on this harvest activity, and they wish to protect and enhance the natural resources upon which they rely. The Tribes measure the protection of these resources in terms of ensuring their sustainability for use by the seventh generation hence. To this end the Tribes wish to protect these resources from threats from invasive species, including harmful nonindigenous insects and other forest pests.

The Tribes seek to promote ecosystem management that protects and restores native communities and species, furthers the diversity of species, and ensures the sustained yield and availability of natural resources that are subject to the Tribes' ceded territory rights (see Figure 1). Invasive forest pests have the potential to diminish these traditions and rights, by harming or eliminating trees that the Tribes have traditionally used, including black ash and other native species. By severely reducing or eliminating these trees, forest pests have the potential to indirectly harm other treaty resources, by significantly and permanently altering ecosystems on which other native plants and animals depend.

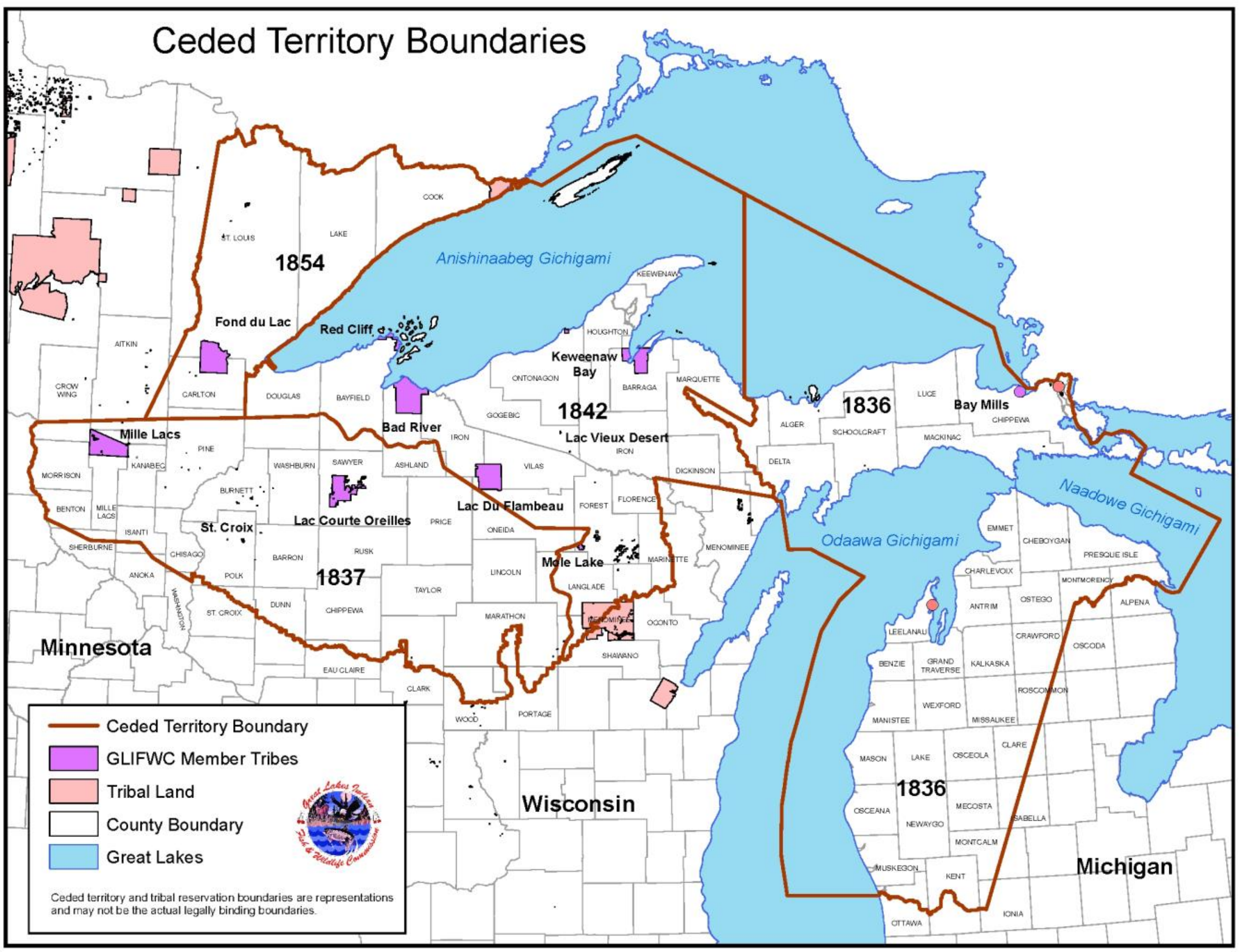

Figure 1. Lands included in the 1836, 1837, 1842, and 1854 treaties and the location of the eleven Ojibwe tribes which are members of GLIFWC.

History of Forest Pest Introduction and Damage in North America

The first recorded introduced forest pest in the United States was the codling moth (*Cydia pomonella* [Linnaeus]), a tree-feeding insect identified in 1635 (Aukema et al. 2010). This Eurasian moth lays its eggs on apples, pears and crabapples. The caterpillars that tunnel through these fruits are known to most people as the "worms" in a wormy apple.

By 1859 another 17 introduced tree-feeding insects had been recorded in the continental United States (Aukema et al. 2010). From 1860 through 2006, an average of 2.4 tree-eating insect pests were detected each year. Over the same time period, the number of high-impact insects, fungi and other tree pathogens (those reported to have a significant negative impact on live trees in the published literature) averaged 0.43 per year. Most of these pests arrived on nursery shipments and other living plant material. Today more than 450 tree-feeding insects and pathogens have become established in the US.

One of the first high-impact pests to arrive was the fungus that causes chestnut blight. Known as the "redwood of the east", the American chestnut (*gichi-zhaaweminan*) dominated forests from southern Maine and Ontario to Indiana and Georgia. These trees could reach at least 15 feet in diameter and 120 feet tall (Figure 2). In July they would burst into bloom, turning whole hillsides white. In the fall they produced huge crops of chestnuts (*gichi-azhaawemin bagaanag*) that covered the ground several inches deep. The nuts fed a wide array of wildlife, from black bears (*makwag*) and squirrels (*ajidamoog*) to turkeys (*mizhiseg*) and the now-extinct passenger pigeon.

After European settlement the chestnut played a major role in the Appalachian economy, as people gathered the nuts as a cash crop and used the tannic acid from the bark in the leather industry. The wood was strong, lighter than oak, and more rot-resistant than redwood, and cabins made from chestnut lumber in the 18th and 19th centuries are still standing today.

Figure 2. Old-growth American chestnut trees. Photo taken in the Great Smoky Mountains of North Carolina, around 1910. Sidney V. Streator, photographer. Courtesy of the Forest History Society, Durham, NC.

The arrival of the Asian chestnut blight fungus in the early 1900s marked the beginning of the end for this magnificent tree. By 1940 the disease had decimated the chestnut across its native range. Wildlife populations crashed, and at least six species of moths vanished forever. Today the wild chestnut population consists almost entirely of the root systems of surviving old trees that shoot out, get reinfected, and die back to the ground.

The next great wave of destruction came in the mid-1900s, with the demise of the American elm (*aniibiig*). A common overstory tree in eastern North American forests, elm trees also lined the streets of many US cities and towns. The American elm is attacked by a native bark beetle, so the arrival of the smaller, closely related European bark beetle wasn't much of a problem for it. Then the fungi that causes Dutch elm disease arrived in infested elm logs brought from France in 1931. Both European and native bark beetles carried the fungi from one tree to the next, wiping out urban street trees and decimating wild populations.

The American elm has fared better than the chestnut. A small percentage of American elm trees have significant resistance to the disease. The elm fungus also does not spread as efficiently as chestnut blight, which blows on the wind. Thus many elm trees escape the fungus long enough to produce their typically abundant seed crops. Through genetic recombination, resistant trees continue to arise and pass their genes on to subsequent generations.

With increased trade with far-flung parts of the world, the rate of pest introduction continues, despite regulatory measures designed to prevent this (Aukema et al. 2010). Introductions from China and Russia are of particular concern, because they have similar climates, and their forests include many plant species that are close relatives of many temperate North American species.

OAK AND OAK WILT

Taxonomy, Distribution and Significance of Oaks

Environmental role

Oaks are members of the family Fagaceae, which also includes beech (*Fagus* spp.) and chestnuts (*Castanea* spp.). In the Americas, oak species naturally fall into three groups: the white oaks (*Quercus* subg. *Quercus*) the black and red oaks (*Quercus* subg. *Erythrobalanus*), and the intermediate oaks (*Quercus* subg. *Protobalanus*) (Voss and Reznicek 2012, Nixon 1997). A fourth group, *Quercus* subg. *Cerris*, is restricted to Eurasia (Juzwik et al. 2011) Only the first two groups occur in the Great Lakes region.

Red and black oaks (hereafter referred to as the red oak group) are easily distinguished from white oaks (Voss and Reznicek 2012, Nixon 1997). The leaves of the red oak group have prominent bristle-tips at the ends of their lobes (or only at the tip of the leaf in shingle oak), while the white oak group (including white oak and bur oak) has rounded leaf lobes that lack bristles. The acorns of the white oak group ripen their first year, while those of nearly all members of the red oak group ripen their second year. Thus the mature acorns of white oaks grow on the ends of the branches with the leaves, while those of red oaks end up on year-old twigs below the leaves. The shells of red oak group acorns are densely pubescent on the inside, while white oak shells are glabrous (hairless) inside. The red oak group has bark that's dark and tight, often shiny, and that becomes furrowed with age. White oaks usually have bark that's gray and flaky. Acorns of the red oaks are much higher in tannins than those of the white oaks, and generally must be processed (soaked) before they can be eaten. Oaks can often hybridize with other species in the same subgenus (Voss and Reznicek 2012), yet ecological pressures keep the species separate (Hardin 1975).

Acorns are an important food source for mice, squirrels, deer, bear, turkeys, some insects, and many other animals (Auchmoody et al. 1993, Lovett et al. 2006). Blue jays love acorns, and some credit them with “planting” the oak forests of the Great Lakes region. Red oak trees start producing acorns at about 25 years, but usually don't produce large crops until about age 50. Seed predation is so great that even in good years only about 1 percent of the acorns become available for regenerating northern red oak. As many as 500 or more acorns may be required to produce a single 1-year-old seedling. Seed-eaters can eat or damage more than 80 percent of the acorn crop in most years, and virtually all of the crop in very poor seed years (sources in Sander 1990).

Acorns were historically an important food for indigenous people in North America, Central America, Europe, and Asia. In some areas, acorn consumption is still important, but because of the intense preparation necessary to remove tannins and strong flavor of especially red oak acorns, they have fallen out of use as human food in developed areas (Nixon 1997).

Oaks are an important and sometimes even dominant component of many eastern forests, especially forests on well-drained uplands. The most common oak species of the western Great Lakes region is northern red oak (*Quercus rubra; mashkode-miizhimizh*, singular, Ojibwe) (Figure 3). Northern red oak is moderately shade-tolerant, and a common component of northern hardwood forests (Sander 1990). Tolerant of a variety of soil conditions, it occurs on sites ranging from moist, cool north slopes to dry sand plains. Seedlings are unable to develop in deep shade, though (Phares 1971).

Northern pin oak, Hill's oak or scrub oak (*Quercus ellipsoidalis; mitigomiizhis-mitigomiizh*) is common in dry, open upland forest and sand plains (Figure 4). It is part of a group of red oaks known as scrub oaks, which are usually associated with dry, sandy soils (Voss and Reznicek 2012). A fire-adapted species, it usually grows as a shrub or small tree. Northern pin oak often holds its leaves well into winter. After fire, it resprouts vigorously. Northern pin oak is closely related to northern red oak, and occasionally hybridizes with it.

Bur oak (*Quercus macrocarpa; mitigomiizh*) is a common tree in the southern and western parts of the ceded territory, with isolated outlier populations in the Upper Peninsula (Figure 5). It is most typical of dry uplands and sandy plains, but is also found on fertile limestone soils and moist bottomlands in mixture with other hardwoods (Johnson 1990). It is moderately shade-tolerant. It is also fire-resistant, and the iconic tree of savannas and prairies. It is frequently planted in shelterbelts in the west.

White oak (*Quercus alba; mitigomiizh*) is a common tree on sandy soils in the southern and western ceded territory (Figure 6). The acorns are highly edible.

Several other oak species are found in a limited portion of the ceded territory (UWSP 2013, Voss and Reznicek 2012). Swamp white oak (*Quercus bicolor*) is found in swampy woods and in floodplains in central and northeastern Wisconsin and the southern half of Lower Michigan. Chinquapin oak (*Quercus muehlenbergii*), an upland species in the white oak group, just reaches the southern edge of the 1836 ceded territory in Lower Michigan. The same is true for the closely-related dwarf chinquapin oak (*Quercus prinoides*). Black oak (*Quercus velutina*, red oak group) is an upland species that reaches the southern 1836 ceded territory in Lower Michigan, with outlier populations in Vilas and Douglas Counties, Wisconsin. Pin oak (*Quercus palustris*, red oak group) reaches the southern 1836 ceded territory in Lower Michigan. It usually inhabits floodplains and poorly drained soils. An outlier population of the more southern scarlet oak (*Quercus coccinea*, red oak group) occurs just outside the 1837 ceded territory in Oconto County, Wisconsin.

Economic value

Oaks are an important source of fuel, fodder, and building materials. They are a valuable source of lumber and veneer (Sander 1990). Other products include tannins and dyes, and oak bark and leaves were often used for tanning leather (Nixon 1997). Both red and white oaks are fairly easy to grow and make excellent shade trees.

The Oak Wilt Fungus

History and distribution

Oak wilt is caused by the fungus *Ceratocystis fagacearum* (Bretz) J. Hunt (Henry 1944, Juzwik et al. 2011). The fungus is known only from the eastern and central United States, where it occurs from Texas to northeastern Minnesota, and east to Pennsylvania and South Carolina (Figure 7). There is some evidence that the fungus was established across most of its current range long before its discovery. While many researchers believe the fungus is not native to the US, it has never been found anywhere else in the world, and its origin remains a mystery (Juswik et al. 2008). It may have originated in central or South America (Juswik et al. 2008), with the highlands of Mexico suspected by at least one researcher (McCullough 2013). The oak wilt fungus continues to slowly expand it range in North America, aided by the movement of logs and firewood (Schwingle 2010, Jensen-Tracy et al. 2009).

The oak wilt fungus was first isolated from dying oaks in Wisconsin in 1942 (Henry 1944, cited in Juzwik et al. 2011). The disease was quickly confirmed in 23 counties of Wisconsin, 5 in Minnesota, 2 in Iowa, and 1 in Illinois. Initially named *Chalara quercina* B.W. Henry, the fungus was eventually renamed *Ceratocystis fagacearum* after the discovery of mating types and a sexual stage (Juswik et

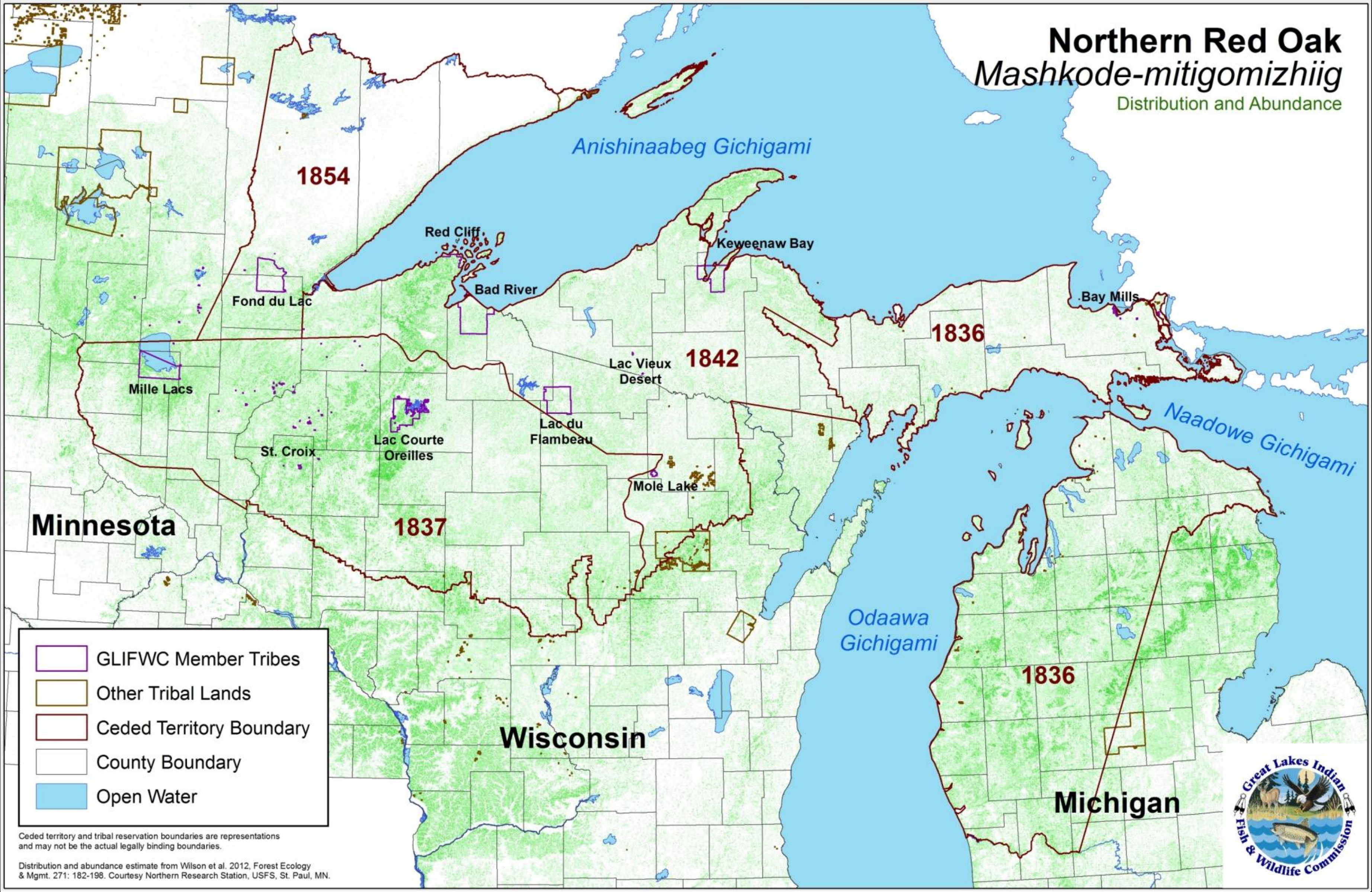

Figure 3. Estimated abundance and distribution of northern red oak in the ceded territory. The green shading indicates red oak abundance. Red polygons indicate approximate ceded territory boundaries. Estimate constructed by Wilson et al. (2012).

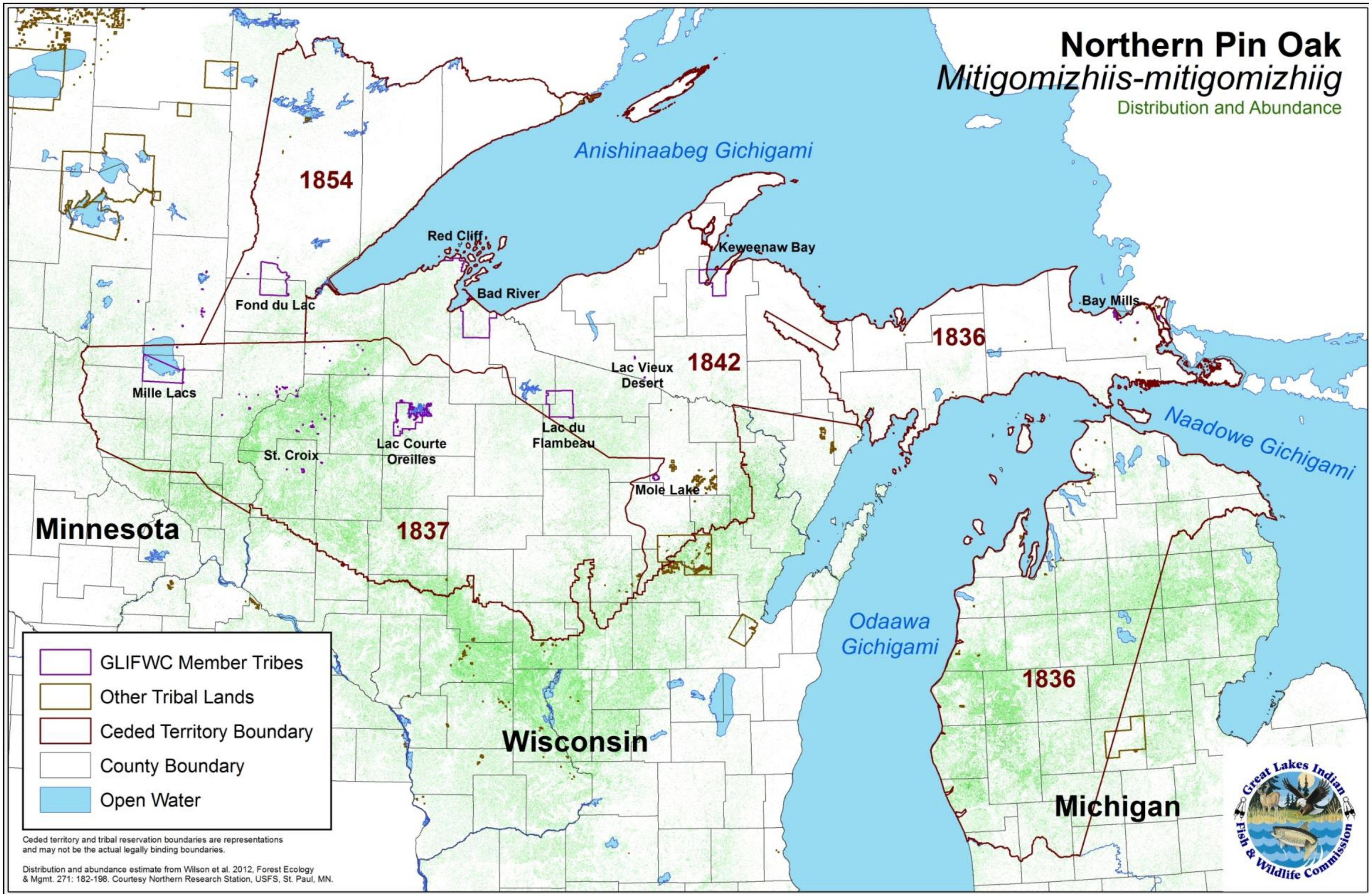

Figure 4. Estimated abundance and distribution of northern pin oak in the ceded territory. The green shading indicates pin oak abundance. Red polygons indicate approximate ceded territory boundaries. Estimate constructed by Wilson et al. (2012).

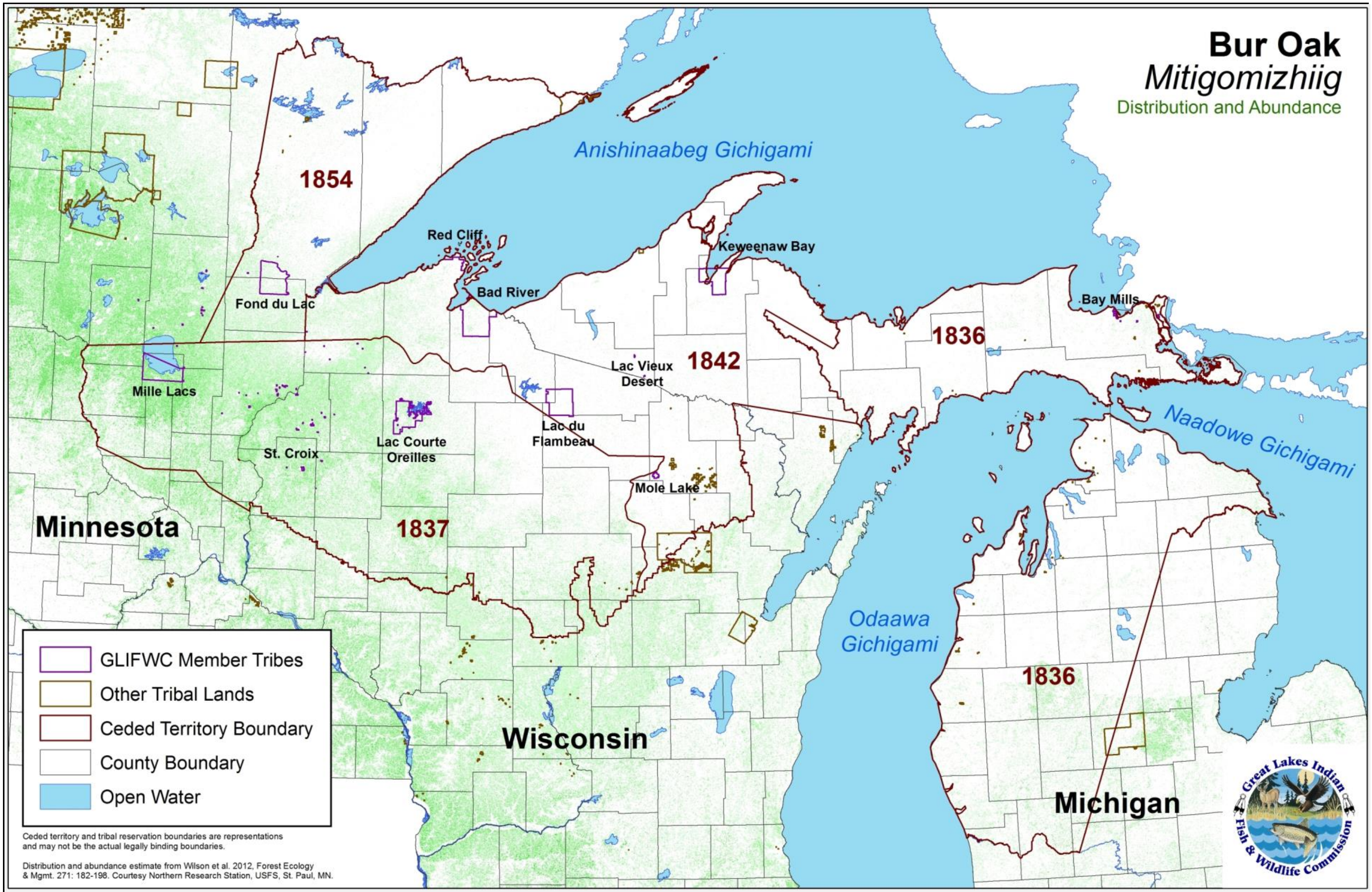

Figure 5. Estimated abundance and distribution of bur oak in the ceded territory. The green shading indicates bur oak abundance. Red polygons indicate approximate ceded territory boundaries. Estimate constructed by Wilson et al. (2012).

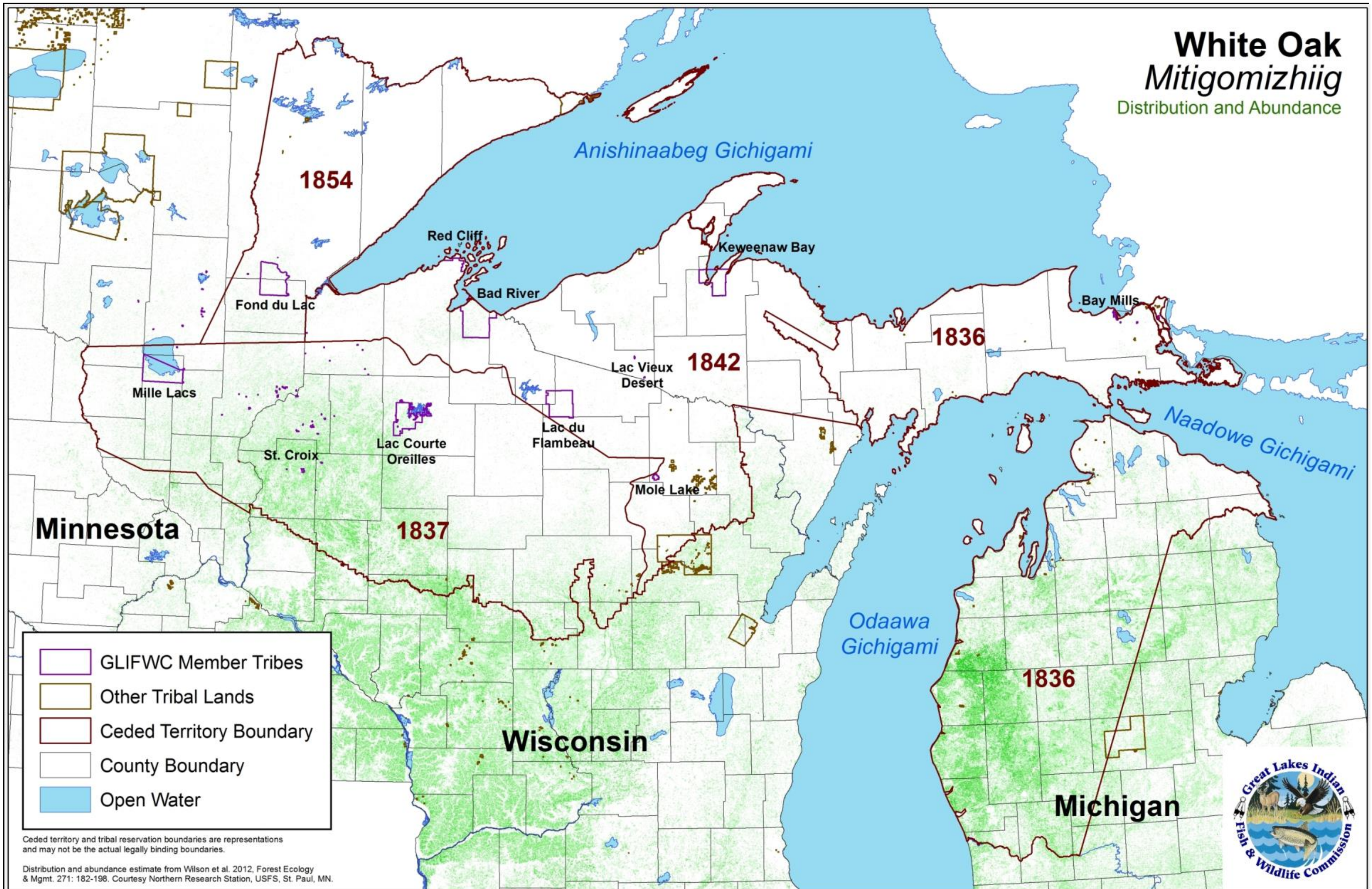

Figure 6. Estimated abundance and distribution of white oak in the ceded territory. The green shading indicates white oak abundance. Red polygons indicate approximate ceded territory boundaries. Estimate constructed by Wilson et al. (2012).

al. 2008). By 2008 the oak wilt and *C. fagacearum* was considered to be present in 829 counties of 24 states. Tens of thousands of oaks now die annually from oak wilt in the Lake States (Juzwik et al. 2011) (Figure 8).

Life cycle

The oak wilt fungus inhabits the wood of the oak tree host, where the hyphae (fungal filaments) grow inside the water-conducting vessels and trachieds (Jacobi and MacDonald 1980). The oak wilt fungus damages its host by clogging the sapwood vessels, starving the wood above the clog for water and minerals.

White oaks tend to be significantly more resistant to the fungus than red oaks (Jacobi and MacDonald 1980, O'Brien et al. 2011). Their greater resistance appears to be related to their physiology and anatomy. If white oaks are wounded or infected, or as part of the natural aging process, they tend to form numerous, minute, balloon-like plugs called tyloses in their sapwood vessels. These plugs, formed by the growth of surrounding parenchyma cells into the hollow conducting cells, make the wood of white oaks impermeable to water, and prevent the fungus from moving throughout the vascular system of the tree. Red oaks make fewer tyloses. In red oaks, the hyphae of the fungus readily grow from one cell to the next through bordered pits (rimmed holes between cells), thus bypassing plugs in the vessels produced by the tree altogether (Jacobi and MacDonald 1980).

After the tree dies, the fungal colony may produce one or more fungal mats (Figure 9). Fungal mats do not form until after the tree is completely colonized and has wilted or died (Juzwik et al. 2011). In the northern US (including the ceded territory) the mats typically appear in fall of the same year or in spring of the next year (O'Brien et al. 2011). They commonly form on red oaks. According to O'Brien et al. (2011), mats can develop on bur oak, but do not form on other white oaks. Red oak mats range in size from 1.6 inch (4 cm) to more than 6.8 ft (208 cm), but are smaller in white oaks (Juzwik et al. 2011).

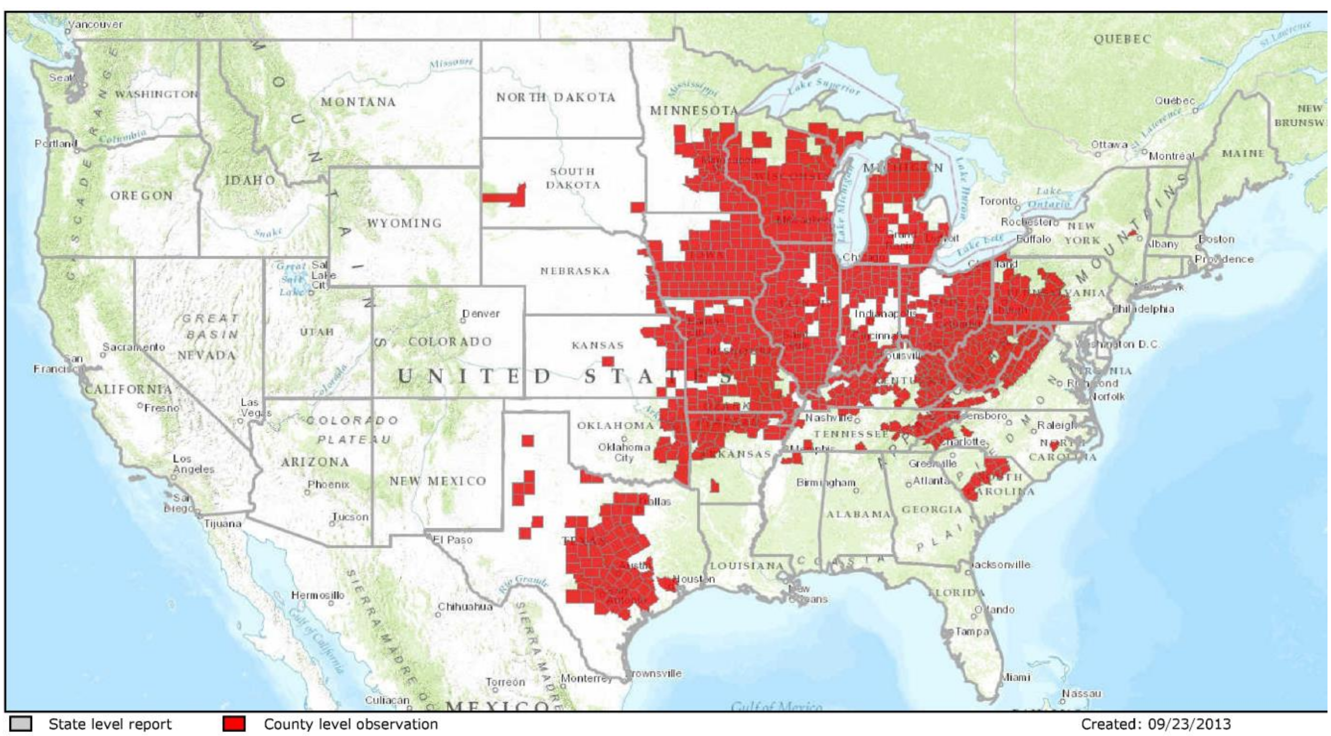

Figure 7. Known distribution of oak wilt. Oak wilt has recently been found in Rusk County, Wisconsin as well. (USDA Forest Service, Forest Health Protection and partners: http://foresthealth.fs.usda.gov/portal/Flex/APE).

Figure 8. Oak killed by the wilt fungus C. fagacearum*. Note persistent leaves. (USDA Forest Service, R8, Bugwood.org)*

As the fungal mat forms under the bark, growths called pressure pads form across from each other, on the sapwood and the inner bark. As these grow, they push against each other, causing the bark to separate from the wood and crack open. The pad also produce a fragrant fruit-like odor that attracts numerous insects, including species of sap beetles (Coleoptera: Nitidulidae) which are relatively effective at carrying fungal spores from tree to tree.

Figure 9. Oak trunk with bark removed, showing a fungal pad. This is the "smoking gun" of oak wilt identification. (Minnesota Dept. of Natural Resources, Bugwood.org)

Impact on oaks

Red oaks will often show symptoms within a month of infection by the oak wilt fungus (Jacobi and MacDonald 1980). The first symptom in red oaks is often a subtle off-green color shift visible in the upper portion of the tree crown (O'Brien et al. 2011). In the northern US this symptom appears in late June to early July. This color shift is quickly followed by the leaves wilting from the top of the crown downward. As the disease progresses, individual leaves quickly discolor, taking on a bronzy appearance. The discoloration progresses around the margins of the leaf from the tip to the base, and the leaves begin to fall. Commonly, infected trees are almost entirely defoliated within a few weeks of symptom onset. Fallen leaves usually are brown at the tips and margins, and sometimes green at the base and along the lower veins. As the wood becomes less and less able to transport water to the leaves, the tree loses most of its leaves (typically from the top downward) and quickly dies. Trees are often killed in groups called disease centers, as the fungus spreads through grafted roots (Figure 10).

Wisconsin Department of Natural Resources (WDNR) forest pathologist Kyoko Scanlon (quoted in Anonymous 2013) describes the symptoms of oak wilt as “branches with wilted leaves and leaves on the ground in summer when you wouldn’t expect to see that. These are not the brown, dry leaves of autumn. These are partially green to bronze-green and are not completely dry” (Figure 11).

Red oaks can be killed in as little as 3 weeks following infection, depending on species, site characteristics, temperature, and other factors. Some trees may last for several years, and there are recorded cases of red oaks recovering from infection (O'Brien et al. 2011).

White oaks show many of the same symptoms as red oaks, except the disease progresses more slowly (O'Brien et al. 2011). The trees usually die slowly, one branch at a time, over a period of one to many years. The leaves show a pattern of discoloration similar to red oaks (Figure 11). White oaks can be killed in one summer, but most will survive for several years, and a minority may survive for a decade or more (Juzwik et al. 2004). Occasionally white oak species will persist indefinitely or even appear to recover from the disease. Brown streaking in the outer growth rings is often readily apparent in white oak twigs, and may be visible in red oaks as well (Figure 12). White oak (*Quercus alba*) is considered “highly resistant” to *C. fagacearum* (O'Brien et al. 2011).

Vectors for spread

The primary way that oak wilt spreads from tree to tree is through root grafts. Root grafts between trees of the same oak species group are common. The oak wilt fungus can easily spread through these connections to the next tree. In light, sandy soils, large, established trees as much as 328 ft (100 m) apart can be connected by root grafts. In areas where oaks are common, the fungus can spread through whole stands, leaving large patches of dead oak forest in its wake.

Two sap beetle species, *Colopterus truncatus* and *Carpophilus sayi* (both Coleoptera: Nitidulidae), constituted 95% of the beetles visiting wounded oak trees in central Minnesota in spring (Juzwik et al. 2004). These beetles also carried relatively high numbers of fungal spores and hyphal fragments, and appear to be the main insect vectors for oak wilt fungus in central Minnesota. Based on data in an unpublished Ph.D. thesis, Juzwik et al. (2004) surmised that these two beetles may be the main vectors of *C. fagacearum* propagules in northern Iowa as well.

Figure 10. Oak wilt easily spreads through root grafts between oak trees. (Ronald F. Billings, Texas Forest Service, Bugwood.org)

New populations of oak wilt are generally initiated with the help of humans. Oak is well-known for being good firewood, and dead or dying oak trees are often used for this purpose (Bruhn and Heyd 1992). Home construction in oak woods is an important factor as well. Carelessness during construction often results in damaged oaks and other trees. Landowners may also bring recently cut oak firewood from infested areas, piling it on the site. All three new oak wilt infestations found in Wisconsin in 2013 (in Lincoln, Sawyer, and Vilas counties) were in yards and had oaks pruned or damaged in late spring (Anonymous 2013). Wounds to the tree must penetrate to the xylem for the fungus to invade (Zuckerman 1954, in Juzwik et al. 2004).

Figure 11. Bur oak leaves afflicted with oak wilt. Brown areas are still moist and flexible. (Fred Baker, Utah State University, Bugwood.org)

Potential pathways of spread

Oak wilt appears to be moving northward in the ceded territory, as people damage trees and bring infested firewood with them from the south where the disease is more prevalent. Thus oak wilt is most likely to appear in areas undergoing residential or recreational development.

No federal quarantines have been implemented for the oak wilt fungus. Oregon California, Canada and the European Union have established oak wilt quarantines, although the details vary. Canada's quarantine prohibits host materials with bark attached from the 22 US states known to have the disease from entering the country.

Figure 12. Discolored outer rings are sometimes evident, particularly in white oaks. (Robert F. Bassett, USDA Forest Service, Bugwood.org)

Detection

Aerial photography has been the standard method for locating oak wilt epicenters over large areas (Bruhn and Heyd 1992). Color infrared transparencies are taken in late July or early August, when most infected trees show symptoms. Bruhn and Heyd (1992) consider a scale of 1:1250 to be about optimum for distinguishing individual trees and detecting of new epicenters. Oak wilt epicenters have a distinctive infrared photo signature in mid to late summer. Healthy trees appear bright red, sick trees appear pink, wilted trees appear tan, and leafless trees are black. During late July or early August, new epicenters will appear as one to several tan trees. Older epicenters are recognized for having one or more tan and/or pink trees surrounding a pocket of black trees or an opening.

The WDNR offers a diagnostic service for detecting oak wilt. Three living twigs from three different branches with wilting leaves need to be collected and sent to the Plant Disease Diagnostics Clinic in Madison. For more information see http://dnr.wi.gov/topic/foresthealth/oakwilt.html.

Control

With cooperation from the public oak wilt is controllable. The development of new oak wilt pockets can be avoided by preventing the development of spore mats on diseased trees and by preventing the transfer of fungal spores to healthy trees. Infected or dead trees should be removed and properly treated to prevent development of spore mats. These treatments include debarking, chipping or splitting, and drying the wood. Covering dead wood with plastic, burying the edges for 6 months, and then air drying for a similar time will kill the fungus and any associated insects. Trees that die in summer should be removed and treated before the following spring, which is when new spore mats can develop (O'Brien et al. 2011).

It is very important not to prune or wound oak trees from April through July, and to take a cautious approach through October. Pruning or injuring the tree causes the tree to release sap, which attracts fungus-transporting insects. If tree removal, pruning, or damage occurs to oak tree trunks or limbs between April and August, it is imperative to immediately seal the wounds with some type of water-based (latex) paint. The paint does not have to be commercial tree wound paint.

The standard practice for stopping the underground expansion of an oak wilt infestation is to cut the root grafts outside the infestation, and then remove the infested trees. A vibratory plow or trencher must be used to cut through existing root grafts. It is critical that the root grafts be cut prior to cutting and removal of the infected trees. That's because unlike a living tree, water is no longer being pulled upward through the root system, and because a dying or dead stump cannot effectively defend itself against the fungus.

Chemical treatments are so far incapable of “curing” the disease (O'Brien et al. 2011). Research on use of fungicides to control oak wilt is continuing, however. Once a tree has died, the fungus may persist in the roots for a year or two, but it is a poor competitor with soil microorganisms and eventually dies out.

Other pests of oak

While gypsy moth (*Lymantria dispar*) (Lepidoptera: Lymantriidae) caterpillars may eat just about anything green during outbreaks, they prefer oak and aspen (*Populus* spp.) (Lovett et al. 2006). Healthy oak trees usually can survive several years of defoliation, but stressed trees are more susceptible to other diseases and pests. The gypsy moth (Figure 13) has now invaded all but the western part of the Great Lakes region. Management efforts have had good success. Three products are sprayed over heavy infestions to control the moth (State of Wisconsin 2013):

- Foray 48B is a bacterial insecticide containing *Bacillus thuringiensis* var. *kurstaki* or Btk. Btk is a naturally occurring soil bacterium that is poisonous to gypsy moth caterpillars when consumed. Btk breaks down in sunlight within a few days.

- Gypchek consists of dead, crushed-up gypsy moth caterpillars infected with the nucleopoly-hedrosis virus. The virus only kills gypsy moth caterpillars (*Lymantria* spp.).

- Pheromone flakes are a mating disruption product. These sticky flakes are flat and green, and about the size of a grain of rice. They are applied at a rate of one of two flakes per square foot of tree canopy. They confuse the males, making it difficult for them to find females.

The establishment of the introduced, gypsy moth-specific fungal pathogen *Entomophaga maimaiga* (Zygomycota: Entomophthorales) may be the “straw” that relegates the gypsy moth to the staus of a fairly minor forest pest in North America (Lovett et al. 2006, Anonymous 2009). This fungus is now established nearly throughout the range of the gypsy moth, except at the periphery (Anonymous 2009). It is one of the one of the most successful fungal biocontrol agents, effectively controlling gypsy moth outbreaks most years.

Figure 13. Gypsy moth caterpillars. Left – healthy caterpillars (Gogebic County, Michigan). Right – caterpillars killed by the gypsy moth-specific fungus Entomophaga maimaiga (Iron County, Wisconsin).

The Asiatic oak weevil *Cyrtepistomus castaneus* (Roelofs) (Coleoptera: Curculionidae) attacks northern red oak seedlings. The larvae feed on the fine roots while the adults feed on the foliage, potentially seriously impacting seedling growth (Sander 1990).

European Oak Borer (*Agrilus sulcicollis*) (Coleoptera: Buprestidae) has been introduced into Canada from Europe (USDA-APHIS 2011, p. 34). It is also established in Lower Michigan. While there is concern about this insect on both sides of the border, the insect is pretty much restricted to dead and dying oaks in its native range, and no declines due to this insect have been noted in North America so far. See http://www.fs.fed.us/foresthealth/technology/invasives_agrilussulcicollis_riskmaps.shtml for more information.

The two-lined chestnut borer (*Agrilus bilineatus*) (Coleoptera: Buprestidae) also infests oak trees. This native insect primarily targets stressed trees, particularly after drought, according to WDNR forest health specialist Mark Guthmiller (see Glaze 2013). Like the emerald ash borer, the two-lined chestnut borer burrows under the bark, leaving zigzag tunnels. It also leaves D-shaped exit holes upon emergence. Healthy oak trees are generally not affected by the insect, though.

Phytophthora ramorum, the pathogenic organism responsible for sudden oak death, has caused severe decline in some oak and tanoak species in the western United States, and has recently spread to the eastern United States through widespread shipments of contaminated nursery stock (Rizzo and Garbelotto 2003. Though *P. ramorum* is not yet widespread in the forests of eastern North America, some common eastern oaks (including northern red oak) are known to be susceptible (Brasier et al. 2002). This disease has the potential to cause major impacts to eastern forest ecosystems, because oak species are dominant in much of the eastern forest from southern New England southward, where they are a crucial source of mast for wildlife and have an important influence on the consumer food web in the forest (Ostfeld et al. 1996, cited in Lovett et al. 2006).

Numerous other (mostly minor) pests also use oaks as a food source (Johnson 1990, Sander 1990). Some of these, such as bacterial leaf scorch, can cause the leaves to superficially resemble early-stage oak wilt (O'Brien et al. 2011). Oak anthracnose is a fungal leaf disease that may be locally severe during cool, wet springs during leaf expansion. Anthracnose diseases usually affect the lower portions of the crown. The lower leaves often fall in early summer, while those in the upper crown may remain attached. The leaves usually develop brown spots or patches that expand outward to the leaf margins. Although the leaves may be curled and distorted, they usually do not wilt.

ASH AND THE EMERALD ASH BORER

Taxonomy, Distribution and Significance of Ash

Environmental role

There are 16 species of ash (*Fraxinus* spp.) in North America north of Mexico (USDA Plants Database 2013). They all belong to the olive plant family, or Oleaceae. Three of these (white ash, green ash, and black ash) are widespread and often common within the ceded territory (Figure 14, 15, and 16, respectively). Black ash (*Fraxinus nigra; baapaagimaak*) is a common tree of swamps, floodplains and wet woods throughout the northwoods. It is often the dominant tree in rich imbedded wetlands. Green ash (*Fraxinus pennsylvanica; aagimaak*) is common across most of the project area, and is the most widely distributed ash species in North America. It inhabits swamps, shores, and occasionally peatlands, as well as upland deciduous forests and old fields. It is often a dominant on floodplains. White ash (*Fraxinus americana; aagimaak*) usually occurs in well-drained upland deciduous forest, but sometimes inhabits floodplains and wetland edges as well (Voss and Reznicek 2012). A fourth species, blue ash (*Fraxinus quadrangulata*), occurs in southern Lower Michigan including Kent County, on the southern border of the 1836 ceded territory (Michigan Flora online). Pumpkin ash (*Fraxinus profunda*) is known from southern Lower Michigan, just south of the ceded territory.

Ash are an important part of many ceded territory ecosystems. They provide browse, thermal cover, and protection for a variety of wildlife, including white-tailed deer and moose. Beaver, rabbits, and porcupines may feed on the bark of young trees (Heyd 2005). A variety of ducks, song birds, game birds, small mammals, and insects feed on ash seeds (Cappaert et al. 2005). The loss of ash trees will negatively impact all of these animals, which in turn will impact hunting as well.

The loss of ash trees is also likely to favor the invasion of non-native plants such as garlic mustard and common buckthorn (Hausman et al. 2010). Aggressive invasives with wetland affinities such as reed canarygrass (*Phalaris arundinacea*) and glossy buckthorn (*Frangula alnus*) sporadically infest openings in black ash swamps, and are likely to become much more abundant (pers. obs.).

A comprehensive literature survey found that 282 native and exotic arthropods are associated with North American ash species (Gandhi and Herms 2010a). Of the native arthropods, 43 are known to require ash for feeding or breeding purposes. These high-risk species include 11 members of the Order Diptera (flies), 9 Coleoptera (beetles), 9 Lepidoptera (butterflies and moths), and 8 Hemiptera (true bugs). The loss of these creatures will likely impact associated species, including specialized bacteria and fungi, and various parasites, predators and mutualists (Gandhi and Herms 2010a).
The loss of ash trees in is so dramatic that it is even harming human health. Donovan et al. (2013) studied the mortality rate from illnesses related to the lower respiratory system and the cardiovascular system in 15 U.S. states where the EAB has become established and killed large numbers of trees. The data they analyzed were by county, and collected from 1990 through 2007. They found that the EAB was associated with an additional 6113 deaths related to illness of the lower respiratory system, and 15,080 cardiovascular-related deaths. This amounts to a 10 percent increase in mortality for these diseases. While the authors were not able to pinpoint specific mechanisms causing this increased mortality, they pointed out that trees improve air quality, reduce stress, tend to increase physical activity, moderate temperatures, and buffer stressful life events, all off which have been shown to increase human health and well-being.

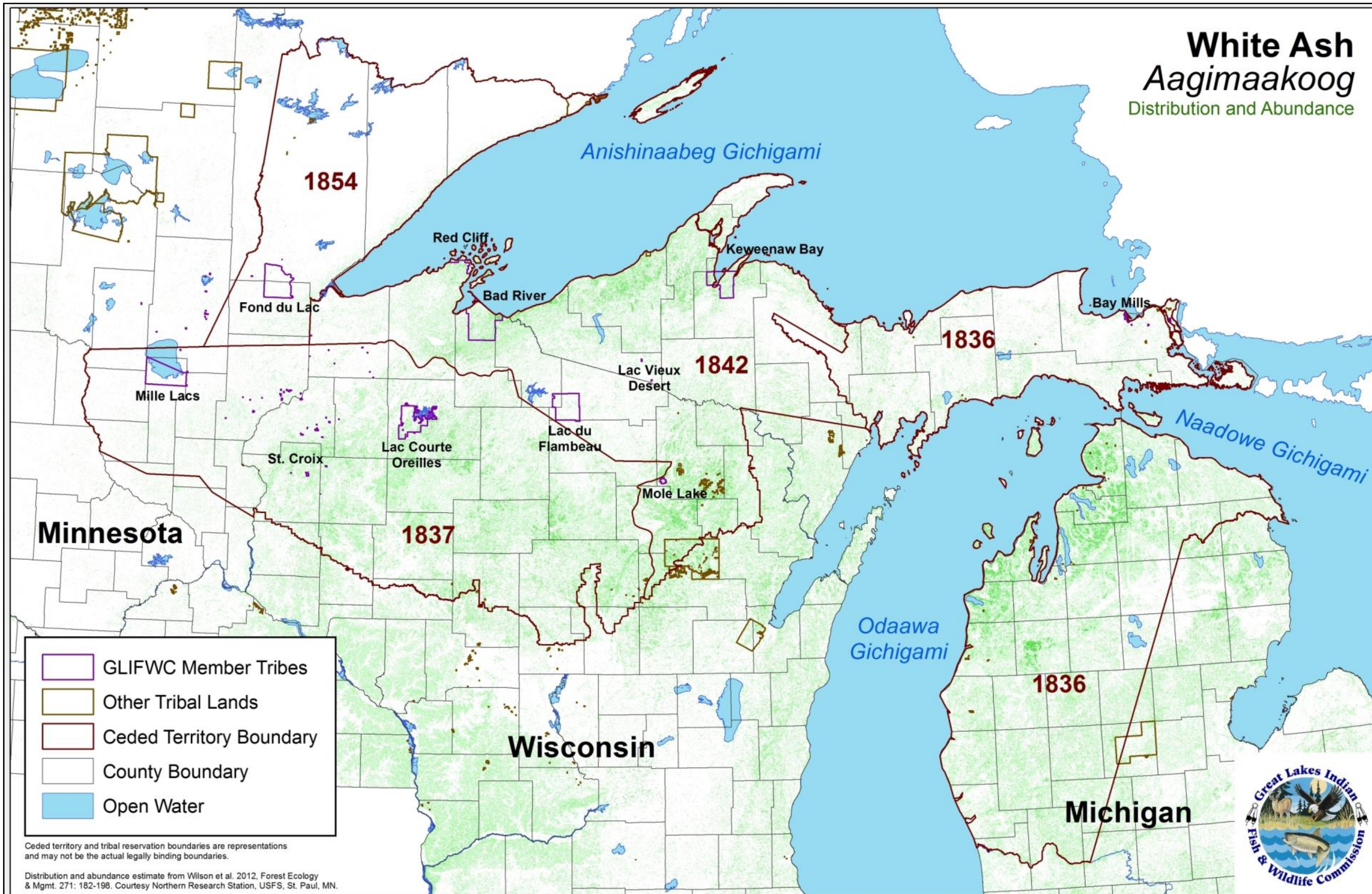

Figure 14. Estimated abundance and distribution of white ash in the ceded territory. The green shading indicates white ash abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

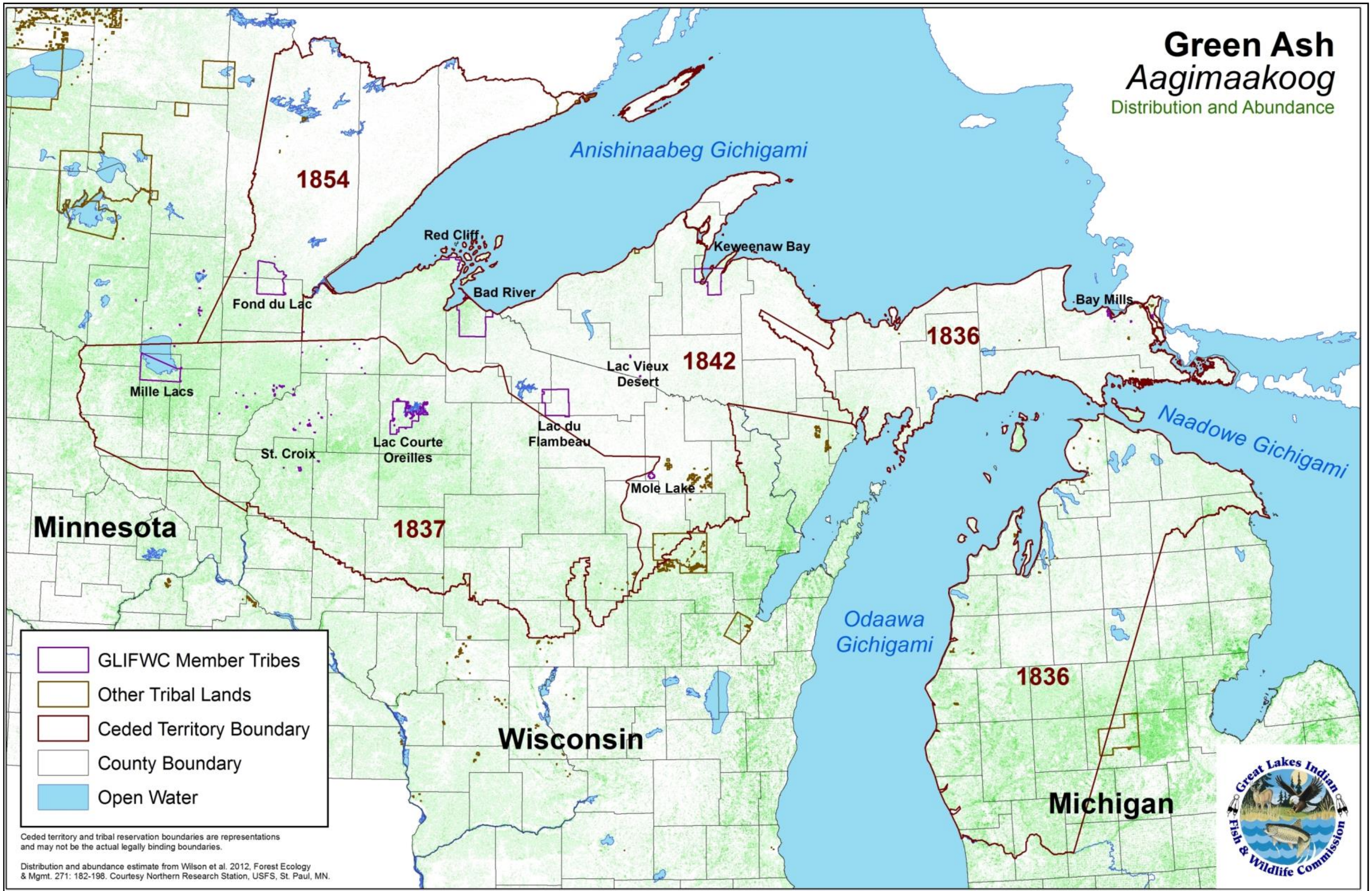

Figure 15. Estimated abundance and distribution of green ash in the ceded territory. The green shading indicates green ash abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

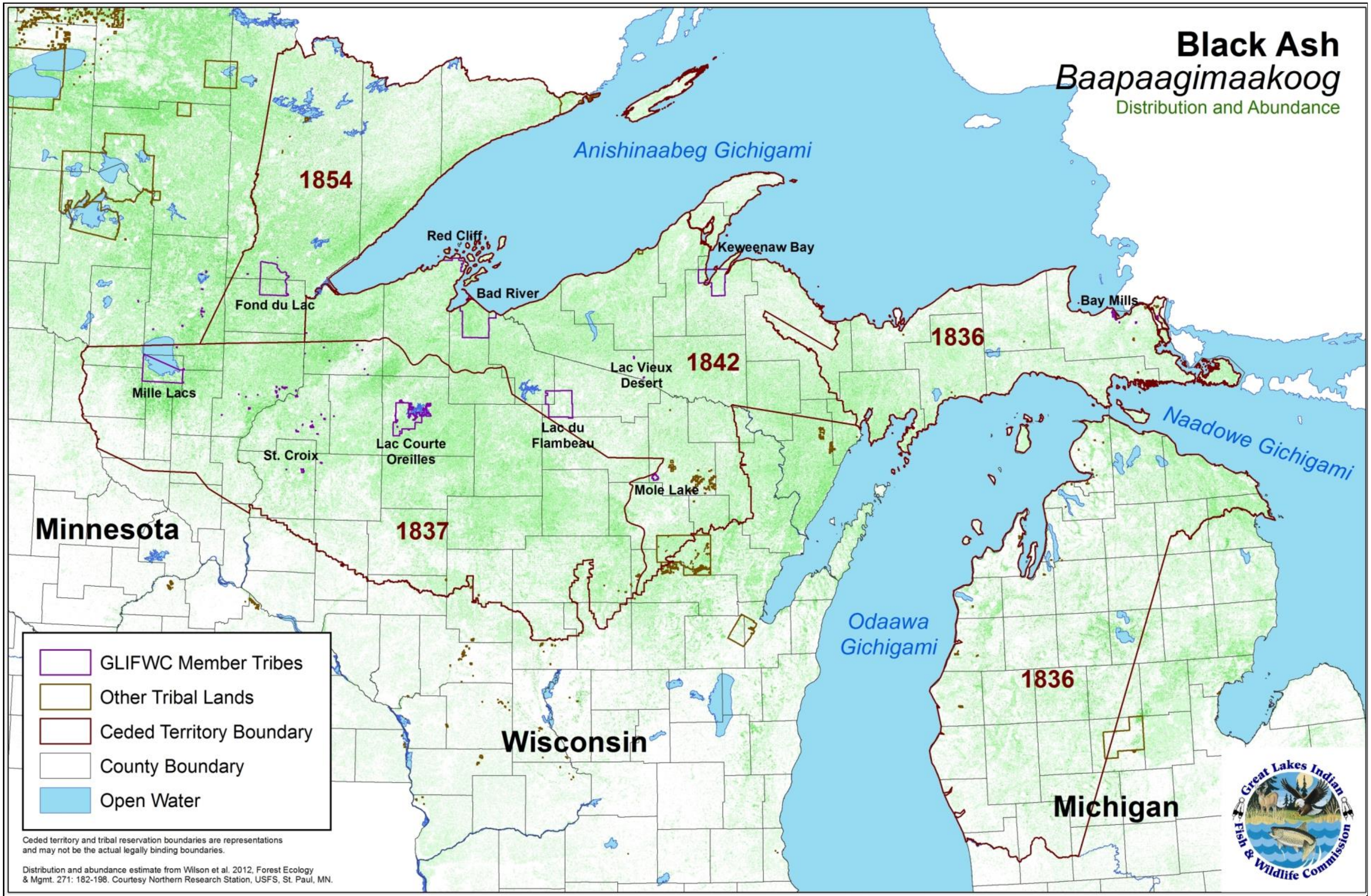

Figure 16. Estimated abundance and distribution of black ash in the ceded territory. The green shading indicates black ash abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

Economic value

Ash wood is used for a variety of applications that require a strong, hard wood with less rigidity than maple. White ash is used commercially for tool handles, baseball bats, furniture, antique vehicle parts, containers, railroad cars and ties, canoe paddles, snowshoes, boats, doors, and cabinets. Green ash is a valued for solid wood products, pulp and paper that require hardwood fibers, crating, boxing, handle stock, and rough lumber. While not as strong as other ash species, black ash is regularly used for interior furnishings, furniture, and cabinets. Damage left by the EAB reduces the quality and market value of wood products, and dying and dead trees are useless for manufacturers (Rabaglia and Chaloux 2011).

White, green and black ash make up more than 7 percent of the hardwood forests in the northeastern US. In certain areas, such as western New York, northern Pennsylvania and the upper Midwest, ash may comprise up 20 to 40 percent of the forest (Rabaglia and Chaloux 2011). The stumpage value of eastern ash has been estimated to be $25 billion, and the total economic value of ash trees in rural and urban forests of the US has been valued at more than $282 billion (Federal Register 2003). A more recent and detailed economic analysis (Aukema et al. 2011) found that the EAB costs the US $38 million in federal expenditures, $850 million in local government expenditures, $350 in household expenditures, $380 in residential property value losses, and $60 million in forestland timber losses, for a total cost of almost $1.7 billion per year. This estimate does not include real but hard-to-quantify impacts of tree mortality, defoliation and reduced growth on non-market ecosystem services such as water and air quality, nutrient cycling, climate regulation, disease control, recreation and cultural services, and damage to entire ecosystems.

Cultivars of green ash and white ash are hardy, fast-growing trees that have long been valued as landscape and street trees, particularly in the midwest. Before the EAB arrived, the nursery industry produced an estimated 2 million ash trees annually, valued at approximately $140 million (Rabaglia and Chaloux 2011). Potential costs associated with removals of urban ash trees in the United States have been estimated at $20-60 billion, not including the replacement costs of these trees (Cappaert et al. 2005). During the early to middle phases of the epidemic dead ash trees and associated costs rise exponentially, following the exponential increase in EAB numbers in response to abundant ash resources. An estimated 40 million to 50 million ash trees had been killed in lower Michigan, and about 60 million have been killed in the eastern US as of 2011.

Persad et al. (2013) found that as early as two years after infestation, major canopy branches are measurably weakened and the trees are more susceptible to wind damage. This weakening of ash trees in Toledo, Ohio led to an increase in work-related incidents among tree workers.

The Emerald Ash Borer

History and distribution

The emerald ash borer (*Agrilus planipennis* Fairmaire) (Coleoptera: Buprestidae) (Figure 17) is native to eastern Asia, including the Russian Far East, China, Korea, Taiwan and Japan (Baranchikov et al. 2008) (Figure 18). In China the emerald ash borer (EAB) attacks stressed and dying Chinese ash (*Fraxinus chinensis* Roxburgh) and Manchurian ash (*Fraxinus mandschurica* Ruprecht) (Liu et al. 2003, Zhao et al. 2005, and Yurchenko et al. . 2007, cited in Baranchikov et al. 2008). The EAB is uncommon throughout most of its native range, and listed as an endangered species in parts of Japan. Initial surveys for EAB infestations in Japan and Korea failed to locate any of the insects. In recent years the EAB has spread westward through Russia, where it has killed many ash trees and now threatens ash in Europe (Baranchikov et al. 2008).

The EAB is extremely rare on Chinese ash and Manchurian ash in eastern Russia. In parts of China where North American ash species have been planted the EAB has become abundant though, and there is a report of an entire green ash plantation being killed by the EAB in eastern Russia (Baranchikov et al. 2008). The phloem chemistry of Manchurian ash differs qualitatively and quantitatively from green and white ash, with several organic compounds found in Manchurian ash but absent from the two North America ash species (Eyles et al. 2007). These compounds may explain Manchurian ash's resistance to the EAB.

The discovery and subsequent spread of the EAB in North America reads a little like a detective story. The following summary is primarily derived from the chronology by Cappaert et al. (2005).

The emerald ash borer almost certainly arrived in North America in solid wood packing material from China. It was first found in North America in Detroit, Michigan in June 2002, when green iridescent beetles (Figure 17) were reared from ash (*Fraxinus* spp.) logs by a concerned University of Michigan extension agent and a landscaper. They sent the beetles to the Michigan State University (MSU) in Lansing for identification. Unable to identify them, entomologists representing MSU, the Michigan Department of Natural Resources (MIDNR), and the USDA, Animal and Plant Health Inspection Service (APHIS) visited the area the following week. They quickly found extensive areas of dead and dying ash trees, even in areas where other tree species appeared perfectly healthy. Specimens of the metallic green beetle were sent to specialists around the world, with a Slovakian expert finally identifying it as the little-known Asian species *Agrilus planipennis*. This was the first time this beetle had been collected outside its native range. Ontario provincial officials were notified, and in August 2002 an infestation was found in neighboring Windsor, Ontario. By the fall of that year, an estimated 5-7 million ash trees in a 6-county area surrounding Detroit were dying or dead.

Tree ring analysis and other research subsequently showed that the EAB had been established in the Detroit area since at least the early 1990s. The population probably multiplied slowly at first, then increased rapidly in the late 1990s and early 2000s. Massive ash die-off followed. This pattern of establishment and slow expansion (the lag phase), followed by an exponential increase in population (log phase), has often been observed in populations of nonindigenous invasive species (Cappaert et al. 2005).

Figure 17. EAB adults are only about 1/2 inch long, easily fitting on a penny. (Howard Russell, MSU, Bugwood.org)

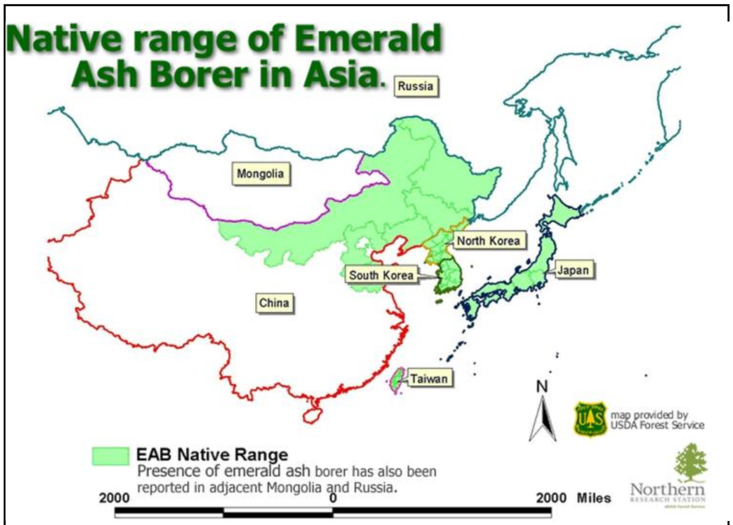

Figure 18. Native range of the emerald ash borer. (US Forest Service, Northern Research Station.)

It soon became evident that the EAB was already established outside Detroit and Windsor as well. Partly in response to the die-off of American elm in the 1950s and 1960s, millions of ash trees had been planted in cities and towns. The most popular ash for planting was a green ash strain called 'Marshall Seedless', a male clone introduced to the horticultural trade in the 1940s (MacFarlane and Meyer 2003). Green ash in particular is tolerant of salt, drought, compacted soils and a wide range of soil pH, conditions typical of urban soils (McComb 1949, cited in MacFarlane and Meyer 2003).

Before the early 2000s ash was one of the most commonly planted trees in new residential and industrial developments in southeastern Michigan. Nurseries in southeastern Michigan had not only been selling ash locally, but had been shipping young ash trees to distant areas of Michigan and to Ohio. The beetles had also hitched rides on ash logs and firewood. More than a dozen outlier populations were soon found in other areas of southern Michigan and in northern Ohio. Nursery records and dendrochronological (tree ring) studies indicated that most of these populations were established before 2002.The Michigan Department of Agriculture (MiDA) imposed a state quarantine on July 16, 2002, to regulate movement of ash nursery trees, logs, and related products from infested counties. These regulations were incorporated into a federal quarantine published by the USDA-APHIS on October 14, 2003 (Federal Register 2003). By March 2005, more than 20 infestations were known inside the quarantine area of southeastern and south central Lower Michigan, and more than 25 localized "outlier" populations had been discovered in western and northern Michigan, northern Indiana, and Ohio (Cappaert et al. 2005). At that point the agencies and researchers still held out hope that the EAB could be contained and perhaps even eliminated. A strategy to construct an 0.25 mile wide "firebreak" around the core infestation where all ash trees were eradicated, implement a quarantine of infested areas, and aggressively work to eliminate outlier infestations that had been found in Michigan, Ohio and Maryland (Herms et al. 2004) fell short, largely due to movement of firewood, logs and nursery trees from infested areas in spite of quarantines. The EAB continued to spread on its own and with human help, and is now considered the most destructive forest pest ever seen in North America (emeraldashborer.info 2013).

As of this writing, the EAB has been found in 21 US states including Connecticut, Illinois, Indiana, Iowa, eastern Kansas, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New York, Ohio, Pennsylvania, Tennessee, Virginia, Wisconsin, West Virginia, North Carolina, and most recently Georgia (Figure 19). It is also established in southeastern Ontario (including Sault Ste. Marie) and southeastern Quebec.

QUARANTINES

A quarantine of an area means that it is illegal to move certain specified materials outside that area. Quarantined materials can include items such as nursery trees, boughs, and untreated logs and firewood of specified trees, which can harbor forest pests.

State quarantines are primarily focused on movement of materials within that state. Federal quarantines are primarily focused on movement of materials across state lines.

Federal quarantines are currently in effect for:

- Gypsy moth,
- Emerald ash borer, and
- Asian longhorned beetle.

Wisconsin state quarantines are in effect for:

- Hemlock woolly adelgid
- European pine shoot beetle
- Thousand canker disease, a serious disease of walnut and butternut trees.

Michigan state quarantines are in effect for:

- Hemlock woolly adelgid
- Thousand canker disease.
- A state quarantine is currently being drafted for balsam wooly adelgid.

The City of Superior infestation

On August 7, 2013, the City of Superior tree crew was removing a dead ash from a boulevard at 608 Grand Avenue in Superior, when they noticed D-shaped exit holes in the bark, and tunneling under the bark (City of Superior 2013). The next day the City Forester and City Arborist visited the site and collected what appeared to be an adult EAB. The identity was tentatively confirmed by officials at the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) and WDNR, and confirmed by an expert at the USDA. The find was announced on August 15th, 2013. The closest known infestation was in Minneapolis, some 130 miles to the south-southwest.

Superior City Forester Mary Morgan was spoken to by phone on August 19th. She said they didn't know how far the beetle had spread or whether this site was the origin of infestation or just an outlier. She pointed out that because this tree had been killed by the EAB, it must have harbored the beetle for 3-4 years. Thus even if this was the epicenter of the infestation, the EAB could now be established several miles away. She said that the city would be taking down ash trees in the neighborhood but that they did not have the resources to take down all the trees in the city at once. She said that they were consulting with experts at the WDNR and DATCP, and would be formulating a plan of action.

The north end of Superior consists of older residential neighborhoods, with mostly 2-story houses surrounded by small yards (pers. obs., August 15th, 2013). Small to large green ash trees are common along the streets and in the nearby park. This neighborhood would appear to be an unlikely destination for ash-infested firewood, and is probably not the original introduction site.

Wisconsin DNR spokesperson Bryan Kuhn was spoken to by phone on August 19th. Bryan reiterated that the state and the City of Superior were in the early stages of formulating a plan, which will depend in part on finding out how widespread the infestation is. He raised the possibility that the EAB had

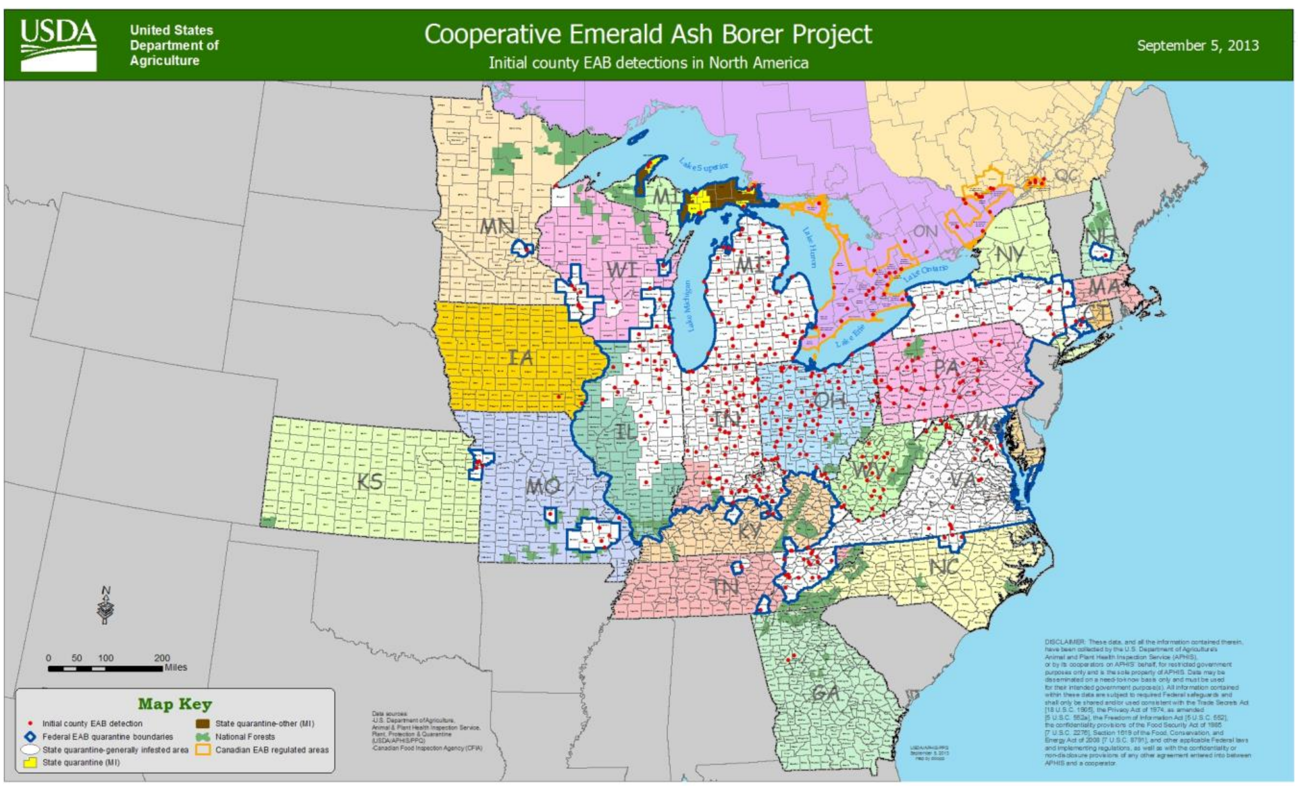

Figure 19. North American distribution of emerald ash borer by county, as of September 5, 2013. Downloaded from http://www.emeraldashborer.info/files/multistate_eabpos.pdf .

reached the city in solid wood packing material (SWPM), via the Port of Superior. When asked whether federal regulations requiring that SWPM be heat-treated or fumigated before entering US ports were adequate, he basically said they were not. He said that some east Asian pallet manufacturers were using fake paperwork and pallet labeling to evade these requirements.

On August 28th the city tree crew was observed taking down dying ash trees (Figures 20 and 21). The crew was working in a neighborhood around 17th Street and John Avenue, about 1 mile south-southwest of the original Grand Avenue site. The 4-person crew planned on taking down 23 trees that day. The crew was quite helpful, allowing the bark to be stripped from one infested tree to see the larva and the damage they cause. Photos of an EAB adult in a treetop (Figure 22) were taken from the bucket of their utility truck. At this point the crew and city officials still did not know how far the EAB had spread, but suspected it was probably present across most of town, according to city arborist John Krivinchuk (pers. comm.). The trees are being chipped and stored in a large parking lot at 7th Street and John Avenue until November, when they can be legally hauled away to be burned as "biofuel", including at the Ashland power plant (Figure 23).

Figure 20. Armed with a lift truck and electric chainsaw, the tree crew makes short work of this ash tree. Superior, Wisconsin.

Figure 21. Ash trees are chipped to kill any larvae in the bark and outer wood. Superior, Wisconsin.

Figure 22. The culprit. But then they didn't get here by themselves... Superior, Wisconsin.

Figure 23. Former street trees reduced to chips. About 10% of the chips are larger than 1 inch thick, so they will have to be stored here until November 1st, when they can be hauled to a biomass plant.

Life cycle

The life cycle of the EAB is similar to native *Agrilus* species such as the bronze birch borer (Cappaert et al. 2005). The adults begin to emerge from the host trees in late spring to early summer, after about 450 degree days (degrees F, Starting date January 1, base temperature of 50°F or 10°C) have been attained (Gould et al. 2012). Peak emergence occurs around 1000 degree days, and continues until roughly 1500 degree days (Gould et al. 2012, JoAnn Cruse, USDA-APHIS, pers. comm.). The adults typically live for 3-6 weeks, feeding on ash foliage (Bauer et al. 2004). Adult females must feed for at least two weeks before laying eggs in crevasses and cracks in the bark (Bauer et al. 2004). The eggs are about 0.04 in (1 mm) in diameter and hatch after 1-2 weeks. The larvae go through four growth stages called instars, becoming larger each time (Figure 24). The 1st instar larvae tunnel through the outer bark into the food-conducting tissue (phloem). The larvae then tunnel beneath the bark of ash trees, consuming the phloem (Figure 25).

After the 4th instar stage, the larvae excavates a chamber in the xylem (wood) just below the cambium, and overwinters as a prepupae. If the larva doesn't reach the 4th instar stage by late fall, it will overwinter as a larvae and then pupate in the spring. While the EAB is thought to primarily undergo a 1-year life cycle (Cappaert et al. 2005), Siegert et al. (2010) found that a 2-year (semivoltine) life cycle was predominant at two nascent Lower Michigan sites.

Impact on ash

Trees in the early stages of infestation (typically the first year or two) often show few or no external symptoms. As the EAB population builds, though, the trees begin to rapidly decline. Symptoms of EAB infestation includes progressive canopy thinning and dieback, and epicormic shoots on large branches or the trunk (Figure 26) (Cappaert et al. 2005). As the infestation progresses the beetles work their way down the tree, and distinctive D-shaped exit holes left by emerging EAB beetles appear in the trunk (Figure 27 and 28), along with larger holes and cracks in the outer bark above larval galleries. Woodpeckers preying on late instar larvae may leave areas of stripped outer bark (Figure 29). The serpentine feeding galleries (tunnels) created by the larvae eventually cuts off transport of carbohydrates through the phloem, effectively girdling the tree (Knight et al. 2012).Infested trees generally succumb to the EAB after 3 to 4 years (Figure 30).

Figure 24. Late-instar EAB larvae. These larvae are what kill ash trees. Superior, Wisconsin.

Figure 25. The larva burrow under the bark, leaving tunnels or galleries that eventually kill the tree. (Michigan Dept. of Agriculture, Bugwood.org)

When the EAB arrived ash trees were already experiencing decline in many parts of the eastern US. Trees in urban areas must contend with air pollution, compacted soil, road and sidewalk salt, and other stresses. In recent decades a disease of unknown origin called ash yellows has also become more prominent (Sinclair and Griffiths 1994).

Ash yellows is caused by a mycoplasma-like organism. In the early stages the symptoms of ash yellows (slow growth, yellowing leaves, branch dieback, and dwarf shoots on the trunk) may be similar to those associated with EAB infestation.

Several native insects also colonize declining or dying ash including the redheaded ash borer, *Neoclytus acuminatus* (F.) (Coleoptera: Cerambycidae) and clearwing borers (Lepidoptera: Sessidae), such as banded ash clearwing borer, *Podosesia aureocincta* Purrington & Neilsen, the peachtree borer, *Synanthedon exitiosa* (Say), and the ash borer, *Podosesia syringae* (Harris) (Cappaert et al. 2005).

All five eastern North American ash species so far encountered by the emerald ash borer are susceptible to EAB infestation, including green, white, black, pumpkin, and blue ash (Cappaert et al. 2005, Poland and McCullough 2006). Of these, only blue ash has shown significant resistance to EAB infestation. In a study of two woodlots in southern lower Michigan, 60-70% of blue ash trees were alive and most of these appeared relatively healthy, even after at least 10 years of infestation (Tanis and McCullough 2012). At the epicenter of EAB infestation in southern Lower Michigan, ash species other than blue ash have experienced essentially 100% mortality (Tanis and McCullough 2012).

Figure 26. Thinning canopy is one of the first signs of EAB infestation. Superior, Wisconsin.

Typically a newly-infested stand of mature trees will go

Figure 27. See if you can find the D-shaped exit hole! The flat side of the "D" can be in any direction. Superior, Wisconsin.

Figure 28. Adult EAB next to D-shaped exit hole, left when it burrowed out of the bark. (Jared Spokowsky, NY State Dept. of Agriculture, Bugwood.org)

from healthy to nearly 100% mortality within 6 years (Knight et al. 2013). Trees that are shaded by other trees or exhibiting dieback tend to be more susceptible to early infestation (Knight et al. 2013).

Vectors for spread

Based on experiments with tethered individuals in flight mills, fertilized adult female EABs are capable of flying more than 12 miles (20 km) on their own (Taylor et al. 2010). Most adults fly less than 328 ft (100 m) when ash trees are nearby, though. At the same time, though it took only 2 years for the EAB to breach a 6.2 mile (10 km) ash-free corridor or "firebreak" established east of the Windsor, Ontario population in 2004 (Taylor et al. 2010).

Figure 29. Woodpecker damage to infested ash tree. The bushy shoots at the base of this tree are also a symptom of infestation. (Steven Katovich, USDA Forest Service, Bugwood.org)

The EAB is readily carried on ash firewood, logs and nursery trees, resulting in widely scattered outlier populations. When infested trees were cut to an average of 10 inches (25 cm) and the logs stored under a hardwood forest canopy, live EAB pupae were found in the wood the second winter, indicating that adults were able to emerge the second season after the wood was cut. (Petrice and Haack 2007). Thus sites such as lumberyards, paper mills and firewood producers are considered high-risk sites for the spread of the EAB (and other pests). Destinations for these types of materials (campgrounds, cabins and camps, powwow grounds, and firewood piles) are also high risk sites where new infestations may start. Nursery ash trees were a major vector for long-distance dispersal of the EAB through the mid-2000s (Cappaert et al. 2005), and the EAB's tendency to become established in cities and towns would seem to indicate that they are still spreading on nursery trees today (Jonathan Gilbert, pers. comm.). Because ash trees were often used as street trees, recent housing and industrial developments are also considered high-risk areas.

Figure 30. The end result of EAB infestation. This scene, on the Michigan State University campus in Lansing, is typical across much of southern Lower Michigan where ash trees were abundant (Leah Bauer, USDA Forest Service Northern Research Station, Bugwood.org)

Potential pathways

Firewood is a high-risk pathway for the movement of forest pests (Borchert et al. 2011). Large commercial firewood dealers in particular may ship firewood long distances. Incredibly, firewood is also imported from other countries. Between 2005 and 2009, the United States received imports of firewood ("fuelwood") with values exceeding $39 million. About 64.4% came from Canada, 33.9% from Central and South America, Europe, or Asia; and a little less than 2% from Mexico. Firewood is generally sold as "green," "seasoned," or "kiln dried", with green wood posing high risk of carrying pest. Seasoned or air-dried wood can still carry pests including EAB larvae, which can overwinter as a prepupa or pupa and emerge in their second spring. Kiln-dried wood is generally dried at over 212ºF (100ºC) for a day or more, and poses little to no risk.

Federal regulations require that imported firewood undergo heat treatments of 71ºC for 75 minutes prior to entrance into the United States, although regulations vary for wood from Canada and Mexico (Borchert et al. 2011). If proof of treatment cannot be provided, the entire shipment is rejected; however, firewood is not inspected upon entry into the United States as long as the importing country provides proof of treatment.

All ash logs and all hardwood firewood from EAB quarantine areas must undergo treatment T314-a, specifically, heat treatment at 71.1ºC for 75 minutes (Borchert et al. 2011). The federal treatment manual also provides treatments permitted for export of oak logs to destroy oak wilt disease (T312-a and -b, methyl bromide) and pine logs to destroy pine shoot beetle [T313-b and D301.50-10(a). All logs (including firewood) from gypsy moth quarantine areas are required to undergo treatment T314-b, specifically heat treatment at 56ºC for 30 minutes.

Because the firewood industry consists of multiple small to large suppliers selling to many buyers, the distance firewood is shipped is difficult to calculate (Borchert et al. 2011). Nonetheless estimates for how far firewood used in residential heating in 2002 is shipped (see Borchert et al. 2011, Figure 4) are quite surprising. Based on data for firewood and other raw wood shipments, the average distance firewood was shipped to homeowners in Minnesota was about 100 miles, while Wisconsin came in at around 130 miles. The average for Michigan was about 240 miles. The greatest average distance from source to homeowner was for Indiana - about 950 miles. These estimates did not include the many homeowners who cut and transport their own wood.

Firewood sold by retailers such as grocery stores, gas stations and convenience stores, and big box stores is a potentially major vector for spread of forest pests. In a study of four western states (Colorado, New Mexico, Utah, and Wyoming), Jacobi et al. (2012) found that over an 18 month period, insects emerged from 47% of the firewood bundles purchased from these outlets. Fungi (especially blue stain fungi) were present in many of the bundles as well. The bundles (often shrink-wrapped) came from as far away as Pennsylvania and British Columbia.

Prepackaged retail firewood is a source that was not considered when this project was designed. The origin of prepackaged firewood in the ceded territory and the upper midwest is unknown. Given the fact that firewood is being shipped to these western states from far reaches of the continent, though, an attempt to determine the origin of bundled firewood sold in the project area would be highly recommended.

Detection

Detecting the EAB in the early stages of infestation has proven to be difficult. Ash trees usually show few symptoms for the first year or two, until they are heavily infested. Early detection consisted of looking for signs of infestation as well as the adult beetles (Cappaert et al. 2005). The beetles also have a strong tendency to attack the upper canopy first, working their way down only after the canopy begins to die back. These shortcomings led researchers to use girdled trees to detect the EAB. Injured trees are more attractive to the EAB than uninjured, healthy trees. In 2004, the Michigan Department of Agriculture girdled 10,000 ash trees across the state of Michigan. That same fall and winter, the trees were cut down and the bark removed to search for EAB larvae and galleries.

Girdled "trap" trees proved to be relatively effective at detecting the EAB, even at low densities. They had the disadvantage of being time-consuming and expensive to deploy and retrieve, as well as potentially becoming a hazard if they were not retrieved. This led to the development of the familiar triangular purple panel traps widely used today.

Insect traps that use male-attracting pheromones are generally highly effective in drawing males to traps. Years of research has been unsuccessful in finding pheromones attractive to the EAB though (Domingue et al. 2013, Cappaert et al. 2005). The purple traps are typically bated with manuka oil (derived from the New Zealand manuka tree (*Leptospermum scoparium* J.R. Forst. & G. Forst.), which produces many of the same volatile compounds as North American ash do (Domingue et al. 2013). Another volatile, (Z)-3-hexenol, also increases the effectiveness of these traps. The USDA-APHIS program uses purple traps bated with both of these materials, and the 26 traps obtained from USDA-APHIS and deployed by GLIFWC and several member tribes this year used these lures also (Figure 31).

Figure 31. Purple panel trap being deployed on Keweenaw Bay Indian Community (KBIC) lands.

The most creative method for detecting the EAB so far may be a partnership with the solitary, ground-nesting wasp *Cerceris fumipennis* (Say). This non-stinging wasp is adept at capturing adult beetles of the family Buprestidae, which includes the EAB (Swink et al. 2013). It is native to most of the US east of the Rockies, as well as southern Ontario (WaspWatcher website). It is most commonly found in sandy areas, where it excavates a burrow in packed sand near wooded areas. Nests are monitored by placing a 1 x 3 inch (2.5 x 7.5 cm) thin plastic strip with a hole at each end, made by a standard office paper punch. The plastic strip is placed on the ground. One hole goes over the wasp's burrow, and the other is used to fasten the strip to the ground with a golf tee. When the wasp returns to its burrow, it is unable to enter with its paralyzed prey, which is then released. The first EAB found in Connecticut was discovered by monitoring a *Cerceris* burrow (Swink et al. 2013). This citizen scientist program has been attempted in a number of eastern states, as well as Wisconsin, Ohio and Michigan (WaspWatcher website).

Careless et al. (2009) provide an excellent short manual on use of *Cerceris fumipennis* for EAB monitoring. They write, “Preliminary studies have shown that the wasp’s EAB detection skills far surpass any comparable human technology.” They point out, though, that colonies of *Cerceris* tend to be widespread but local in eastern North America, and are only capable of foraging over a limited area. There probably aren't enough well-placed natural colonies to use *Cerceris* as the primary surveillance tool within Canada and the US. Researchers are looking into the development of mobile transplant wasp colonies, which could vastly improve the value of *C. fumipennis* as an EAB surveillance tool.

Wisconsin DATCP Forest Entomogist Renee Pinski and others have done some work on *Cerceris* monitoring for the WDNR (pers. comm. by email, 12 September 2013). They spent some time locating and monitoring colonies in southern Wisconsin, but found that the colonies were few and far between and rarely located near ash trees or other high risk areas that were of interest. They also found that colonies needed to be rather large (at least 35 nests) to work as a successful monitoring tool. They tried deploying mobile colonies in high risk areas, but had little success with the wasps returning to their mobile home.

Many sources (Gould et al. 2012, for example) state that woodpecker feeding is one of the best indicators of early EAB infestation. As they feed woodpeckers pull off flakes of the dark, thin outer layer of bark to get to the larvae just below (Figure 29). However, one member of the City of Superior tree crew mentioned that they really haven't seen woodpecker damage with the infestation there.

Control

Stand thinning: Stand thinning has generally proven ineffective at reducing numbers of EAB. The rate of ash mortality is faster in lower density stands, so reducing ash density is unlikely to protect the remaining ash trees (Knight et al. 2013). Thinning stands may also simply encourage the beetles to fly farther in search of hosts, thus increasing the rate of spread (McCullough and Mercader 2012).

***Systemic pesticides*:** Until recently the most commonly used systemic pesticide against the EAB was imidacloprid (Herms et al. 2009). Imidacloprid is sold under several brand names. It can be applied as a soil drench or injected into the trunk of the tree. The best time to apply it to the soil is mid-May in southern Michigan. Basal trunk sprays with dinotefuran provide levels of control similar to imidacloprid (McCullough et al. 2011).

Drawbacks of these pesticides are that they are relatively expensive and must be reapplied every year (Herms et al. 2009, McCullough et al. 2011). Also, both imidacloprid and dinotefuran belong to a class of pesticides called neonicotoids, which are extremely toxic to all insects. There is growing concern here and overseas that neonicotoids may be a major factor in honeybee colony collapse.

Recently, a new product called TREE-äge® (emamectin benzoate) has proven to be very effective in preventing damage by the EAB, even under intense pest pressure (McCullough et al. 2011). McCullough et al. found that trees given a single injection of emamectin benzoate had less than 1% of the larvae as untreated control trees, even 2 years after the treatment. Furthermore, all of the adults fed leaves from emimectin-treated trees quickly died. In addition to being much more effective than imidacloprid, emamectin benzoate is less expensive and is relatively safe for humans, birds and other animals (Herms et al. 2009, McCullough et al. 2011).

Purdue University has constructed an online cost calculator, to calculate the cost of EAB infestation to cities and towns. The model behind the calculator assumes it takes 8 years for EAB to kill all the ash trees in your city after it has been detected in your county. To use the calculator you need three pieces of information: 1) an inventory of the number and size of ash trees, 2) an estimate of costs for removing and treating trees based on the size of each tree, and 3) an estimate of costs for replacing each ash tree that is removed. Forest managers have 3 options available for managing emerald ash borer: 1) treat ash trees with insecticides, 2) remove ash trees, and 3) replace ash trees with resistant trees. See http://extension.entm.purdue.edu/treecomputer/ for more information.

Biocontrol: Three tiny, stingless parasitic wasps from the EAB's native range in northern China have been introduced to attempt to control the EAB (Figure 32). These include *Oobius agrili* Zhang and Huang (Hymenoptera: Encyrtidae), whose larvae parasite EAB eggs, and *Tetrastichus planipennisi* Yang (Hymenoptera: Eulophidae) and *Spathius agrili* Yang (Hymenoptera: Braconidae), which parasitize the EAB larvae. After testing the USDA-APHIS approved the release of all three of these insects in 2007. In 2009 the USDA APHIS PPQ finished construction of the Biological Control Production Facility in Brighton, MI to produce EAB parasitoids for field release. By 2011, 5000 *Oobius*, 100,000 *Tetrastichus*, and 50,000 *Spathius* were being raised and released in EAB-infested areas of the eastern US.

Female *Oobius* (Figure 33) lay one egg inside an EAB egg (Gould et al. 2013). The larva then grows inside the egg, destroying it. The females are parthenogenic, meaning that they can lay viable eggs without males (MnDA 2011). The mature larva overwinters inside the old EAB egg and emerges the next spring and summer. In China, *Oobius* females lay an average of 80 eggs which parasitize up to 60% of EAB eggs laid during the summer in some areas (Gould et al. 2013).

Tetrastichus larvae are endoparasites, meaning they live inside the EAB larva (Gould et al. 2013). *Tetrastichus* can also detect EAB larva beneath the bark, attacking the 3rd and 4rd instar larva (MSU 2011). These 4th instars are the final EAB larval stage, which pupate to become adults. One EAB larva can produce more than 130 *Tetrastichus* adults (Gould et al. 2013). *Tetrastichus* completes up to 4 generations each year (MNDA 2011). The late-season larva survive the winter as larvae inside their host or host gallery under the bark of ash trees (Gould et al. 2013). *Tetrastichus* attacks and parasitizes up to 50% of EAB larvae in some areas of China.

Spathius larva are ectoparasites, meaning they consume the immobilized EAB larvae from outside, feeding on it at their leisure (Gould et al. 2013). *Spathius* attacks 4rd instar larvae (MSU 2011). The females are attracted to ash trees and detect EAB larva by the vibrations the feeding larva make under the bark (MNDA 2011). Female *Spathius* drill through the bark and lay an average of 8 eggs on the outside of its host (Gould et al. 2013). *Spathius* completes up to 4 generations per year and parasitizes 30% to 90% of EAB larvae in ash trees in China (MNDA 2011, Gould et al. 2013).

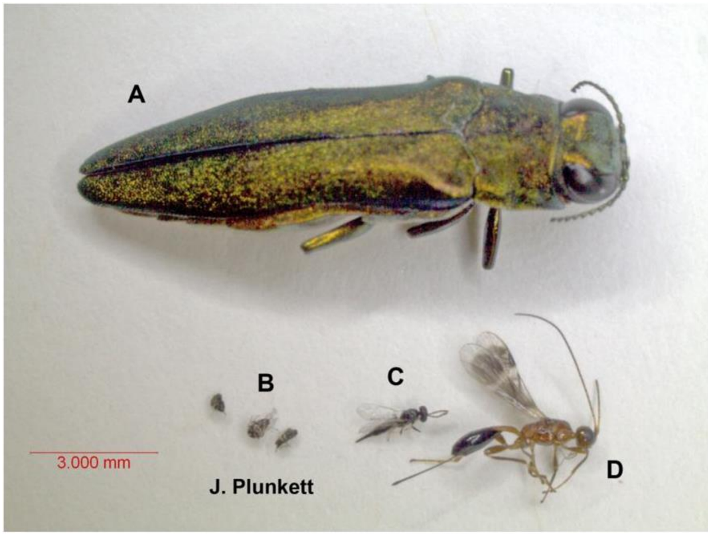

Figure 32. Adult EAB with the parasitoids that control it in China, including the egg parasitoid, Oobius agrili *(B), and two larval parasitoids,* Tetrastichus planipennisi *(C) and* Spathius agrili *(D). (Josh Plunkett, Minnesota Dept. of Agriculture)*

Tetrastichus was first released in six 25 acre (10 ha) release plots, at six woodland sites in three counties in south central lower Michigan in 2007 (Duan et al. 2013). These plots were each paired with a “control” plot 0.6 to 3.7 miles (1-6 km) away. From 2008 to 2012 the percent of living trees in the release plots that had at least one *Tetrastichus* colony within its bark went from 33% to 92%, while the percent of EAB larvae infested with *Tetrastichus* larvae went from 1.2% to 21.2% (Duan et al. 2013). In the control plots, brood prevalence went from 4% the year after release to 83% in 2012, with the rate EAB parasitism going from 0.2% the year after to 12.8% in 2012. These results showed that *Tetrastichus* populations were increasing and spreading relatively rapidly, indications that it is likely to significantly impact EAB populations.

Figure 33. Female Oobius *laying an egg inside an EAB egg. This tiny wasp is a little less than 1/32 inch (1 mm) long. (Debbie Miller, USDA Forest Service, Bugwood.org)*

Oobius and *Tetrastichus* have both been released in southern Wisconsin, including in 2013 (Williams 2013). Wisconsin has discontinued releases of *Spathius* because survival in the relatively cold upper midwest has been poor. The Minnesota Department of Agriculture (MnDA) has released all three wasps in the Minneapolis area (their northernmost known EAB population), and initiated an experiment in late 2011 to monitor their effectiveness and survival rate (MNDA 2013).

In addition to these Asian parasitoides, several native insects have been found to attack EAB larvae. The most promising so far is another small parasitoid wasp, *Atanycolus cappaerti* Marsh and Strazanac (Hymenoptera: Braconidae) (Cappaert and McCullough 2009). This insect was first described in 2009 (Marsh et al. 2009). It parasitizes several native *Agrilus* wood borers as well as the EAB (Cappaert and McCullough 2009), and is now becoming common in Lower Michigan (McCullough 2013).

The larvae of the native beetle *Chariessa pilosa* live in the tunnels of wood borers including *Agrilus* species. They are predators of *Agrilus* and other beetle larvae. For more information see http://bugguide.net/node/view/8206 .

Woodpeckers avidly feed on EAB larvae, consuming from 5% to 95% of the available larvae in Lower Michigan (Cappaert et al. 1995). Predation tends to be highest in natural, forested sites, and lower in golf courses and residential areas. Despite the high predation in some areas, though, the EAB has continued to spread.

The Slow Ash Mortality Project

The SLow Ash Mortality (SLAM) project was initiated in 2008 (McCullough and Mercader 2012). Its goal is to develop, implement and evaluate an integrated strategy to delay the onset of ash mortality in outlying infestations that are relatively isolated from major EAB infestations. SLAM sites are located in three areas of Upper Michigan, including one in the Houghton area. They encompass areas with mixed land use, ranging from towns and farmland to natural forests and wetlands.

The SLAM program integrates surveys of emerald ash borer distribution and density, surveys to assess ash abundance and distribution, treatments with the insecticide TREE-äge®, girdled trees, release of biological control agents, regulatory measures, and public outreach and education (Poland and McCullough 2010, McCullough and Mercader 2012). Girdled trees are the most effective means found so far of attracting EAB adults and are used both for detection of the EAB and as population “sinks”. Larvae infesting these trees are removed from the population the following fall and winter, when the trees are chipped or used as firewood under agreements with landowners (Poland and McCullough 2010). Ash and EAB densities are intensively monitored at the SLAM sites and at untreated control sites, to measure the effectiveness of the project. Because detection of low densities of the EAB is so difficult, and the spread of the EAB so hard to stop, the focus of SLAM is on the ash trees in and around the infested area (McCullough and Mercader 2012).

The SLAM project is an attempt to use all the knowledge, strategies and techniques developed since 2002 to understand and fight the EAB. The results from this ongoing project will help inform management of ash in years to come.

National and state control strategies

Rabaglia and Chaloux (2011) summarize the strategy of the “National response framework for emerald ash borer” as follows:

“Outreach and public education activities are conducted by a wide range of parties, including APHIS, FS, state departments of agriculture, state foresters, local governments, and private sector parties like

The Nature Conservancy. These efforts have focused on five core messages (detection, control, regulatory, personal responsibility, and compliance) that are simple and easily understood by target audiences, in order to raise public awareness and support for the effort to manage EAB in the United States and encouraging helpful behaviors such as not moving untreated firewood. The core messages address the critical mission of the program, and allow for agency autonomy and the evolution of the program. Outreach and public education efforts have been a critical component of the campaign against EAB and are regarded as a successful and worthwhile use of resources."

Management and preparedness is based on whether or not an area has established EAB populations. If an area has infestations, an attempt is made to slow the spread of the EAB through quarantines as well as public outreach and education. A response plan should be formulated that includes an accurate and up-to-date ash inventory. This inventory will facilitate surveys for infested trees and plans for tree treatment and/or removal. If an isolated infestation is caught while it occupies a relatively small area, eradication may be the best option. If the area is in close proximity to other infested areas, though, other options must be considered. Depending on a number of factors ranging from the amount of ash to the resources of the community, these options may range from release of biocontrol agents to removal of ash trees. For more information see http://www.fs.fed.us/foresthealth/docs/EAB_National_Framework.pdf .

MAPLE AND THE ASIAN LONGHORNED BEETLE

Taxonomy, Distribution and Significance of Maples

Maples (*Acer* spp.) are now members of the family Sapindaceae, which also includes the horse chestnuts (*Aesculus* spp.). Sugar maple or *ininaatig* (*Acer saccharum* Marshall var. *saccharum*) is highly shade-tolerant tree that is a dominant of northern hardwood forest (Figure 34). In the eastern part of the ceded territory, west to Marquette County, Michigan and along the east shore of Wisconsin, it is often codominant with the equally shade-tolerant American beech (*Fagus grandifolia*). In some portions of its range it also shares dominance with eastern hemlock. Sugar maple is often found on limy soil (UWSP 2013).

Red maple (*Acer rubrum; zhiishiigimewanzh*) is common in the ceded territory (Figure 35). It is only moderately shade-tolerant (pers. obs.). Red maple grows on diverse sites, from dry ridges and southwest slopes to peat bogs and swamps (Walters and Yawney 1990). It commonly grows in the very wet or quite dry extremes. It tolerates poorer soils and is tolerant of a wide range of soil moisture. Common habitats include sand plains, open pine forests, lakeshores and wetland edges.

Silver maple (*Acer saccharinum; zhiishiigimewanzh*) (Figure 36) and box elder (*Acer negudo; aajaagobiimag*) (Figure 37) are typically inhabitants of floodplains. Both tolerate seasonal flooding but avoid continuously saturated soils. Both have only moderate shade tolerance. Box elder can also be weedy, colonizing fencerows, old fields, and other disturbed areas (pers. obs.).

Environmental role

Many animals feed on sugar maple without serious effect except in locally and in certain situations (Godman et al. 1990). Red, grey, and flying squirrels sometimes gnaw or feed on the seed, buds, foliage, and twigs of sugar maple. Porcupines may feed on the bark and can kill the top by girdling the upper stem. Deer often browse sugar maple seedlings to the snow line in winter (Jacobs et al. 1969). Sapsuckers sometimes put holes in sugar maple trees and feed on sap in the spring (Rushmore 1969). White-tailed deer select forests with sugar maple understory cover during severe winters in central Ontario (Jenkins et al. 2007).

High mast years by sugar maple, red maple, beech and American mountain-ash have been shown to lead to increased populations of mice and other small mammals (Jensen et al. 2012). This in turn leads to increased populations of martens and fishers the following year. Large mast years also directly provide food for these two mustelids, which often eat fruits, berries and nuts (beechnuts) in the fall (Martin 1994, cited by Jensen et al. 2012).

The sugarbush

Maple syrup was one of the most important plant foods of the Ojibwe (Densmore 1928). Sugar maple was generally preferred over other maple species because the sugar is more concentrated (Joe Rose Sr., pers comm.). The spring sugarbush camps were a time for families to gather and celebrate the coming of spring (Densmore 1928). Each family or small group of families had their own sugarbush, and the camp and structures were repaired as necessary and used from year to year.

Originally the sap was boiled in lodges that were open on both ends. These lodges were originally framed with stout poles, and covered with cedar or birch bark. A bench ran along each side for sleeping and for and sitting and working on the syrup. A double shelf was also often fastened to a wall of the lodge for storing utensils and containers. A smaller, closed storage shed was also constructed for storing utensils in the off-season. One or more kettles with syrup were hung over the fire on long

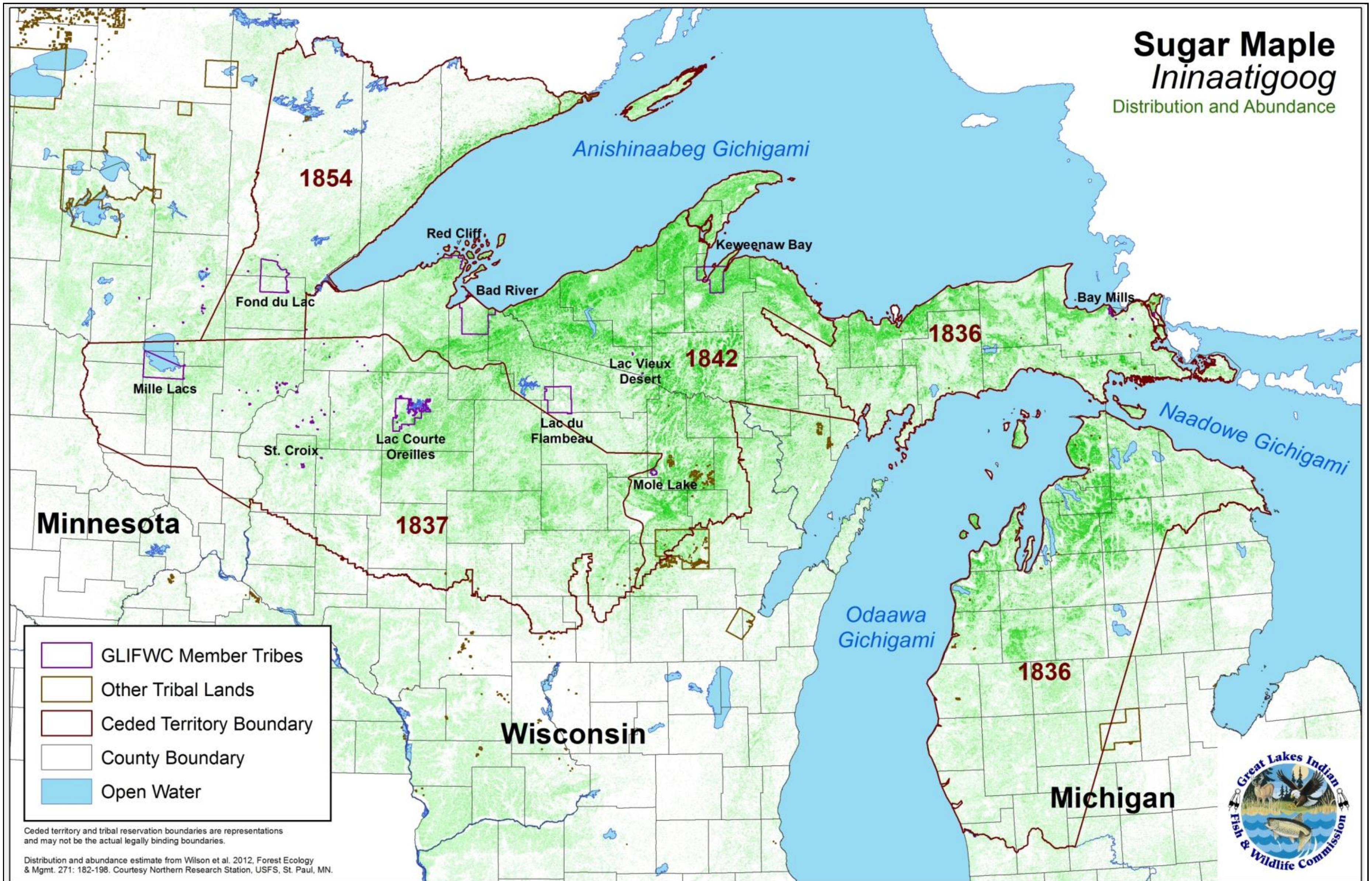

Figure 34. Estimated abundance and distribution of sugar maple in the ceded territory. The green shading indicates sugar maple abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

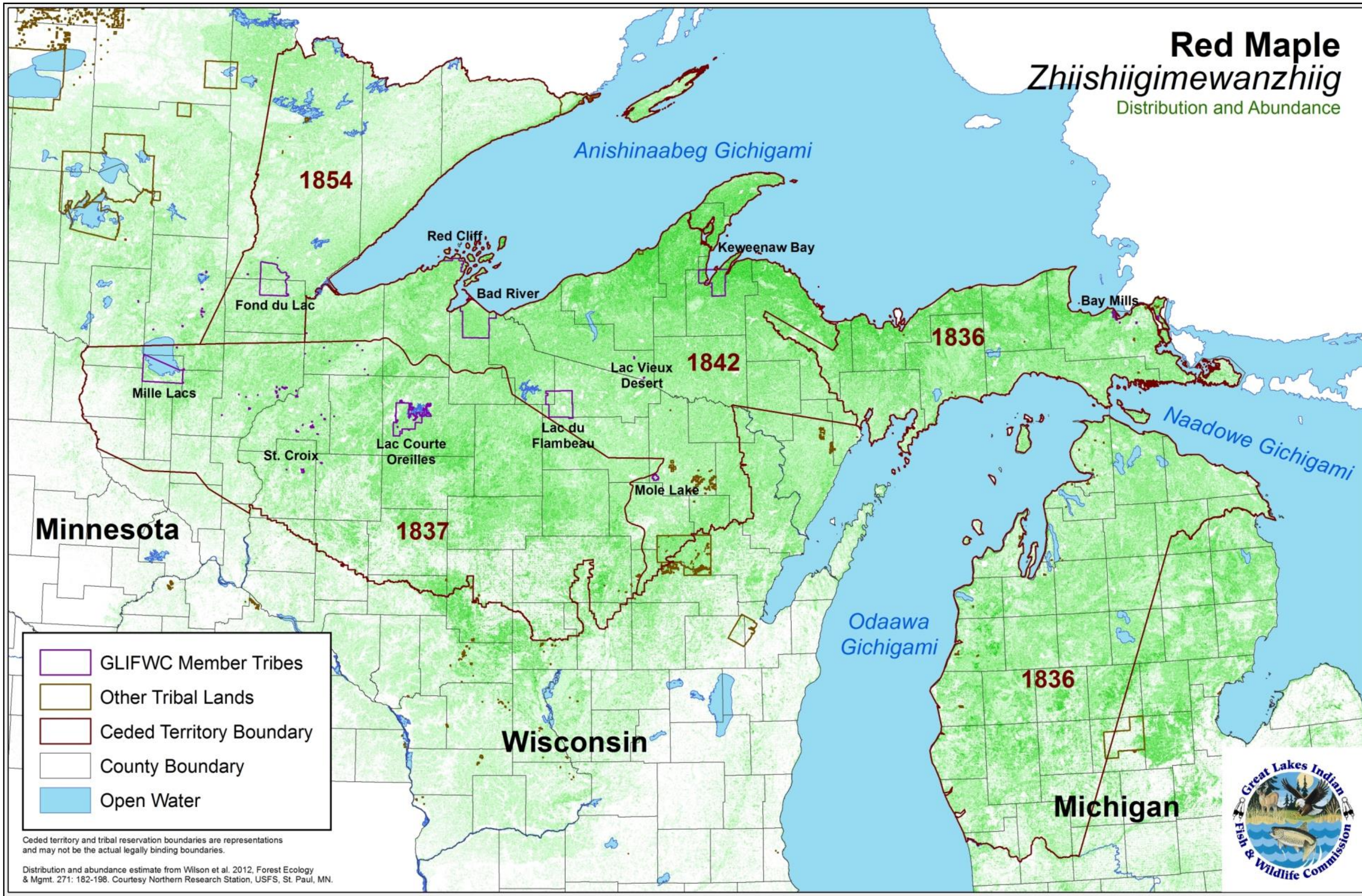

Figure 35. Estimated abundance and distribution of red maple in the ceded territory. The green shading indicates red maple abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

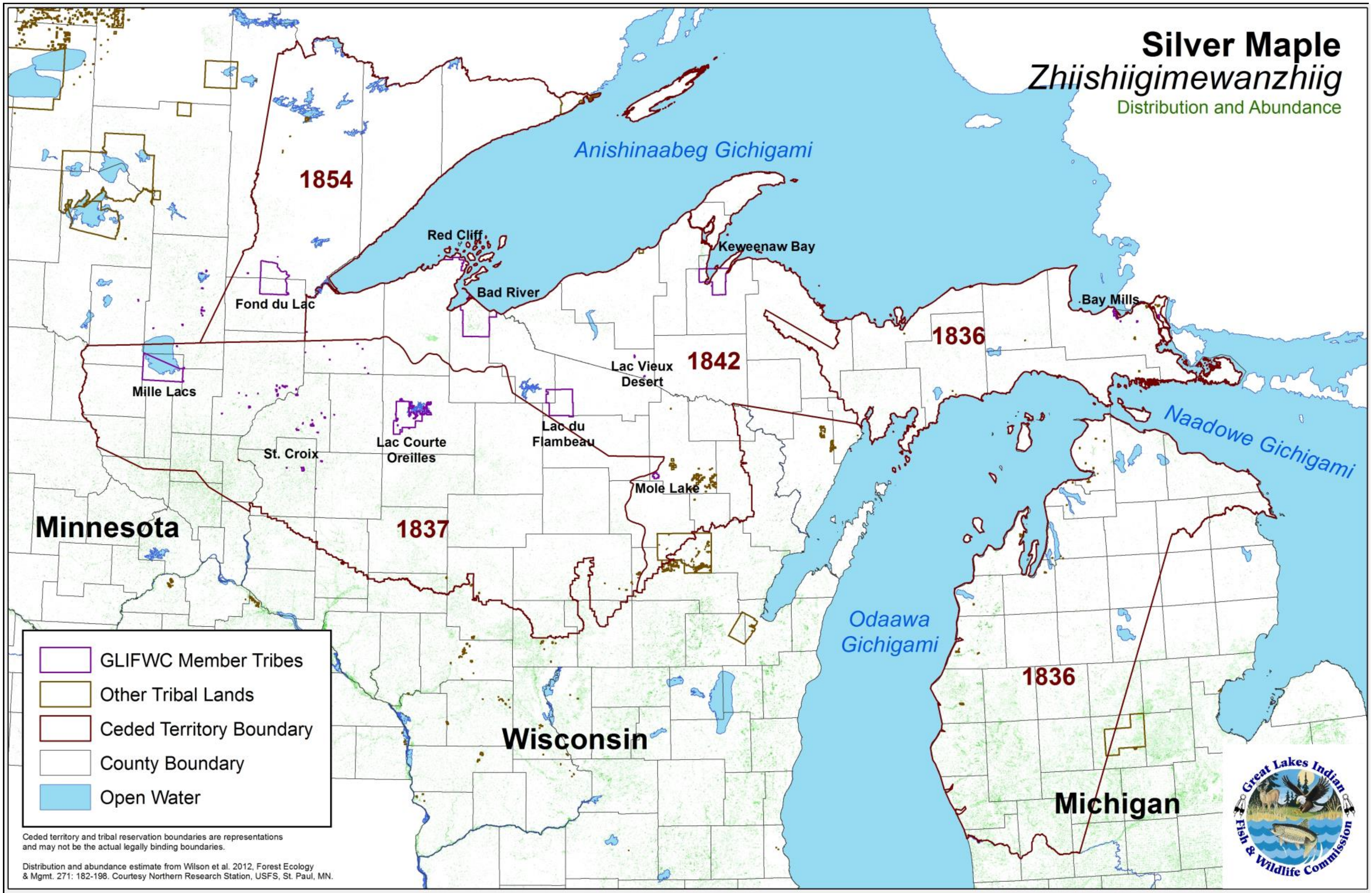

Figure 36. Estimated abundance and distribution of silver maple in the ceded territory. The green shading indicates silver maple abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

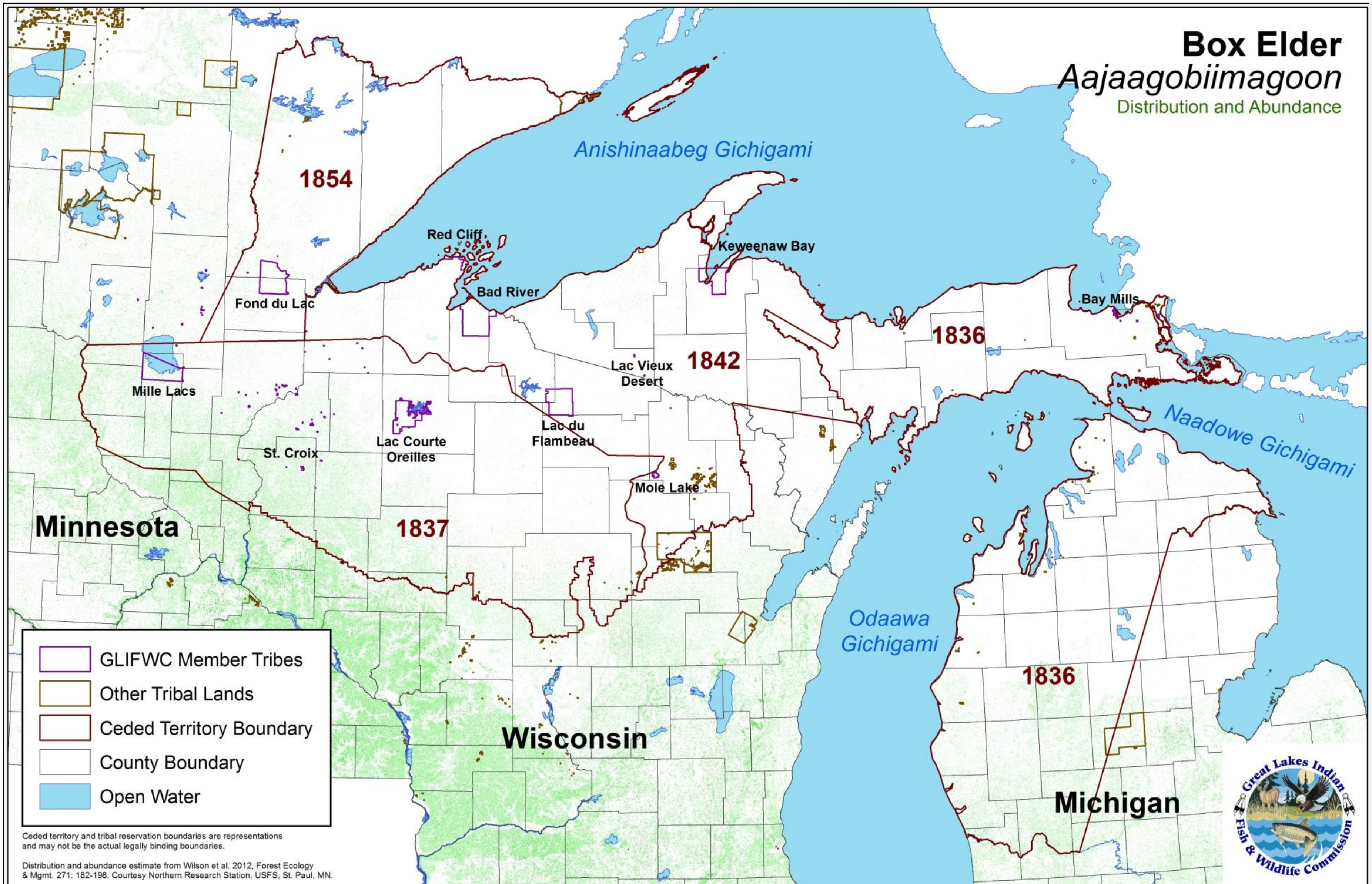

Figure 37. Estimated abundance and distribution of box elder in the ceded territory. The green shading indicates box elder abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

poles. These poles were suspended over perpendicular cross-frames on each side of the lodge, so that the kettles could be placed over any part of the fire. Originally the kettles and other containers for the syrup were made from bark and wood, but metal kettles were quickly adopted. Stirring paddles and other large utensils were made from solid maple wood (Densmore 1928).

The sugar maple season usually began in early March, when snow still blanketed the ground. If the lodge needed heavy repairs the men would be first to break camp, but otherwise the women would break camp. Typically the women would make their way on snowshoes, carrying long roles of birch bark to cover the frame of the lodge. They the set about repairing utensils and retrieving blankets and furs to make the lodge comfortable.

The size of the sugarbush was measured in number of taps (typically made of slippery elm), with very large trees often receiving two or three taps. An average-sized camp might have 900 taps, with some camps (observed by Densmore) having as many as 2000. The syrup was eventually processed into solid sugar, granulated sugar, sugar gum, a sugar drink (by dissolving the sugar in water), and other products. For more on traditional Ojibwe sugar-making, see Densmore (1928).

Economic value

Sugar maple is a major timber tree in the Great Lakes region. It is the hardwood most used for durable goods such as flooring, mallets and handles, chopping blocks, and furniture and veneer (Voss and Reznicek 2012). In Wisconsin, the “hard maple” (which they define as sugar maple and the closely related black maple) harvest comprised about 56.5 million cft, or 16% of the total roundwood cut. As of 2009, 60% of “hard maple” was used for pulpwood and 26% for sawlogs and veneer, accounting for 20% of statewide production for these two products (WDNR 2013).

The production of maple syrup and sugar was important long before European settlement, and continues to be a valuable subsistence and cash product today (Figure 38).

Figure 38. Maple sap is gathered by tribal members and other northwoods residents to produce maple syrup and maple sugar. This tradition would be severely threatened if the ALB becomes permanently established.

Most maples make excellent shade trees. The foliage of sugar maple turns yellow to bright orange in the fall, while (true to its name) red maple leaves turn reddish. Silver maple is commonly used as a shade tree because of its rapid growth, but has fallen into disfavor with some because it is relatively brittle. Mountain maple and striped maple are both attractive native understory trees, whose horticultural benefits have gone largely untapped. A European species, Norway maple (*Acer platanoides*), is a popular shade tree in eastern North America. In some parts of the country (especially the eastern US) it has become invasive in woodlands. Like native maples it is highly susceptible to the ALB.

The Asian Longhorned Beetle

History and distribution

As recently revised by Lingafelter and Hoebeke (2002), the genus *Anoplophora* (Coleoptera: Cerambycidae), consists of 36 species of wood-boring beetles, all native to Asia. Two of these beetles have (so far temporarily) become established in North America: The Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky) and the nearly identical-looking citrus longhorned beetle, *Anoplophora chinensis* (Forster). The Asian longhorned beetle (ALB, Figure 39) is native to China and Korea, while the citrus longhorned beetle (CLB, Figure 40) is native to these two countries as well as Japan (Haack et al. 2010). Both beetles are capable of killing healthy trees. Thanks to human movement of nursery trees, raw lumber, and solid wood packing materials, the ALB is now established in locations around the world (Haack et al. 2010).

The first appearance of the ALB in North America was in 1992, when ALB-infested wood was intercepted at Loudenville, Ohio and in Vancouver, BC (Haack et al. 1997). Interestingly, interceptions at ports around the world jumped around that time, perhaps due to outbreaks in China (Haack et al. 2010). It wasn't until 1996, though, that an established population was found in North America. That's when a resident of Brooklyn, New York reported that the Norway maple trees in front of his house had holes in their trunks and branches, and also reported several large, dark beetles (Haack et al. 1997). Thinking the holes were the work of vandals, he called the New York Department of Parks, which sent a city forester out the next day. The forester collected a specimen and sent it to Cornell University, where it was identified as the ALB. The USDA-APHIS was notified in September 1996. By following the movements of arborists and firewood dealers, a second infestation was quickly found in nearby Amityville. An eradication program was formulated, and by October 1997 1,450 infested trees had been cut down, chipped and burned.

Figure 39. Adult Asian longhorned beetle.

The next infestation was detected in the Ravenswood area of Chicago in 1998 (Antipin and Dilley 2004). There a resident had noticed the beetle on firewood he had gotten from a neighbor, who had cut limbs from a tree in his yard. The resident found the beetle online, called the APHIS hotline, and a few days later the beetles were identified as the ALB. The Chicago population was declared eradicated in 2008 (USFS-UVT 2012).

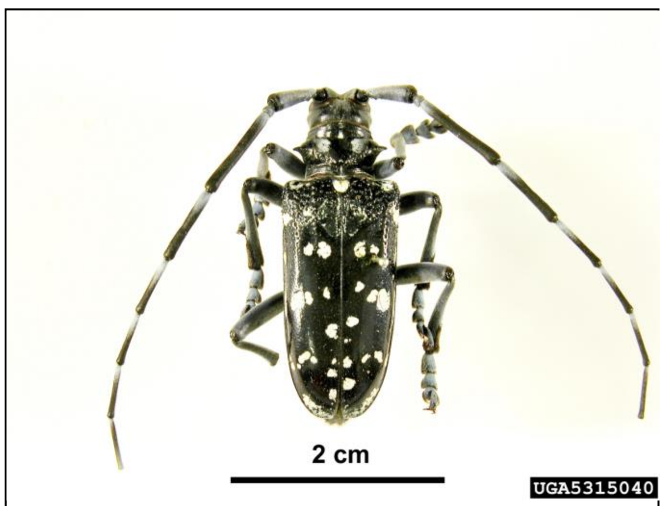

Figure 40. Citrus longhorned beetle. Note pitted "shoulders". (Pest and Diseases Image Library, Bugwood.org)

Subsequent infestations have appeared in Jersey City, NJ in 2002, Toronto, Canada in 2003, Carteret, NJ in 2004, Linden, NJ in 2006, Staten Island, NY in 2007 (Smith et al. 2009). Adult ALBs were also discovered in Sacramento, CA in June 2005. The Toronto population declared eradicated in August of this year. The New Jersey infestations were also declared eradicated this year (State of New Jersey and USDA-APHIS 2013), as were the Staten Island and Manhattan infestations (USDA-APHIS 2013a) (Figure 41).

While these infestations were all in urban areas, the most recent infestations (Worchester, MA in 2008 and Clermont County in southwest Ohio in 2011) are in areas with suburban neighborhoods and natural forests (Dodds and Orwig 2011, Beetlebusters.info). The Worcester infestation is largest infestation found in North America so far,

Figure 41. Asian longhorned beetle infestations through July 2012. The Toronto infestation was declared eradicated in August 2013. Infestations in New York, New Jersey, Massachusetts and Ohio are ongoing. (USFS-UVT 2012, page 3).

with more than 860,000 trees searched, 18,800 infested trees found, and 20,000 trees removed within a quarantine area of 94 square miles (243 km2) in North America (Dodds and Orwig 2011). The Ohio infestation is a fairly close second, with 61 square miles quarantined, 363,158 trees surveyed, 9,563 infested trees found, and 9,246 infested trees removed as of May 2013 (USDA-APHIS 2013b).

The ALB has also become established in a number of European countries, including Italy, Austria, Germany, France, and Poland (Smith et al. 2009). Despite having cut more than 1,700 trees and spent nearly 550,000 Euros, none of these infestations had been eradicated by 2010 (Haack et al. 2010).

Life cycle

Adults of the ALB and the CLB are rather striking in appearance. Both are very dark blue (almost black), with (typically) 10-20 white blotches on their elytra (wing covers) (Haack et al. 2010). Occasionally the ALB may have yellow to yellow-orange blotches, and the CLB may have light yellow blotches. The body length of both ranges from 17 mm to 40 mm long. The insects have long antennae, with those the males averages about 2 times the body length, and those of the females about 1.5 times their body length. The upper quarter of the elytra of the CLB have about 20-40 tubercles (small bumps or projections), while the elytra of the ALB (Figure 39) are fairly smooth.

In the US, ALB females lay eggs from July to November (Lingafelter and Hoebeke 2002, in Keena and Moore 2010). The female ALB chew shallow, round oviposition pits (Figure 42) through the bark and into the phloem tissue of the host tree ((Haack et al. 1997, 2010). After making each pit, they lay one egg. After 1-2 weeks the egg hatches, and the larvae begin to tunnel through the phloem and vascular cambium. As the larva grows it tunnels into the sapwood and the heartwood (Figure 43). After a year or more it reaches a critical body mass, whereupon it tunnels to within about 0.4 inch (1 cm) of the surface and pupates (Haack et al. 2006). Most ALB pass the winter in the larval stage, and pupation usually occurs in the spring or summer (Haack et al. 1997). The adult then emerges from the pupa and tunnels its way out, leaving a round exit hole roughly the diameter of a dime (about ¼ inch). Adults can live for 40 days or more (Haack et al. 1997). They feed on leaves or the bark of twigs before mating and laying eggs.

Unlike the EAB, the ALB usually attacks the tree near the base of the crown along both the trunk and main branches (Haack et al. 2006). Tunneling weakens the tree (Figures 44 and 45), and eventually the major branches and even the trunk often snaps off, creating a hazard in populated areas. The larvae also weaken trees by damaging the phloem and reducing nutrient transport from the leaves downward into the rest of the tree (Dodds and Orwig 2011).

The favorite host of the ALB in eastern North America appears to be maple (Dodds and Orwig 2011, USFS-UVT 2012). This became evident from the Worchester infestation, where beetles invaded two mixed hardwood forest preserves. There the beetles attacked maples exclusively, even though other potential host trees were present (Dodds and Orwig 2011). Of the three maple species inhabiting the two

Figure 42. The female chews shallow pits into the bark, and lays one or more eggs in each pit. Dime-sized exit holes are present also. (Dennis Haugen, USDA Forest Service, Bugwood.org)

Figure 43. ALB larvae burrow through the wood, riddling the tree with tunnels. (Kenneth R. Law, USDA APHIS PPQ, Bugwood.org)

Figure 44. An ALB with holes the larvae tunneled through the wood. These holes weaken and eventually kill the tree. (E. Richard Hoebeke, Cornell University, Bugwood.org)

preserves, red maple was most often attacked, though sugar maple and the introduced Norway maple were also infested. The next choices of the ALB appear to be elm (*Ulmus* spp.), willow (*Salix* spp.), horse chestnut and birch (*Betula* spp.) (USFS-UVT 2012). Ash (*Fraxinus* spp.), hackberry (*Celtis* spp.), European mountain ash (*Sorbus aucuparia*), and bigtooth aspen (*Populus grandidentata*) have rarely been attacked. The beetle also attacks a number of introduced trees, including London plane tree (closely related to the native American plane tree or sycamore , *Platanus occidentalis*) and the introduced golden rain tree (*Koelreuteria paniculata* Laxm.

Figure 45. Maple riddled with ALB exit holes. (Pennsylvania Dept of Conservation and Natural Resources, Bugwood.org).

Northern red oak is not usually considered to be a potential host for the ALB. However, in a greenhouse experiment, young larva ALB inserted into northern red oak saplings either matured and emerged successfully, or died after killing their host tree (Morewood et al. 2005). The authors concluded that while this beetle is not likely to cause extensive damage to oaks, the possibility of oaks serving as host trees should be taken into consideration during quarantines and eradication programs.

Ominously, the CLB has completed development on an even wider range of trees than the ALB has. Where the CLB has become established in Europe, its preferred food is maple, followed by birch and hazel (*Corylus* spp.) (Herard et al. 2006). Other hosts include *Carpinus*, *Citrus*, *Cornus*, *Salix*, and *Ulmus*, as well as *Malus*, *Prunus*, *Pyrus* and other rose family genera (Haack et al. 2006). It is even known to attack pines (family Pinaceae) and certain conifers in the family Cupressaceae, to which cedars and junipers belong (Lingafelter and Hoebeke 2002 and CABI, cited in Haack et al. 2010).

Vectors for spread

Adult ALB are capable of flying several hundred meters at a time (Haack et al. 1997), and have the potential to fly more than 1.2 miles (2000 m) in a season (Hu et al. 2009). They typically only fly as far as they need to to find a suitable host though (Hu et al. 2009, USFS-UVT 2012). A mark-recapture study of ALB dispersal in an agricultural area in China (Smith et al. 2001) found that the mean dispersal distance for ALB adults during the season (June through early October) was 853 ft (266 m), and that 98% flew 1837 ft (560 m) or less during their lifetimes. Most dispersed less than 50 ft (15 m) per day. The maximum dispersal distances recorded over a single season were 0.64 mile (1,029 m) for males and 0.90 mile (1,442 m) for gravid females.

Potential pathways

So far it appears that all primary North American ALB and CLB infestations have originated when packing material from overseas. The ALB was a fairly innocuous beetle in China, until the country began growing aspen and other trees from North America and elsewhere, both as ornamental trees and in large-scale reforestation schemes. (USDA-FS 2012). These introduced trees had little resistance to the ALB, and ALB populations soon exploded in some areas, leaving dead and damaged trees in their wake. Because the wood was useless for construction, much of it was made into pallets and crates for shipments around the world. The Federal government has regulations requiring that SWPM be heat-treated or fumigated before entering US ports, However, some east Asian pallet manufacturers are using fake paperwork and pallet labeling to evade these requirements (Bryan Kuhn, WDNR, pers. comm.).

Worldwide, 97% of interceptions of the ALB have occurred in shipments of wood packing material from China, while 99% of CLB interceptions have been on bonsai trees and other living plants from several east Asian countries (Haack et al. 2010). Once established, ALBs are easily transported on logs and firewood.

The US Forest Service, Forest Health Technology Enterprise Team has constructed susceptibility maps for the ALB, showing probability of introduction and establishment based on the abundance of susceptible maple species and proximity of industries importing commodities associated with ALB interceptions. (Figure 46).

Detection

Surveys: Currently tree surveys or beetle sightings are the standard way to detect infestations. One clear sign of infestation is the presence of round exit holes the size of a dime. Binoculars are useful in seeing holes and other damage higher up in the trees. Another distinctive sign are the shallow, funnel-shaped oviposition pits in which the female lays her eggs. Usually one egg is layed under the bark in each pit, though occasionally the female chews a pit and leaves it empty. These pits sometimes ooze sap, making the area below the pit appear wet and often drawing ants, flies, beetles and other insects. Beetles are most active from midsummer through early fall (Beetlebusters.info).

The larvae also leave clues of their presence. As the larva tunnel, they sometimes push sawdust-like shreds of wood called “frass” out of a hole and onto the bases of branches or the ground (Beetlebusters.info). Large, dime-sized tunnels in the wood are also strong indications of ALB tunneling. After a few years tunneling may lead to dead branches and eventually cause the entire tree to become structurally unsound.

Through its ALB website, the USDA has declared August of every year as “Tree Check Month”. The program encourages people to conduct a 10 minute tree check every August for signs of the ALB. For more information see www.beetlebusters.info .

***Pheromone traps*: ** One piece of good news on the ALB front is that substantial progress is being made towards developing a pheromone trap for the beetle (USDA-FS 2012). Pheromone traps are far more effective at detecting infestations at low densities than are the purely “lure”-based traps such as those used for the EAB. The new traps use a pheromone produced by the male ALB and discovered in 2002, along with volatiles from maple leaves. The male pheromone attracts the female to the trap. The traps were first tested in China and then at various locations around the Worchester infestation, and have successfully detected new infested trees (USDA-FS 2012). For more information see http://ento.psu.edu/publications/Using%20Traps%20to%20Detect%20Asian%20Longhorned%20Beetle-Final.pdf .

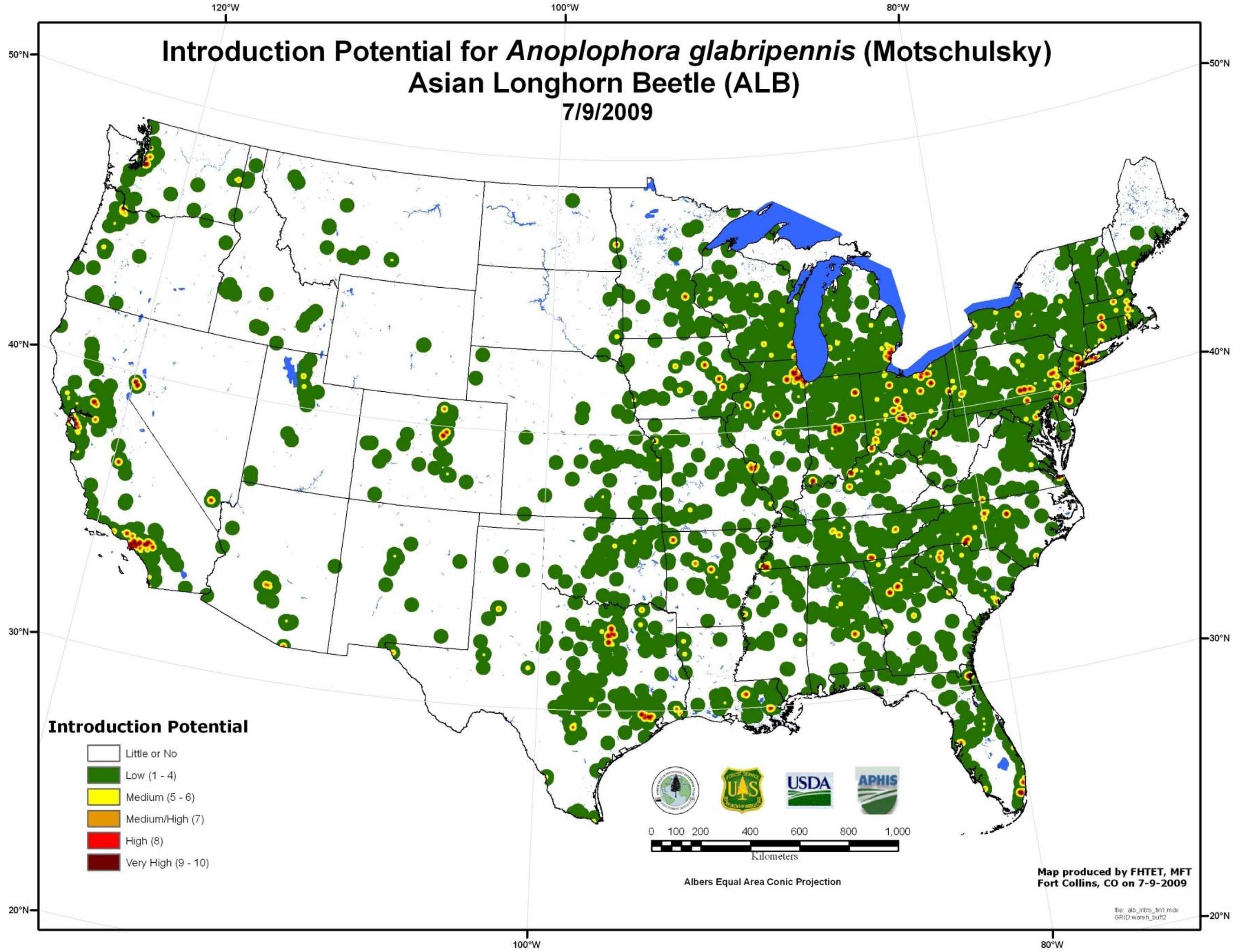

Figure 46. Susceptibility map showing probability of introduction of the ALB based on presence of susceptible maple species and proximity of industries importing commodities associated with ALB interceptions. In the ceded territory, risk is highest in Great Lakes ports and near light industries that import bricks, stone, metal and glass from overseas. (US Forest Service, Forest Health Technology Enterprise Team. http://www.fs.fed.us/foresthealth/technology/invasives_anoplophoraglabripennis_riskmaps.shtml)

Control

Manual and chemical control: At this writing the primary method of control is to cut down and chip up all infested trees.

The only pesticide currently registered for use against the ALB is imidacloprid (USDA-FS 2012). The insecticide must be injected or used as a soil drench, by a registered pesticide applicator under the supervision of an ALB control program.

The USDA-APHIS is currently gathering information from tribal leaders and others to formulate an Environmental Impact Statement (EIS) to deal with new infestations of the ALB as they may arise (Bech 2013).

Biocontrol: Entomopathogenic (internally disease-causing) fungi have been developed for the control of the ALB, and entomopathogenic nematodes, coleopteran and hymenopteran parasitoids and predatory woodpeckers have been investigated as biocontrol agents (Hu et al. 2009).

Economic impacts

Eradication of nascent ALB and CLB populations has proven to be feasible. It has also proven to be expensive. From 1997 through 2008, 8543 ALB-infested trees and 33,595 high-risk host trees were cut in the United States (Haack et al. 2010). These control efforts cost state and federal governments about $67 million and $306 million, respectively (Haack et al. 2010). The potential loss to urban, suburban, agricultural areas and forests, and the industries they support is undoubtedly far higher. Nowak et al. (2001) estimated that if the ALB were to become established across the continental US, US cities would lose 30.3% of their trees (1.2 billion trees) and 34.9% of their total canopy cover, for a monetary value loss of $669 billion in urban areas alone.

In 2001, 369 maple bonsai trees were imported from Korea and stored outside at a nursery in Tukwila, Washington. Soon after they arrived three live CLB were found at the nursery, and a total of 8 exit holes were found on the trees. Fearing that 5 beetles had escaped into the surrounding landscape, Washington State initiated an eradication program in 2002. This program included destroying all 369 bonsai trees, cutting and chipping over 1000 host trees within 656 ft (200 m) of the nursery, treating 1500 host trees that were 656-1312 ft (200-400 m) of the nursery with systemic insecticides, and conducting annual surveys of host trees within 0.5 mile (800 m) of the nursery. The quarantine was lifted in January 2007 because no sign of CLB infestation was ever found beyond the nursery. The approximate cost of this five-year eradication program was $2.2 million (Haack et al. 2010).

The discovery of an ALB infestation in an industrial park north of Toronto, Canada in 2003 resulted in another massive effort to eradicate the beetle (Haack et al. 2010). A regulated area of about 62 square miles (160 km^2) was drawn. Within this area all infested trees and all high-risk trees (whittled down to maple, birch, aspen and willow) within 1312 ft (400 m) of an infested tree were chipped to less than 0.6 inch (15 mm) on a side and composted. No pesticides were used. Extensive, targeted surveys were conducted within the quarantine area through 2012, and the Canadian Food Inspection Agency declared the beetle eradicated from the Greater Toronto Area on April 5, 2013 (CFIA 2013). Some 30,000 trees had to be taken down to eliminate the beetle.

BALSAM FIR AND THE BALSAM WOOLLY ADELGID

Taxonomy, Distribution and Significance of Balsam Fir

Environmental role

The range of balsam fir (*Abies balsamea; zhingob*) extends from Newfoundland and Labrador west through the northern Quebec and Ontario, in scattered stands through north-central Manitoba and Saskatchewan to the Peace River Valley in northwestern Alberta, then south through Minnesota west of Lake-of-the-Woods and southeast to Iowa, east to central Wisconsin and central Michigan into New York and central Pennsylvania, then northeastward from Connecticut to the other New England States. Balsam fir is also present locally in the mountains of Virginia and West Virginia (Frank 1990) (Figure 47).

Balsam fir is an iconic tree of the northwoods. In northern hardwood forest it is often an understory tree, but in riparian forest and boreal forest it may be a dominant. It has fairly high shade-tolerance (Frank 1990). It provides a number of benefits to the environment, including shade for streams and winter thermal cover for white-tailed deer, grouse and other animals.

Balsam fir is a major source of food for moose in winter (Frank 1990). In a northern hardwood-conifer forest north of Sault Ste. Marie, Ontario, moose preferentially browsed balsam fir, eastern hemlock and red maple in winter (Routledge and Roese 2004).

Other mammals also use balsam fir to varying degrees. Snowshoe hares use it for cover, and there is some seed and phloem feeding by various species of mice and voles. Red squirrels occasionally feed on balsam fir seed, bark, buds and wood. Beaver sometimes use the wood for dam building, but little is used as food. Black bear strip bark and lick the exposed surfaces between bark and wood (Bakuzis and Hansen 1965, cited in Frank 1990). Various species of mice and voles feed on the seeds and phloem to some extent (Frank 1990). Spruce grouse and ruffed grouse feed sparingly on the buds, tips, and needles, and grouse and other birds use dense stands for shelter. Thickets of balsam fir provide shelter for both birds (Bakuzis and Hansen 1965, cited in Frank 1990).

Balsam fir is the primary host of the eastern spruce budworm (*Choristoneura fumiferana* Clemens) (Lepidoptera: Tortricidae), a native moth whose caterpillars defoliate their hosts (Frank 1990). (Despite its name, the spruce budworm prefers fir over spruce.) It is most likely to cause heavy damage and mortality in stands that contain mature fir, or that have a high proportion of fir in relation to other species. Vast budworm outbreaks have occurred in eastern North America, perhaps as many as 11 since 1704. Stands attacked by the spruce budworm attract numerous insect-eating birds, especially warblers and woodpeckers (Johnston 1986).

Economic value

Balsam fir is grown or taken from the wild in large numbers for Christmas trees. Wisconsin is a major producer of farm-grown Christmas trees. According to the website savorwisconsin.com (http://www.savorwisconsin.com/product_feature/feature_dec06.asp), Wisconsin ranks fifth in the nation in tree production, behind the states of Oregon, North Carolina, Michigan and Pennsylvania. The industry has a $50 million economic impact on the state. Wisconsin producers harvest 1.8 million Christmas trees and create over 600,000 garland and wreaths each year. For more information see the Wisconsin Christmas Tree Producers Association website (http://wfbf.com/farm-bureau-news/real-christmas-trees-good-for-wisconsins-economy-and-environment/).

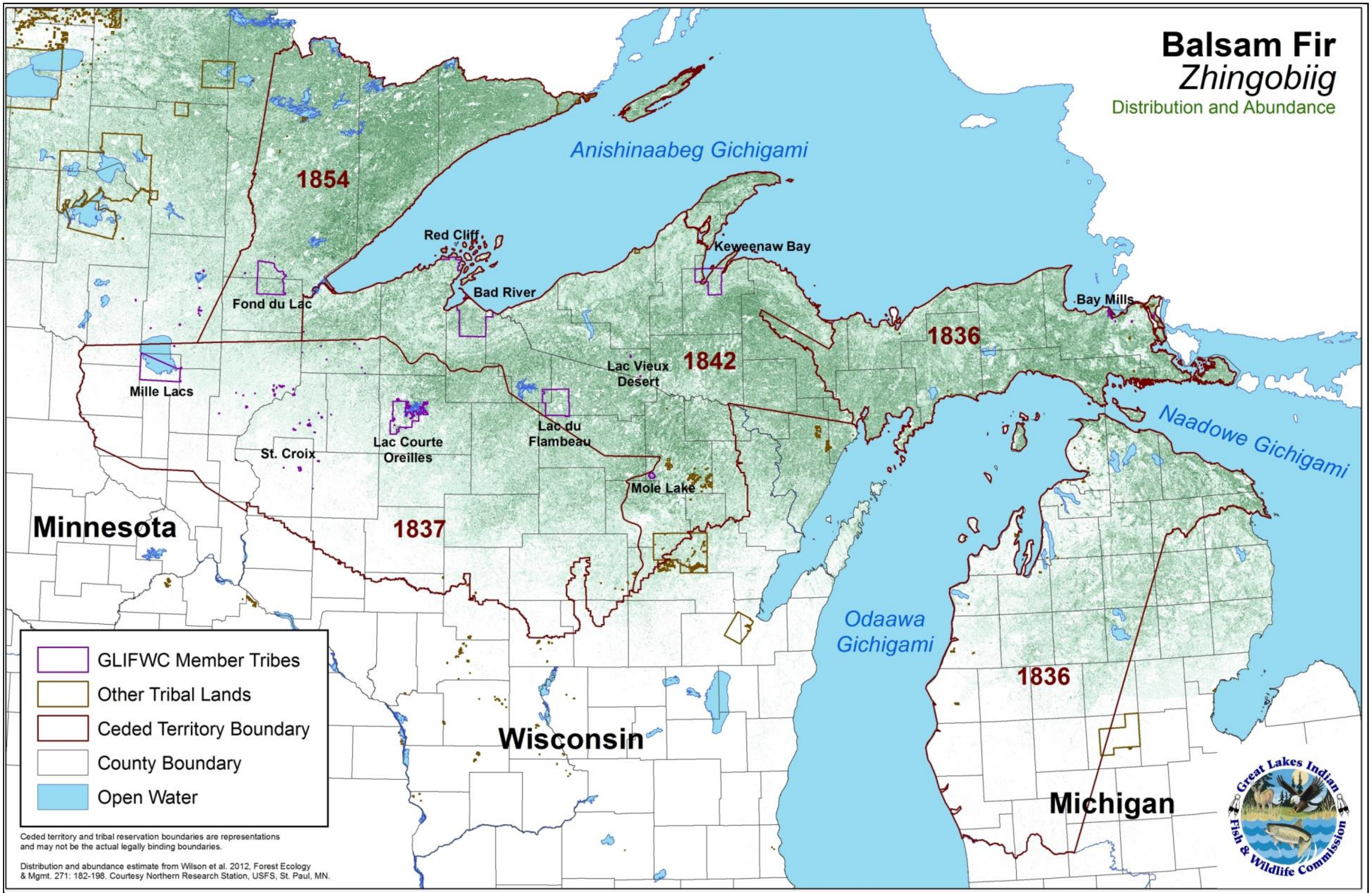

Figure 47. Estimated abundance and distribution of balsam fir in the ceded territory. The green shading indicates balsam fir abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

Christmas tree farming can be quite lucrative (Hope 1990). Using the standard evergreen planting configuration (placing seedlings six feet apart in every direction), roughly 1,100 trees can be grown on a single acre of good ground for a crop with a retail value in the vicinity of $45,000 (1990 dollars). Evergreen seedlings are commonly sold in lots of 1,000. In 1990 the seedlings were selling for anywhere from $80 per thousand for Scotch pine to $150 per thousand for blue spruce.

Once the balsam woolly adelgid becomes established, Christmas tree growers face the added expense of pesticide treatments to keep their trees reasonably healthy until harvest. Nearly all Fraser fir Christmas trees produced in North Carolina need to be treated at least once during their 5- to 10-year rotation to prevent or lessen damage caused by this adelgid. About half the growers in western North Carolina own their own equipment, while the rest must hire someone to treat their trees at a cost of $300 to $500 per acre (Sidebottom 2008). These chemical treatments cost the industry over 1.5 million dollars per year (Potter et al. 2005) and may compromise the effectiveness of integrated pest management systems (Newton et al. 2012).

Balsam and other fir species are used for pulp and for light frame construction (Frank 1990). The lumber from heavily infested trees warps and splits unevenly when dried, and the pulp is of inferior quality.

The most commercially important products made from balsam fir wood are pulpwood and lumber. The wood is lightweight, relatively soft, low in shock resistance, and has good splitting resistance. Nail-holding capacity is low. The major use of balsam fir lumber is for light-frame construction. Minor uses include paneling, crates, and other products not requiring high structural strength (Frank 1990).

Last but not least, balsam boughs provide welcome income for tribal members and other northwoods residents in the fall. The balsam woolly adelgid could devastate balsam fir stands, greatly diminishing or even ending this fall tradition (Figure 48).

The Balsam Woolly Adelgid

History and distribution

The balsam woolly adelgid, or BWA (*Adelges piceae* Ratz.) (Hemiptera: Adelgidae) is native to Europe. Sometime in the late 1800s this tiny insect arrived on the east coast of North America. The bugs almost certainly hitched a ride on nursery stock from Europe. They apparently attracted little if any notice until 1908, when specimens in Brunswick, Maine were identified by a scientist as the balsam woolly adelgid. In 1931 scientists in Nova Scotia started investigating an abnormality on balsam fir branches call "gout disease". They quickly realized this insect was the cause, and that it was becoming a big problem for the area's balsam fir. Frequent surveys in the Canadian maritime provinces showed that by 1930 the BWA inhabited southern coastal New Brunswick, and was found throughout Nova Scotia and Prince Edward Island (Balch 1952). In 1934 MacAloney (1935) conducted widespread surveys for the BWA in the northeastern US, and found that the balsam woolly adelgid had already spread across most

Figure 48. Balsam boughs provide needed fall income for tribal members and non-members alike. (Charlie Otto Rasmussen, GLIFWC)

of New Hampshire, Vermont, southern and central Maine, and into parts of Massachusetts and New York as well. By 1949 populations were found in maritime Newfoundland, where they had been established by 1940. Tree ring analysis showed the BWA had been established in southern Nova Scotia by 1910. It very likely arrived on nursery stock (Ragenovich and Mitchell 2006).

Around 1955 the BWA reached the isolated, high-elevation Fraser fir [*Abies fraseri* (Pursh) Poiret] stands of the Appalachian Mountains. Along with red spruce, Fraser fir (a close relative of balsam fir) was a dominant tree on these mountaintops. Fraser fir has little resistance to the BWA. The insect spread rapidly, carried by the wind as well as by people moving firewood, logs, boughs, nursery plants and Christmas trees. Over 90% of the mature Fraser fir trees in these stands have now been wiped out. Pockets of infestation now occur in West Virginia, North Carolina, Kentucky and Tennessee as well.

The BWA is also established Pacific Northwest, where it presumably arrived on nursery stock (Ragenovich and Mitchell 2006). First found there in 1929, is now well-established across most of southern British Columbia, Washington, Oregon, and northern Idaho, with an outlying population in coastal central California (AFPE 2013) (Figure 49). Some western fir species like noble fir (*Abies procera* Rehder) are fairly resistant to BWA infestation, but others including sub-alpine fir [*Abies lasiocarpa* (Hooker) Nuttall] are highly susceptible. The BWA has not yet been found in the ceded territory.

Life cycle

There are only about 50 species of adelgids in the world, all native to the northern hemisphere (McCullough 2013). Though related to aphids ("plant lice"), they form a distinct, monophyletic group.

Figure 49. Balsam woolly adelgid distribution in the US. The BWA is also established in southeastern Ontario, southeastern Quebec, Newfoundland, Nova Scotia, New Brunswick and Prince Edward Island, and southern British Columbia (USDA Forest Service, Forest Health Protection and partners: http://foresthealth.fs.usda.gov/portal/Flex/APE).

Both adelgids and aphids have threadlike, piercing mouthparts which they use like a straw to siphon plant juices. Adelgids differ from aphids in a number of aspects. Aphids have two small prongs called “cornicles” on their abdomen, while adelgids lack cornicles. While aphids feed on sugars in the plant's sap, adelgids feed on starch stored in the plant's cells. Aphids secrete excess sugar through their cornicles as "honeydew", while adelgids secrete excess starch as a waxy substance that covers their bodies and makes them look look fuzzy or “woolly”. All adelgids species alternate hosts over two or more generations, with a spruce (*Picea* spp.) being one host, and another conifer such as pine, fir or hemlock the other.

Like most other aphid relatives, the life cycle of the BWA is complicated. The BWA has 5 life stages – the egg, three immature instars, and the adult (Ragenovich and Mitchell 2006). Except for the (nonviable) winged progrediens stage, the first instar or “crawler” is the only life stage that is mobile (Figure 50). These crawlers are tiny, measuring less than 1/32 inch (0.8 mm) long. Right after hatching they look for a place to feed, usually in a rough area of the stem, the node of a twig, or at the base of a terminal bud. The crawler then inserts its thin, strawlike mouthparts into the tree, and without molting, transforms into a sessile, flattened, wax-fringed resting stage called a neosistens. The neosistens is the only stage of the BWA that can survive winter temperatures below freezing (Balch 1952). After surviving the winter it molts twice more, before finally molting into an adult. These last two immature forms and the adult are collectively called sistentes. As the sistentes feed, they secrete a whitish, waxy substance that gives them a woolly appearance (Figure 51).

Figure 50. This BWA "crawler" is the size of a pepper dot. (USDA Forest Service, Ashville Archive, Bugwood.org)

The BWA usually has two generations in the northern part of its range, but a partial third generation usually develops in North Carolina, and three generations with a partial fourth occur in lowland areas of Oregon and Washington (Ragenovich and Mitchell 2006).

A rare adult stage of the BWA called a progrediens has been found in Europe, in the Canadian maritime provinces, and perhaps elsewhere (Ragenovich and Mitchell 2006). This stage is mobile, and sometimes winged. Fortunately this stage requires a European spruce species in order to feed and reproduce, and is unable to reproduce on any North American spruce species.

Figure 51. Waxy secretions conceal BWA sistentes and eggs. (Robert L. Anderson, USDA Forest Service, Bugwood.org)

While about 20% of BWA individuals in Europe are male, only females are known from North America. This is because males must develop from stages that use spruce as a host. The females are parthenogenic, meaning that each individual can produce eggs without fertilization. Because of this one adult female can start a new infestation.

Impact on balsam fir

After the BWA reaches an uninfested stand of balsam, the population often grows exponentially, in part because all the BWA individuals are females (Ragenovich and Mitchell 2006). This rapid population growth usually causes massive dieoff of the mature trees over several years.

The BWA can attack the stems (trunks) and the foliage of fir trees. In thinner stands or in mixed forests, and in colder parts of their range, fir trees are more likely to suffer foliage attacks. These attacks are associated with crown distortion and dieback, gouting of the branches, and branch death. As it feeds, the BWA injects a hormone into the phloem that causes the twigs to become swollen at the branch nodes and below the buds, and the ends of the branches to become stunted (Balch 1952) (Figure 52). Only current-year shoots are susceptible to gouting (Guillet et al. 2010).

If the tree survives for several years the terminal stem begins to grow at an angle instead of straight up, giving the tree a “fiddle-shaped” or “curled” appearance. This causes the tree to lose its apical dominance (Fowler et al. 2001). As the upper stem begins to thin and die back it is often infected by wood-rotting fungi (Ragenovich and Mitchell 2006). Eventually the infested tree's needles start to turn yellow and fall off. Cone and seed production is greatly reduced. The tree continues to decline and eventually dies.

Fir trees are also susceptible to "stem attack", where the truck becomes heavily infested with BWA (Figure 53). Stem attacks tend to be more common in denser stands. Trees that are pole-sized, about 1.6 inch (4 cm) or larger in diameter, are most heavily attacked (Ragenovich and Mitchell 2006, Smith and Nicholas 2000). Populations of BWA frequently reach densities of 100 to 200 adelgids per square inch of bark surface (Ragenovich and Mitchell 2006). The adelgid's saliva caused the tree to produce trachieds (the water-carrying cells in conifers) that are high in lignin and don't conduct water well, causing the tree to slowly die of dehydration (Smith and Nicholas 2000). Fraser fir is highly susceptible to stem attacks, but balsam fir is susceptible as well.

Stem feeding causes the tree to produce dense, brittle wood. This wood is not as good at transporting water to the canopy of the tree. It is also much less valuable for lumber and pulp. The foliage turns yellow and then deep red or brown, before the tree finally dies. In the southern Appalachians, trees that are heavily stem-attacked often die within a few years (Figure 54). In the northeast, stem-attacked trees usually die more slowly, with some persisting for 10 years or more.

The BWA's spread and impact is limited by cold in the north (Quiring et al. 2008). A study in Nova Scotia found that in areas with average January temperatures of 12° F (-11°C) and below, damage to balsam fir was relatively minor. Another study (Greenbank 1970) found that 80% of BWA crawlers exposed to -30° F (-1°C) for 5 days were killed, and none survived even brief exposure to -34° F (-37°C). (BWA sheltered below the snow line often survive extreme cold, though.) These conditions roughly correspond to USDA Zone 4a (Quiring et al. 2008), which includes the western and central UP, the northern third of Wisconsin, and the northern half of Minnesota. The rest of the Great Lakes region is classified as zone 4b or warmer, and would already be susceptible to BWA damage if the insect arrives. Under current climate conditions, the eastern part of the ceded territory

Figure 52. Swelling (“gouting”) and needle loss caused by the BWA. (Ladd Livingston, Idaho Department of Lands, Bugwood.org)

including Lower Michigan and parts of the eastern and central UP are in the damage zone, while much of the western ceded territory might experience only minor damage. The warming climate will likely move all these regions except perhaps northeast Minnesota into zone 4b within a decade or two, though.

North American fir species range from resistant to highly susceptible to the BWA. Both eastern North American species are unfortunately highly susceptible. Only balsam fir is found in the ceded territory, with Fraser fir native to the Appalachians. Fraser fir is often grown in the Great Lakes region by the Christmas tree industry, though.

After the initial dieback increased light to the forest floor often results in a flush of new seedlings. Seedlings make a significant amounts of the compounds juvabione and its physiological precursor dehydrojuvabione (Fowler et al. 2001). Juvabione interferes with the BWA's physiology and provides the seedlings with some protection from BWA infestation (Fowler et al. 2001, McCullough 2013). The seedlings can still become infested though. Newton et al. (2011) state that "Fraser fir seedlings as young as one year old can be infested with BWA." and that "even the youngest trees in Fraser fir Christmas tree plantations are vulnerable to infestation."

Figure 53. Stem attack on Fraser fir. Heavy stem infestations often kill the tree. (William M. Ciesla, Forest Health Mgmt. Intl., Bugwood.org)

Vectors and potential pathways for spread

Balch (1952) traced a crawler for 1 hour at 70° F and found that it had traveled 21 inches. In another experiment 20% of the crawlers in containers were still crawling after 8 days. From these observations Balch assumed that crawlers could travel at least 100 ft before settling down. The crawlers are somewhat sticky, and may also spread on the feet of birds or the bodies of squirrels, deer or other mammals (Balch 1952).

Significantly, this effectively weightless insect is able to ride the wind for long distances (Amman 1966, Guillet et al. 2010). Balch outlines an experiment where glass microscope slides smears with vaseline, and hanging upside down under suspended metal hoods in an open field, captured eggs and crawlers as far as 300 ft from infested trees. Amman (1966) outlines cases where eggs and/or crawlers apparently were blown from the site of the original Appalachian infestation on Mt. Mitchell, North Carolina to three other peaks as far as 45 miles away.

Figure 54. Dead stand of mature Fraser fir in North Carolina. Seedlings and saplings are more resistant to the BWA and continue to grow. (Gerald J. Lenhard, Louisiana State University, Bugwood.org)

Movement of this tiny but prolific insect is presumably aided by people moving firewood, logs, boughs, nursery plants and Christmas trees. Both Fraser fir and balsam fir seedlings are shipped from infested areas to Christmas tree growers in the upper Great Lakes region, representing a clear and present pathway for infestation of forests in this region (McCullough 2013).

Detection

Detection of the BWA (and the closely related hemlock woolly adelgid on hemlock) has typically been done visually, through field and areal detection surveys for the insect and the resulting damage to the trees (Cook et al. 2010). Both insects cause the needles of their host to discolor from deep green to grayish green. Cook et al. (2010) measured percent reflectance of subalpine fir [*Abies lasiocarpa* (Hooker) Nuttall] in Idaho, and eastern hemlock in North Carolina. They found that heavily infested fir and hemlock both gave greater percent reflectance across most of the reflectance curve (between 400 nm and 2400 nm) than lightly or unifested fir or lightly infested hemlock, respectively. They note, however, that while this method appeared useful for detecting stressed trees, it was unable to distinguish whether the adelgids were the cause.

Aside from possible high-tech methods, infestations are found through areal surveys and by watching for the symptoms of infestation.

Control

Pesticides: Insecticides are effective against the BWA. In western North Carolina (the primary area for Fraser fir Christmas tree production in the US) trees generally must be sprayed at least once to keep them from being seriously damaged or killed by the BWA (Sidebottom 2008). Insecticides are applied with a high-pressure sprayer, at a rate of 300 to 800 gallons per acre depending on tree size and density. Only 2-3 rows can be treated at a time. Farmers that do not own this type of equipment must hire an applicator at a cost of $300 to $500 per acre. Large trees are difficult to treat and are usually cut down.

Biocontrol: Three beetles and three flies from the BWA's native range in Europe have so far been introduced to combat it. Unfortunately these biocontrol insects appear to feed primarily on the BWA stages that have little to do with BWA reproduction in North America, and so have proven ineffective.

National and state control strategies

No federal quarantine exists for the BWA. The State of Michigan is proposing a statewide quarantine on the importation of balsam and Fraser fir timber and nursery trees from infested areas (John Bedford, MDARD, pers. comm., Bryan 2013). Seedlings and transplants less than 3 years old would not be included in the quarantine. Also Christmas trees, wreaths, and other holiday greenery would be exempted between November 1 and January 31.

GLIFWC has commented on a draft of Michigan's proposed BWA quarantine. Recommendations were as follows:

1) Under “REGULATED AREAS”, GLIFWC recommended that list all states with known infestations be specified, rather than including a subset of them, followed by “any other areas”.

2) Under “EXEMPTIONS”, “Seedlings and transplants of true fir (Abies spp.) no greater than 3 years old from initial date of propagation that have been produced under an active pest management program are exempt.”, GLIFWC recommended that “active pest management program” be defined, and pointed out that though they are more resistant, Fraser and balsam fir seedlings can still carry the BWA.

A copy of the PDF document with these recommendations was sent to tribal officials at Lac Vieux Desert (Gete-gitigaaning), Keweenaw Bay Indian Community (Gakiiwe 'onaning), and Bay Mills (Ginoozhekaaning).

EASTERN HEMLOCK AND THE HEMLOCK WOOLLY ADELGID

Taxonomy, Distribution and Significance of Hemlock

Environmental role

Eastern hemlock (*Tsuga canadensis; gaagaagimizh*) is a shade-tolerant, long-lived climax species native to eastern North America. Its range extends west to the Lake Superior region, with small, widely scattered outlier populations in northeastern Minnesota (Figure 55). Eastern hemlock can take 250 to 300 years to reach maturity, and may live for 800 years or more (Godman and Lancaster 1990). One of the largest eastern hemlock trees ever recorded measured 76 inches (193 cm) diameter at breast height (dbh) and 175 ft (53.3 m) tall. Though much less abundant than before the big cut over 100 years ago, eastern hemlock is often co-dominant with sugar maple in upper Great Lakes forests. A closely related species, Carolina hemlock (*Tsuga caroliniana*), is limited to the slopes of the Appalachians from Virginia and West Virginia into Georgia (Godman and Lancaster 1990).

Hemlock communities are unique evergreen ecosystems within the largely deciduous forest region of eastern North America (Martin et al. 2013). They are characterized by a damp, shady microclimate and slowly decomposing, acidic litter (Orwig and Foster, 1998; Martin and Goebel 2013). Transpiration in hemlock forests is distributed more evenly throughout the year, with higher rates in the spring than in deciduous hardwood forests (Ford and Vose 2007). Hemlock was much more prevalent in the Great Lakes forests before they were extensively logged and burned in the late 1800s and early 1900s.

Hemlock stands provide cover for ruffed grouse, turkey, snowshoe hare, and rabbit (McClure et al. 2001). Even hemlock-cedar stands as small as a few acres are used by martens for food, shelter and denning (McCann et al., *in review*). Hemlock stands provide valuable shelter and bedding of white-tailed deer during the winter (Godman and Lancaster 1990). At least 90 species of birds use hemlock as a food source, nesting site, roost site, or winter shelter (McClure et al. 2001). Black-throated warbler, solitary vireo, and northern goshawk all require hemlock forest habitats. Plant associates include leatherwood (*Dirca palustris*), rattlesnake plantains (*Goodyera* spp.), bunchberry (*Cornus canadensis*), goldthread (*Coptis trifolia*), Canada mayflower (*Maianthemum canadense*), wood sorrel (*Oxalis acetocella*), and many other herbs and shrubs. Hemlock shade over streams and wetlands helps maintain a cool and moist microclimate for coldwater fish such as brook trout (Snyder et al. 2002). In winter hemlock stands are warmer than hardwood stands because their dense crowns provide protection from wind. Other species benefiting from hemlock stands include salamanders and aquatic macroinvertebrates (Ross et al. 2003).

In a study of hemlock mortality from the hemlock woolly adelgid (HWA) as related to bird composition and abundance, overstory hemlock mortality was highly correlated with avian community composition (Tingley et al. 2002). Abundance of eastern wood-pewee (*Contopus virens*), brown-headed cowbird (*Molothrus ater*), tufted titmouse (*Baeolophus bicolor*), white-breasted nuthatch (*Sitta carolinensis*), red-eyed vireo (*Vireo olivaceus*), hooded warbler (*Wilsonia citrina*), and several woodpecker species was highest at points with >60% mortality. Black-throated green warbler (*Dendroica virens*), Acadian flycatcher (*Empidonax virescens*), blackburnian warbler (*Dendroica fusca*), and hermit thrush (*Catharus guttatus*) were strongly associated with intact hemlock stands that still has suffered little or no mortality from HWA.

Hemlock is also beneficial in sequestering atmospheric carbon. There were 9.7 million tons of aboveground biomass in live hemlock trees in 2012, an increase of 76% since 1983. This is equivalent to approximately 4.8 million tons of carbon and represents 1.6% of all biomass statewide (WDNR 2012).

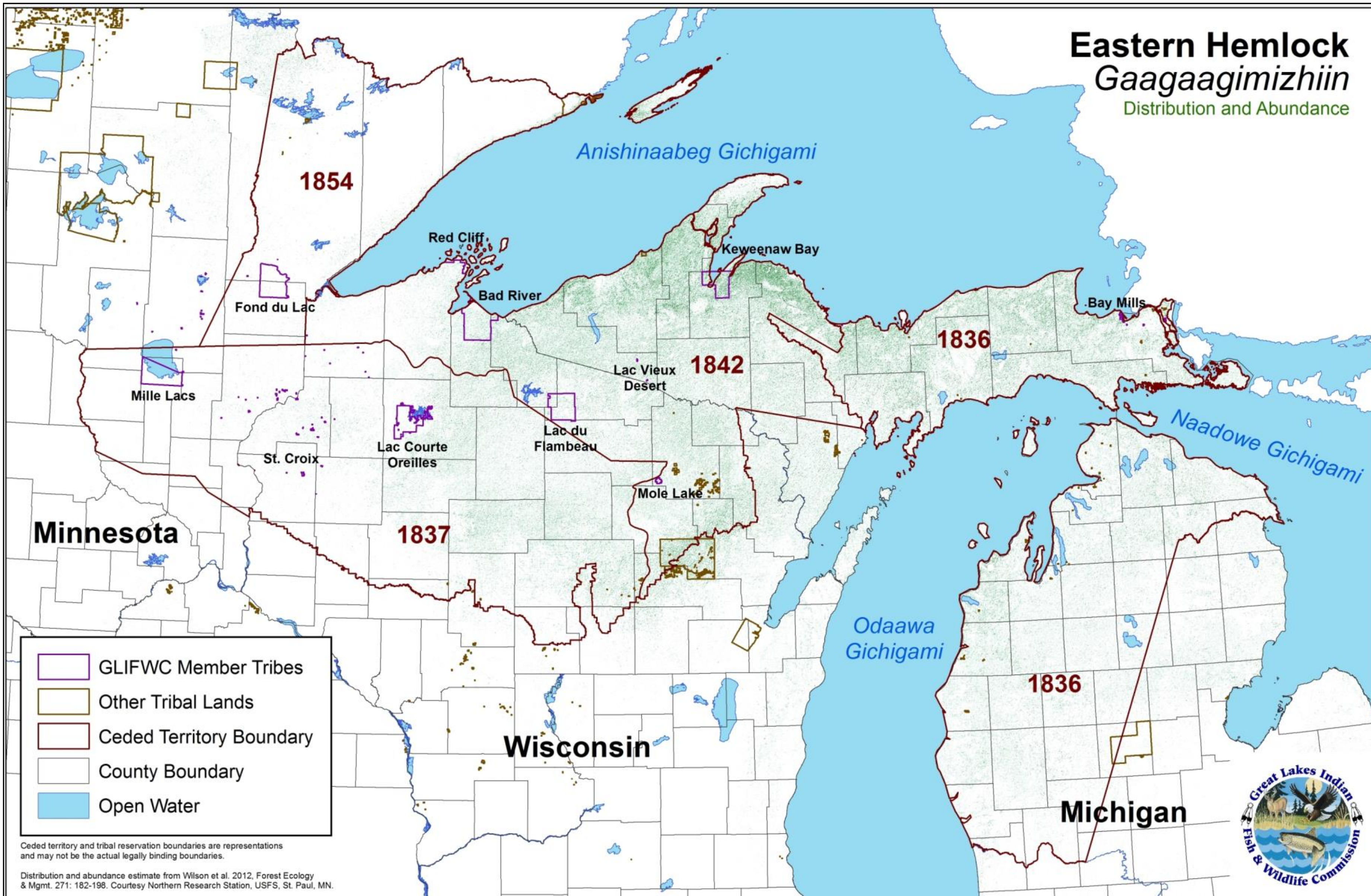

Figure 55. Estimated abundance and distribution of eastern hemlock in the ceded territory. The green shading indicates hemlock abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

Hemlock has long been used to make “northwoods tea”. This pleasant-tasting tea is easily brewed by boiling the twigs and needles of eastern hemlock in water for a few minutes (pers. obs.).

Economic value

Though not as abundant as it once was, hemlock is still used for products ranging from pulp and paper to lumber and mulch. Hemlock is sometimes used for pulpwood and for building barns, sheds, and other structures (McClure et al. 2001). More hemlock is logged in the northeastern US than in the midwest. Hemlock was estimated to be 7 percent of the sawlogs and 12 percent of the annual pulpwood harvest in New England in 1999 (Ward 2004) In contrast hemlock in Michigan represents less than 1% of the cover type and less than 1% of the harvest on state land (Pedersen 2005). In Wisconsin 2% of all volume and 1.4% growth of trees are hemlock and hemlock makes up less than 1% of the volume of logs cut (WDNR 2012). In Michigan and Wisconsin, management efforts to preserve that small base of hemlock remaining in the landscape as seed trees for continued regeneration of the species have limited logging of remaining hemlock stands on public lands (Pedersen 2005, pers. obs.). Eastern hemlock is at the western edge of its range in northeastern Minnesota, where it is very rare (MNDNR 2013).

Hemlocks are highly valued for their beauty. There are 274 cultivars of eastern hemlock, making it one of the most cultured and cultivated landscape trees in the United States (McClure et al. 2001).

The Hemlock Woolly Adelgid

History and distribution

The hemlock wooly adelgid or HWA is very similar to the balsam woolly adelgid (BWA) discussed above. The HWA (*Adelges tsugae* Annand) (Hemiptera: Adelgidae) is native to China and Japan. It also occurs in western North America from coastal southern Alaska to northern California (Havill et al. 2006). The first collection of the HWA from western North America was in 1907 from South Bend, Washington, and the first clear published record was from isolated native western hemlock trees [(*Tsuga heterophylla* (Raf.) Sargent)] in Vancouver, British Columbia in 1907.

The HWA was first recorded in eastern North America in 1951, in a municipal park in Richmond, VA, where it probably was introduced on exotic ornamental hemlocks (Stoetzel 2002, cited in Havill et al. 2006, Hain 2006). It spread slowly at first and was not considered a significant pest, because it was only a minor pest in the west and in its native range (Ward 2004). The HWA reached southeastern Pennsylvania in 1969 (Ward 2004) and southern New England by 1985 (McClure 1990). As of 1989 its range extended from Rhode Island and Delaware southeast through New Jersey and Pennsylvania to North Carolina (McClure 1989). In the last two decades it has spread considerably, decimating hemlock stands in the Eastern United States. The HWA is now found nearly throughout the Appalachians, and the eastern seaboard from North Carolina to southeastern Maine (Figure 56).

The HWA reaches Lower Michigan (temporarily)

In 2006 the HWA was discovered in hemlock trees planted in Harbor Springs, Michigan (Emmet County) for residential landscaping. (Emmet County is the northeasternmost county in Lower Michigan). The trees were traced back to an infested nursery in West Virginia. They were removed and the area was treated and surveyed for the next several years. Subsequent infestations have been found in the Harbor Springs/Petoskey area of Emmet County (2007 and 2010), the Utica and Clinton Township areas of Macomb County (2010), the Grand Haven and Holland areas in Ottawa

County(2010) and the New Buffalo area of Berrien County (2012). At each of these sites, the Michigan Department of Agriculture and Rural Development (MDARD) required the removal and destruction of the infested trees, treated hemlocks in close proximity to those infested trees with insecticides and is conducting follow-up surveys. As of this writing all five infestations are believed to be eradicated (MDARD 2013).

Analysis of HWA mitochondrial DNA taken from multiple locations in eastern and western North America, mainland China, Taiwan, and Japan showed that eastern North American HWA belonged to one lineage, indicating that this population originated from a single introduction (Havill et al. 2006). The DNA of the eastern North American population matched the DNA from the population of HWA inhabiting the island of Honshu, southern Japan. Other HWA lineages were found in other areas of Japan. (Genetic variation within a species is typical within its native range.) The mainland East Asian lineages were clearly divergent (of a different lineage) from insects in eastern North America and Japan.

How the western North American HWA populations are related to these other populations was unclear from this study. However, multiple lineages are found in the western North American population. This

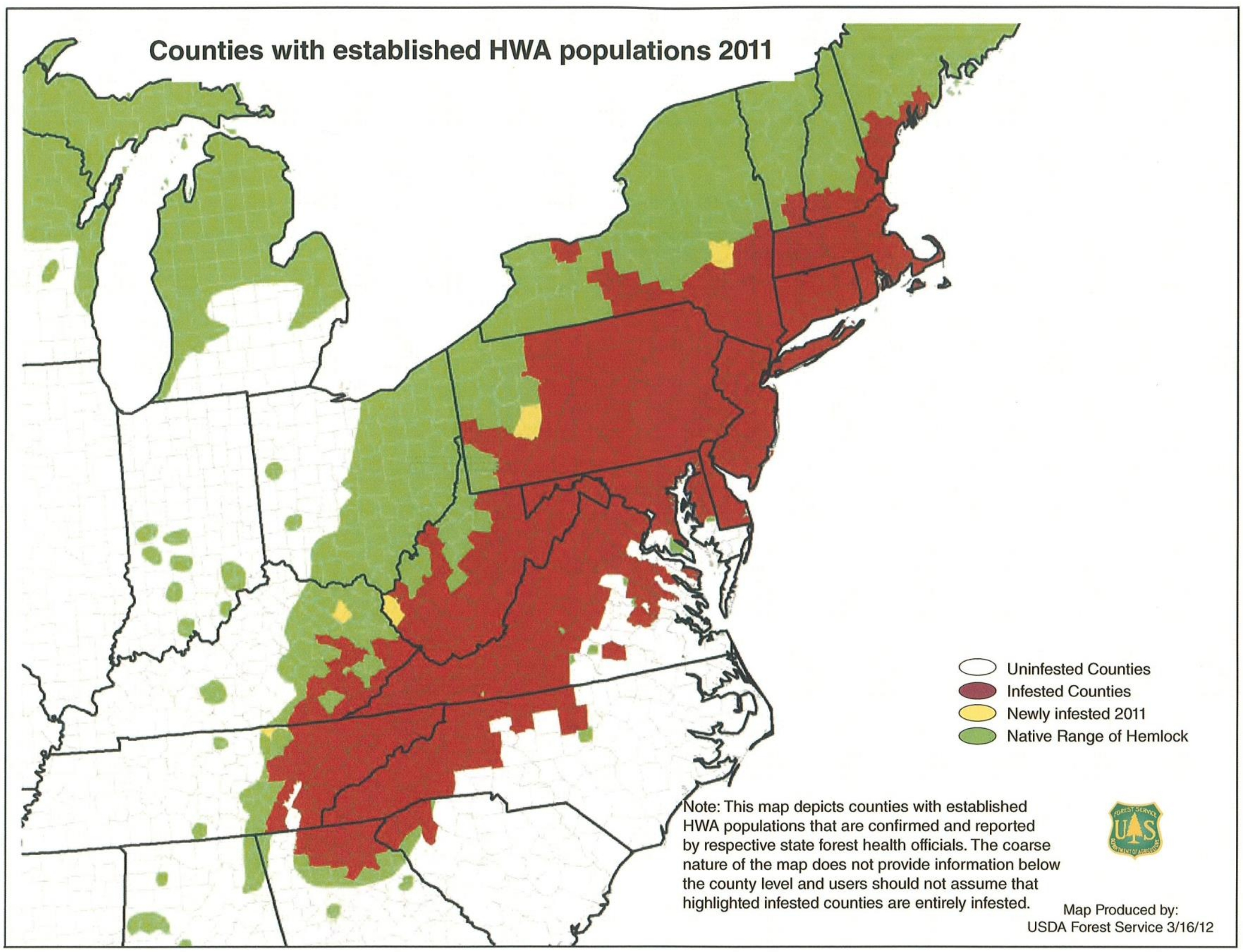

Figure 56. Range of eastern hemlock and the HWA as of 2012. The range of hemlock also extends north into southern Nova Scotia, New Brunswick, Quebec and Ontario, and west across Upper Michigan and northern Wisconsin, with outlier populations in northeastern Minnesota. Isolated Michigan populations found as recently as 2010 are now believed to be eradicated.

along with the facts that both native western hemlocks are resistant to the adelgid, and that a diversity of native predators inhabit the HWA's western range, provide evidence that the HWA may be native to western North America (Havill et al. 2006).

Life cycle

In early spring the adult sistens, which have survived through the winter, lays its eggs. The sistens (Figure 57) are all parthenogenic females, meaning they lay viable eggs without mating. They are less than 1/32 inch (1 mm) long. Each sistens produces a white, cottony ovisac within which she lays up to 300 eggs (McClure et al. 2001). The eggs are nearly microscopic, measuring around 0.36 mm (about 1/64 inch) long (McClure 1989). Each new egg hatches to become one of two HWA life form: a progrediens or a sexuparae (McClure et al. 2001). In early summer the progrediens lays eggs which hatch to become an immature (1^{st} instar) sistens called a crawler. This tiny crawler averages a little over 1/64 inch (about 0.44 mm) long (McClure 1989). In midsummer, this immature sistens begins a summer dormant period called aestivation. The sistens breaks aestivation in the fall, and goes through three more instar stages before becoming an adult sistens. Then the cycle starts over. The HWA usually completes two generations per year.

Like the BWA, the winged sexuparae normally initiates one or more generations on spruce (*Picea* spp.) As the density of the adelgids reached high levels and the health of the host hemlock tree declines, the proportion of eggs that become sexuparae increases (McClure et al. 2001). The offspring of these parthenogenic sexuparae (which hatch on spruce) are the stage of the HWA that reproduce sexually. They are unable to complete development on any North American spruce species, though, and die within a few days (McClure 1989).

More than half of the offspring produced by the sistens develop into winged sexupara, which leave hemlock in an unsuccessful attempt to locate a suitable spruce species (McClure 1989). Despite losing more than half of the individuals each year, HWA populations are still able to increase rapidly in numbers on hemlock because they have two annual generations, high reproductive potential, and lack of any other significant mortality factors. If the HWA were to encounter a spruce species (native or introduced) on which the sexuparae could successfully reproduce, the threat to hemlock could be even greater because generations of the HWA developing on spruce could migrate back to hemlock, contributing significantly to the insect's spread.

Impact on hemlock

Unlike aphids which feed on plant sap, the HWA and other adelgids feed on the stored starch reserves inside the tree's cells. The HWA builds up to such high levels that it depletes the starch reserves that the tree needs to survive the winter and add new growth in the spring.

The most obvious sign of infestation is the presence of white woolly egg sacs (ovisacs) on the underside of hemlock needles, especially on new growth (Figure 58). The adelgids feed on twigs and new growth by piercing the cells at the base of the needles. This

Figure 57. This adult HWA is less than 1/32 inch long. Yet these creatures are killing hemlock stands across the eastern US. (M. Montgomery, USDA Forest Service, Bugwood.org

feeding desiccates the needles, making them turn grayish-green and fall to the ground (McClure et al. 2001). Most buds are also killed, so little if any new growth is produced on infested branches. Dieback of major limbs can occur within two years. Dieback progresses from the bottom of the tree upward, even though the infestation may be evenly distributed throughout the tree. Trees may die within four years, but some may survive for a decade or more with only sparse foliage at the very top of the crown. There is evidence that some weakened trees may recover. The factors that lead to recovery are not well understood (McClure et al. 2001). Hemlock seedlings and saplings don't have natural resistance to adelgids like young balsam fir do, and the HWA kills hemlock of all ages (Hain et al. 2006).

The HWA is causing severe mortality to both eastern hemlock and Carolina hemlock in eastern North America (Figure 59). The unchecked population growth of the HWA on hemlocks is likely because of limited tree resistance and a lack of natural enemies in its introduced range (Ward et al. 2004).

Decline and dieback of hemlock will likely lead to the invasion of nonnative plants. In the Delaware Gap National Recreation Area of Pennsylvania and New Jersey, dieback of hemlock and corresponding increase in light levels led to an increase in the number of species in permanent plots over a 9-year period (Eschtruth et al. 2006). Though nonnative invasive plants were absent from these ravines in 1994, 35% of the permanent vegetation plots included at least one invasive plant, including such aggressive invaders as Japanese stiltgrass [*Microstegium vimineum* (Trin.) A. Camus], garlic mustard (*Alliaria petiolata*), and Japanese barberry (*Berberis thunbergii*). Similar results were seen in a study in Connecticut (Orwig and Foster 1998) at the southern limits of the northern hardwood forest.

Figure 58. Hemlock branch heavily infested with the HWA. (USDA Forest Service Region, Bugwood.org)

Figure 59. Appalachian forest giants killed by the HWA. (William M. Ciesla, Forest Health Mgmt Intl., Bugwood.org)

Vectors for Spread

In a multifaceted study in Connecticut, McClure (1990) demonstrated that the HWA is dispersed by wind, birds, and deer. Birds were mist-netted near a heavily infested hemlock stand and an open field well away from any hemlock. The captured birds were rinsed in a bucket with slightly soapy water to dislodge any adelgids. Of 22 birds caught near the hemlock stand, 19 birds representing 13 species were found to be carrying adelgids. Additionally, 3 of the 14 birds captured in an old field at least 1.2 miles (2 km) from any known hemlock trees were carrying adelgids. The captured birds represented 13 species, with a robin carrying the most adelgids. Adelgid crawlers were abundant in the canopy and on the forest floor of the infested stand, where they could become attached to birds, mammals, and other forest floor inhabitants.

The eggs and crawlers are readily carried in the wind. In McClure's (1990) experiment, adelgid eggs and crawlers dispersed up to 0.8 miles (1350 m on the breeze. McClure also planted uninfested nursery hemlock seedlings upwind of the infested hemlock stand. Seedlings that were browsed by deer were more likely to be infested with adelgids than those that hadn't been browsed.

In the northeastern US, dead hemlock stands have prompted salvage logging, which is likely to contribute to long-range adelgid dispersal. Large numbers of HWA ovisacs were attached to the trunks of both hemlock and hardwood species. The eggs and crawlers can survive for up to 15 days without food in a laboratory (McClure 1990).

Humans are the main vector for long distance dispersal, as demonstrated by the small populations recently found in lower Michigan, hundreds of mile from the previously known populations in the Appalachians. In the northeastern US, the HWA has been spreading at an average rate of 12-19 miles (20-30 km) per year (McClure 1990).

It appears that the spread of the HWA may be limited by cold in the north. In the northeastern US the HWA spreads more slowly in colder areas, with a mean minimum temperature of -15°F (-26ºC) (plant hardiness zone 5B) delineating areas of slower range expansion. HWA also spreads more slowly during cold years, those with lower than average mean January temperatures (Evans and Gregoire 2007).

Potential pathways for spread

Hemlock is popular in the nursery trade, and nursery trees shipped from infested areas appear to be the primary source of new HWA infestations (MDARD 2013).

Detection

As of this writing there are no formal methods to detect the HWA, other than visual surveys for the insect and the dying trees. Areal surveys are used to detect severe infestations (declining or dead stands of trees). As mentioned under BWA detection, both the BWA and the HWA cause the needles of their host to turn from deep green to grayish green. The percent reflectance of healthy trees is lower than the percent reflectance of stressed trees (Cook et al. 2010). The method is not yet capable of distinguishing between adelgid-stressed trees and trees stressed from other causes, though.

Control

Pesticides: Pesticides are useful in treating individual trees. Several have been tried, including the systemic pesticide dinotefuran (Safari®), which is registered for use against the HWA. These herbicides can protect individual trees. Large infestations in wooded areas are next to impossible to control with herbicides, though. Additionally, dinotefuran is a neonicotinoid pesticide, and is highly toxic to pollinators and other insects.

Fertilization of infested trees appears to increase the damage done by the HWA, presumably because the insects thrive on the additional nitrogen (McClure 1992).

***Biocontrol*:** Field surveys and cage exclusion experiments on hemlock in the southeastern US found no significant predators of the HWA (Wallace and Hain 2000). This prompted a search for predators in western North America and overseas. An HWA predator beetle endemic to the Pacific Northwest, *Laricobius nigrinus* Fender (Coleoptera: Derodontidae), was an obvious choice for release (Mausel et al. 2010). From 2003 through 2005, *L. nigrinus* (Figure 60) was released in 22 localities from Georgia to Massachusetts. Release sites spanned the invasive range of the eastern HWA across USDA plant hardiness zones 5a through 7a. A native eastern North American relative, *Laricobius rubidus* LeConte (Coleoptera: Derodontidae) that feeds on the native pine bark adelgid, *Pineus strobi* (Hartig) was found completing development on the HWA as well (Mausel et al. 2008).

Figure 60. The western North American HWA predator Laricobius nigrinus *has been introduced to the eastern US to fight the HWA. (Ashley Lamb, Virginia Polytechnic Institute, Bugwood.org)*

So far *L. nigrinus* has been recovered (indicating establishment) at 59% of the release sites, but has had little noticeable effect on adelgid populations (Mausel et al. 2010). Also, establishment rates in the northern release sites (zone 5) was low. The collection site of the beetles was in Vancouver, British Columbia, which is zone 8b. Inland populations in the northern Rockies may be more cold-tolerant and have better survival rates in temperate eastern North America. Beetles from northern Idaho were collected in 2007-2010 and are undergoing evaluation.

A relative of these two North American beetles, *Laricobius osakensis* Montgomery and Shiyake (Coleoptera: Derodontidae), native to Japan, and a *Leucopis* spp. beetle from the Pacific Northwest, are currently being evaluated. It is possible that one or more of these insects will eventually provide significant control of the HWA.

Three coccinellid beetles from Japan and China have also been released in an attempt to control the HWA, including *Sasajiscymnus tsugae* Sasaji and McClure (Coleoptera: Coccinellidae), a small black lady beetle from China. So far these insects have had little effect (Mausel et al. 2010).

BEECH AND BEECH BARK DISEASE

Taxonomy, Distribution and Abundance of American Beech

Environmental role

American beech (*Fagus grandifolia; azhaawemizh*) is the only beech species native to the Americas. It is native to eastern North America, from east Texas and northern Florida north to Nova Scotia New Brunswick, and west to eastern and central Upper Michigan and eastern Wisconsin (Nixon 1997) (Figure 61). Along with the oaks and chestnuts it is a member of the Fagaceae. An outlier population in Mexico is probably a remnant of the period before the last ice advance (the Wisconsinan glaciation), when American beech probably flourished across most of North America (Heyd 2005). The westernmost known population in the Great Lakes region is northwest of Marquette Michigan. It is therefore found throughout nearly all of the 1836 ceded territory and the very eastern portion of the 1842 territory. It is absent from the central and western 1842 territory, and all of the 1837 and 1854 territories.

American beech is a valuable tree to animals and people alike. It is a slow-growing, long-lived deciduous species that attains ages of 300 to 400 years (Heyd 2005). It is a major component of many eastern deciduous forest types. It is highly shade-tolerant, and is often a co-dominant with sugar maple. The branching characteristics of beech make it attractive to raptors for perches, and several species of hawks prefer to nest in beech trees (McCullough et al. 2005). Standing beech trees that have some decay are used for nesting, roosting or insect foraging by a variety of birds, ranging from pileated woodpeckers to nuthatches. Pine martens, fishers and other mammals use cavities in beech trees for shelter or dens (McCullough et al. 2005).

Beech trees begin to produce substantial numbers of nuts at about 40 years old (McCullough et al. 2005). By age 60, large nut crops are produced every 2 to 8 years. This mast is especially important in northern forests where oak and hickory are rare. The distinctive triangular, bur-enclosed nuts are an important food for a wide variety of birds and mammals, including mice, squirrels, chipmunks, black bear, deer, fox, ruffed grouse, ducks, and blue jays (Heyd 2005). They are also enjoyed by people.

Economic value

Once considered a “weed tree” by some foresters (Houston 1975), beech wood wears well, is easily treated with preservatives, and is used for flooring, furniture, turned products and novelties, veneer, plywood, railroad ties, baskets, pulp, charcoal, and rough lumber (Heyd 2005). It also has high density and good burning qualities, and makes an excellent fuelwood (Heyd 2005). Wood from badly diseased trees is usually only good for firewood though (Houston 1983).

Even though beech reaches the western end of its range in Michigan and Wisconsin, both states still have a lot of beech trees. According to the 1993 USDA Forest Service Survey, Michigan has 7.16 million acres of Maple-Beech-Birch type containing 1.67 billion board feet of beech, or 138 million trees in all size classes. This includes 15 million beech trees greater than 9 inches dbh, and 0.9 million greater than 21 inches dbh (Heyd 2005). The most recent forest inventory estimated the Wisconsin beech tree population at about 16.6 million trees (WDNR 2009).

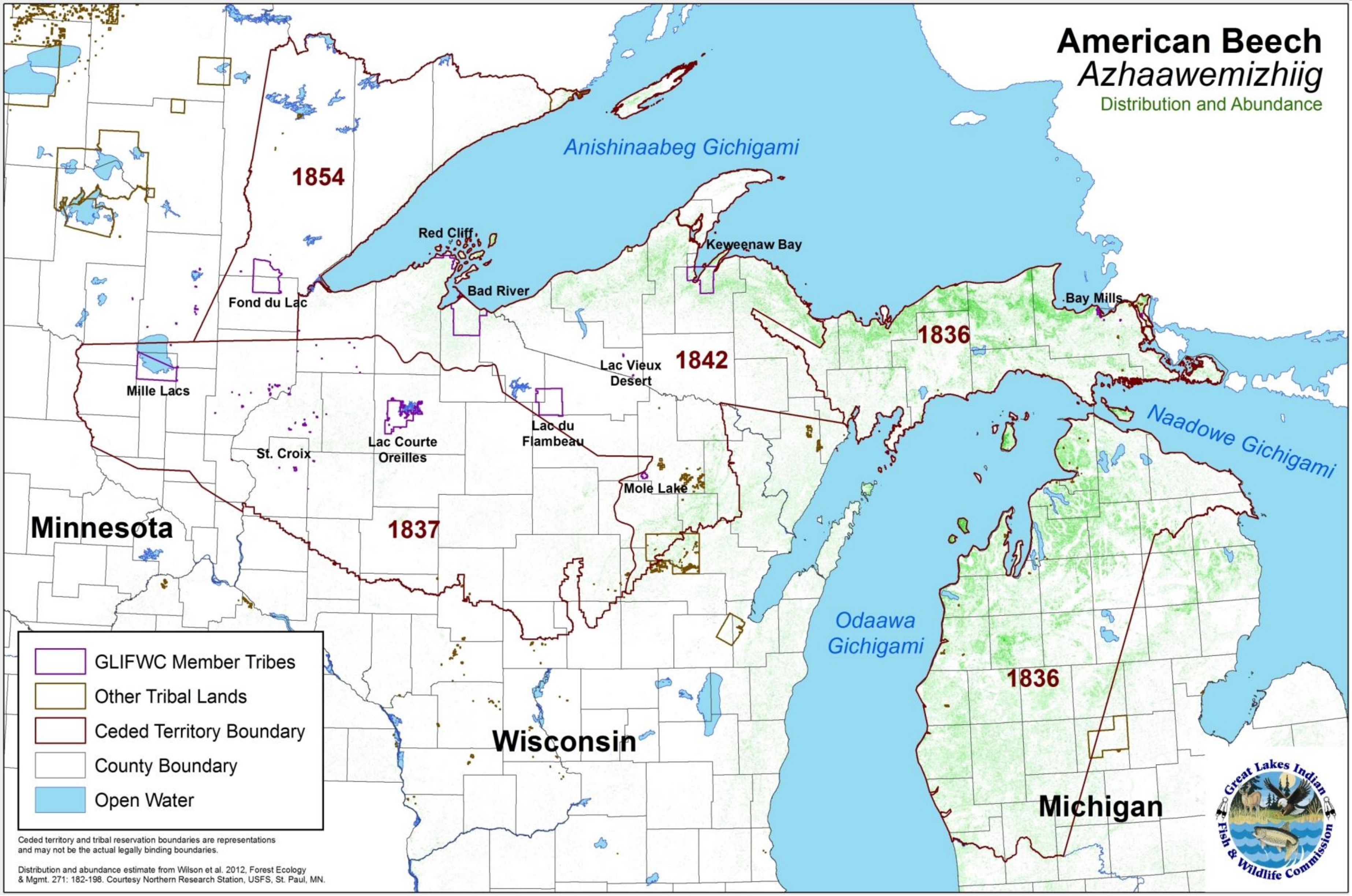

Figure 61. Estimated abundance and distribution of American beech in the ceded territory. The green shading indicates beech abundance. Shading in western Upper Michigan and the Lake Superior counties of Wisconsin indicates suitable habitat, but no wild American beech is known to occur there. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

Beech Bark Disease

History and taxonomy

The beech scale was introduced into Halifax, Nova Scotia, from Europe on ornamental European beech trees around 1890 (Ehrlich 1934). Whether one or more disease-causing *Neonectria* fungi came with it is uncertain in light of recent genetic analysis (Castlebury et al. 2006). Nonetheless the first outbreaks of beech bark disease in stands of American beech occurred in the Maritime Provinces 30 years later, and by 1931 trees were being killed in localized areas of eastern and south central Maine (Houston and O'Brien 1983). By 1975 the "killing front" of the disease (see below) had spread into Vermont, New York, and Pennsylvania (Houston 1975). The beech scale was found in Michigan in 2000, and today the scale and the disease have spread throughout most of the northern range of American beech (McCullough 2013) (Figure 62). The only stand of beech in Upper Michigan still free of the disease is the westernmost known stand, west-northwest of Marquette (Deb McCullough, 28 March 2013, pers. comm.).

Beech bark disease is a disease complex caused by an introduced scale insect (Figure 63) and one or more *Neonectria* species (Mackenzie and Iskra 2005). First the bark is attacked and altered by the European felted beech scale, *Cryptococcus fagisuga* Lind. (Hemiptera: Eriococcidae). This insect pierces and kills cells just below the surface of the outer bark, causing the bark to shrink and resulting in minute openings through which one or more ascomycete fungi of the genus *Neonectria* can enter (Ehrlich 1934, Castlebury et al. 2006).

The other component of beech bark disease is one or more *Neonectria* fungi (Figure 64). The two species of *Neonectria* (formerly *Nectria*) most commonly implicated in beech bark disease are *Neonectria faginata* (M.L. Lohman, A.M.J. Watson & Ayers) Castlebury & Rossman (formerly

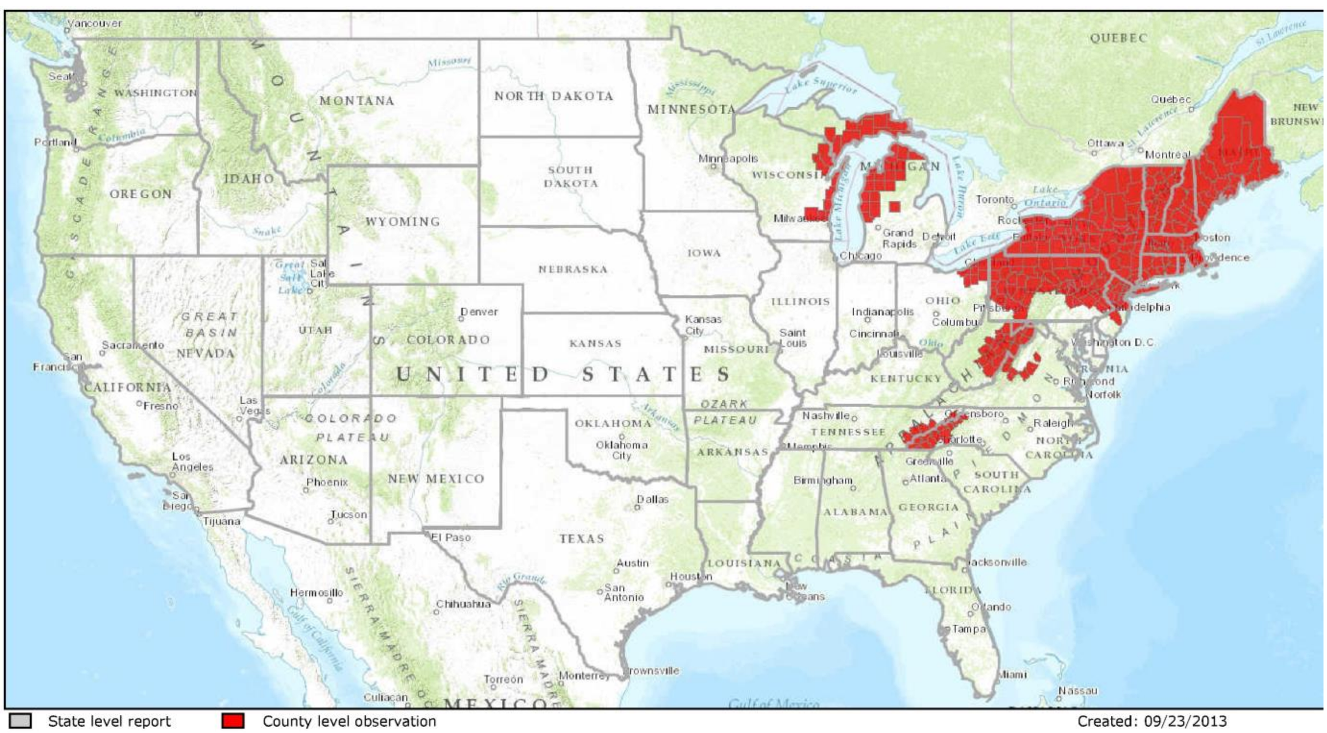

Figure 62. Beech bark scale distribution in the US. Several fungi that cause beech disease are widely established in eastern North America. (USDA Forest Service, Forest Health Protection and partners: http://foresthealth.fs.usda.gov/portal/Flex/APE).

Neonectria coccinea (Pers.:Fr.) Rossman & Samuels var *faginata* Lohman, Watson & Ayers, in part), and *Neonectria ditissima* (Tul. & C. Tul.) Samuels & Rossman (formerly *N. galligena* (Bres.) Rossman & Samuels) (Castlebury et al. 2006). Based on genetic analysis, Castlebury et al. separated *N. coccinea* from *N. coccinea* var. *faginata*, recognizing *N. faginata* as a separate species. Long thought to be introduced from Europe, *Neonectria faginata* has only been found on American beech and is apparently native to North America (Castlebury et al. 2006). On the other hand, *Neonectria ditissima* has long been considered to be indigenous to North America, but genetic evidence suggests that it may be native to Europe as well (Castlebury et al. 2006). *Neonectria faginata and N. ditissima* can be reliably distinguished with a dissecting microscope, based on differences in ascospore size and shape (Cotter and Blanchard 1981, Castlebury 2006). *Neonectra coccinea* has only been found on the bark of European beech (*Fagus sylvatica* L.) in Europe, and has never been detected in North America (Castlebury et al. 2006). Apparently *N. ditissima* is normally a minor pest on the outer bark of a variety of tree species, and it and *N. faginata* only become deadly to beech if an opening allows them to reach the inner bark of the tree. Castlebury et al. conclude by warning that care should be taken to avoid inadvertently introducing *N. faginata* to Europe, or *N. coccinea* to North America.

Life cycle of beech scale

Adult beech scale insects are yellow, soft-bodied and 0.02 to 0.04 inch (0.5 to 1.0 mm) long (McCullough et al. 2005). The adults are legless and wingless and have only rudimentary antennae. Several glands secrete the white, wooly wax that covers their bodies. The scales reproduce by parthenogenesis, meaning that all beech scales are females and lay eggs without mating. Because all the adults lay eggs, scale populations build rapidly when suitable hosts are present.

Figure 63. European felted beech scale nymphs. The cottony wax has been pushed aside for this photo. (Chris Malumphy, The Food and Environment Research Agency, Bugwood.org)

Beech scales have one generation per year (McCullough et al. 2005). Adults lay pale yellow eggs on the bark in midsummer and then die. The eggs are attached end-to-end in strings of four to seven. The eggs hatch from late summer until early winter. The immature scales are called crawlers or nymphs (Figure 63). These crawlers have functional antennae and legs and can move about. When a crawler finds a suitable location on a host tree, it forces its long, tubelike stylet into the bark and begins to drink sap from the tree. It then molts to become a second-stage crawler. This stage has only rudimentary legs and is immobile (Houston 1994). These second-stage

Figure 64. Fruiting bodies (perithecia) of Neonectria ditissima*, one of the fungi known to cause beech bark disease. (Joseph O'Brien, USDA Forest Service, Bugwood.org)*

crawlers produce white wax that eventually covers their bodies. Second-stage crawlers overwinter and molt to the adult stage the following spring, starting the cycle anew (McCullough et al. 2005).

Impact on beech

Crawlers prefer to colonize areas of the tree where the bark is rough (McCullough et al. 2005). Infestations often start near old branch stubs, under large branches, or sometimes beneath mosses or lichens. The first small spots or patches of “white wool” usually appear around areas of rough bark. As the scale population builds, the entire trunk and large branches may become covered with white wool (Figure 65).

One of the first symptoms that the bark has died are “tarry” spots (Houston 1994). A reddish-brown, tar-like liquid sometimes oozes from the bark tissues killed by the fungi (Figure 66). Fungal perithecia sometimes form around the tarry spots (McCullough et al. 2005). Other injuries, however, can also cause tarry spots to form.

As the disease progresses the *Neonectria* fungi kill areas of woody tissue, sometimes creating cankers on the tree stem and large branches Figure 67). Typically only the bark is killed by the fungi, but occasionally the cankers are infected by other fungi, which may invade the sapwood (McCullough et al. 2005). The fungi may infect localized areas on the tree, causing linear strips of bark to die along the trunk or branches. If the fungus invades only narrow strips of bark on vigorous trees, callus tissue often forms and the bark becomes rough. Sometimes the tree is able to wall off these cankers if they are small. If beech scale numbers are high, however, the *Neonectria* fungus often spreads or coalesces rapidly despite callus formation. If larger or more numerous areas are infected, the trunk of the tree may be girdled and killed.

Figure 65. Beech scales forming white patches on beech tree trunks. (Joseph O’Brien, USDA Forest Service, Bugwood.org)

Figure 66. Tarry spots are one of the first symptoms of beech bark disease. The bark in these spots has died. (Joseph O’Brien, USDA Forest Service, Bugwood.org)

Scales cannot survive on tissue that has been killed by the fungus (McCullough et al. 2005). A strip of scale-free bark running down an otherwise infested tree often indicates where bark has died.

On younger trees infection is less abundant, the fungus advances less readily, and individual lesions frequently become surrounded by healthy bark and wood, and eventually form depressed areas but never typical cankers (McCullough et al. 2005). Once the trees become generally infested by the beech bark scale, *Neonectria* infection develops on the majority of them within three years and kills some of them in one or two years.

A third species of *Neonectria*-like fungus, *Bionectria ochroleuca* (Schwein.) Schroers & Samuels, has been found on infested beech in several eastern states, and the asexual form has been found in Michigan (McCullough et al. 2005).

Both beech bark fungi produce fruiting bodies called perithecia. Perithecia of *N. ditissima* (Figure 63) and *N. faginata* are tiny and bright red and occur in clusters on living or dead bark. Perithecia of *B. ochroleuca* are lighter in color — usually salmon or pink. Each perithecium is filled with sacs of spores. These spores are the sexual stage of the fungi. Spores are released from perithecia in the fall and can be carried in the wind. On some infected trees, perithecia are abundant, causing large areas of the bark to appear red. In Michigan and some other areas, however, perithecia are often difficult to find.(McCullough et al. 2005).

Trees dying from *Neonctria* infection usually have a distinct appearance when viewed from a distance (McCullough et al. 2005). Emerging spring leaves do not mature and crowns appear sparse or ragged. Leaves remain on the trees but become yellowish later in the summer (Figure 68). As infestation progresses, the foliage and twigs dry and die, whole branches cease to leaf out, and large areas of bark on the trunk crack, often loosening from the wood and eventually falling away (Ehrlich 1934). Infested trees are often further weakened by ambrosia beetle galleries, making them susceptible to being snapped off by high winds (Heyd 2005, Papaik et al. 2005). This breakage is called “beech snap” and presents a hazard to humans where beech trees occur in campgrounds homes, or other populated areas.

As with other tree species under attack by virulent introduced diseases and pests, this may have been the end of the line for North American beech trees. But the American beech has another trick up its sleeve. Unlike chestnuts and most other tree, beech trees have the ability to sprout from their roots (Houston 1983). After the main trunks of the trees are killed, the root systems sprout prolifically, leading to thickets of saplings and small trees. These “beech thickets” have little value for wildlife though, and are also susceptible to beech bark disease.

Presently, BBD occupies less than 30% of the range of American beech in North America, and is expanding at a rate of approximately 14.7 ± 0.9 km ⁄ year (Morin et al. 2007). It likely already affects stands containing most of the beech basal area in the United States (Morin et al. 2007, Evans and Finkral 2010).

Figure 67. Cankers on susceptible tree caused by Neonectria *fungi. These cankers can coalesce and girdle the tree. (Linda Haugen, USDA Forest Service, Bugwood.org)*

Figure 68. Yellowing upper leaves are a sign of beech bark disease. (William M. Ciesla, Forest Health Mgmt Intl, Bugwood.org)

Vectors and pathways for spread

The crawlers are the only mobile stage of the beech scale, but are wingless and can only walk short distances. Like the balsam and hemlock wooly adelgids, however, a small percentage blow significant distances on the wind, carried on upward currents above the forest canopy (Wainhouse 1980). A very small percentage of the crawlers are probably also carried by birds.

Humans are probably the main vector in long-distance dispersal of the BBS. Moving infested beech firewood between midsummer and early winter when the first-stage crawler is present can spread the scale to new areas. The West Virginia outbreak (1981) began at a well-visited scenic area, and the Ohio infestation (1984) began at a popular arboretum (Houston 1994). The beech scale infestations in Luddington, Michigan, was centered on a campground (McCullough et al. 2005).

Control

Very cold winter temperatures around -30°F (-35°C) or lower and heavy fall rainfalls are both highly correlated with lowered beech scale levels (Houston and Valentine 1988). Presumably overwintering populations are reduced by cold temperatures, while heavy fall rains wash the crawlers off the trees.

Several insect predators of beech scale are known, the most important of which in North America is the native twice-stabbed lady beetle *Chilocorus stigma* (Say) (Coleoptera: Coccinelidae) (Ehrlich 1934). Although all four larval instars as well as the adults of this beetle feed on the beech scale and the beetle can build up to fairly high levels, the beetle is not effective in reducing scale populations at the stand level (Mayer and Allen 1983).

Effects on the forest

Three stages of beech bark disease have been defined: The advancing front, the killing front, and the aftermath zone (Houston and O'Brien 1983). The **advancing front** includes areas that have been recently invaded by the beech scale. These are characterized by forests with many large, old trees supporting scattered, sparse but increasing populations of beech scale. Studies in the northeastern US indicate that this front advances at roughly 6 miles per year (McCullough et al. 2005).

Once the scale insects build to large numbers, the forest becomes part of the **killing front**, characterized by high beech scale populations, severe *Neonectria* attacks, and heavy tree mortality.

After heavy beech mortality has occurred, forests are characterized by some residual big trees and many stands of small trees, often of root-sprout origin. The stand enters the **aftermath zone**. Paradoxically, stands in the aftermath forest often have more beech stems than before the disease arrived. The young stems are often rendered highly defective, though, through the interactions of established populations of beech scale, *Neonectria* fungus, and another, native scale insect, *Xylococculus betulae* (Perg.) Morrison. This native scale insect is much more damaging to beech after the trees have been weakened by beech bark disease (Houston 1975, Houston and O'Brien 1983). Yet not all of the trees are reduced to shrub thickets.

Even though the American beech is generally more susceptible to the beech scale insect than European beech, a few trees across the range of the disease often remain uninfested even when insect populations are high (Houston 1994). Insect- and disease-free trees are most obvious in long-affected forests, where they contrast sharply with the general population of susceptible and diseased trees. Resistant trees make up less than 1% of the population in the eastern US (Houston 1994), but in Michigan 1-2% appear to be resistant to the scale insect (McCullough 2013). Because resistant trees often occur in groups, relatively large numbers of them may occur locally within some forests while other forests may have few or none (Houston 1983, 1994).

Houston (1983) tested the resistance of scale-free, disease-free trees in infested stands Maine and New Hampshire directly, by attaching disks of bark with fresh eggs cut from heavily infested trees to these disease-free trees, and enclosing them beneath foam squares. Nearby, infested trees were used as controls by scrubbing areas of bark free of scales before attaching the disks to them. By the next year the test areas of the trunks of all the formerly infested trees had become reinfested, while the scale was either unable to become established or unable to complete its life cycle on disease-free trees. This demonstrated that the disease-free trees were resistant or immune to infestation by the scale.

Grafting experiments (Ramirez et al. 2007) found that resistant stems on susceptible, infested trees supported significantly fewer scales than susceptible stems, or were colonized by adult scales but remained free of eggs or attached crawlers, also indicating partial to total resistance. Analyses of polymorphic isozymes have revealed that resistant trees in groups are often related, and are clones of root sprout origin, families closely related by descent, or mixtures of these (Houston and Houston 2000).

Houston (1994) writes, “In long-infested aftermath stands, severely affected trees eventually lose vigor, grow slowly, and then die, while the more vigorous, more resistant beech trees and trees of other species take over. In any particular forest the rate and pattern of this shift depend in large part on the relative density and frequency of the beech component and on the distribution patterns of resistant Trees, a legacy of past forest management practices. There can be, therefore, a third phase to this disease-a phase of accommodation wherein aftermath forests continue to adjust to the disease. This accommodation phase is most readily observed in forests undisturbed by harvest. However, harvest operations in these badly diseased and slowly declining beech stands can trigger once again the formation of new highly susceptible thicket stands.”

The future of American beech

In many ways the future of American beech looks brighter than for the American chestnut, North American ash species, and other trees being decimated by highly virulent, introduced diseases and insects. The European felted scale and its fungal accomplices will not eradicate American beech from the landscape. It may take generations, but (climate change and human population growth aside), this vigorous tree will eventually prevail over beech bark disease, and once again become an important part of North America’s forests.

BIRCH DECLINE AND THE BRONZE BIRCH BORER

White birch

It is hard to think about the northwoods without thinking of white birch. White birch (*Betula papyrifera; wiigwaasatig*) is found most often in even-aged stands that have developed after heavy cutting or fire (Marquis et al. 1969, Safford et al. 1990). White birch is also found in uneven-aged stands as scattered long-lived individuals or occasionally in small groups, where logging or some natural disturbance created a canopy opening. White birch tolerates a wide variety of soil conditions, though it is usually more abundant on drier sites than on wet or poorly drained soils. The best-developed stands are on well-drained, sandy loams, on cool moist sites (Safford et al. 1990). Saplings and mature trees have relatively low shade tolerance, though shade-tolerance of seedlings is high (Perala and Alm 1990). White birch is relatively short-lived, reaching a maximum age of about 140 years (Marquis et al. 1969).

With its light, wind-blown seeds, white birch is a good colonizer of disturbed forest, taking advantage of logged sites and blowdowns (Safford et al. 1990). It is a weak competitor with shade-tolerant northern hardwood trees such as sugar maple, yellow birch, and balsam fir though, and generally disappears from such stands after one generation (Marquis et al. 1969).

During the course of writing this paper several tribal elders and at least one member of the Voigt Intertribal Task Force expressed concern about the decline of white birch over the years. Birch stands frequently experience dieback after 60-75 years (Jones et al. 1993). Birch decline is caused by multiple factors including drought, excessive heat, soil compaction, and is aggravated by the bronze birch borer (*Agrilus anxius* Gory) (Coleoptera: Buprestidae) (Marquis et al. 1969).

A close relative of the emerald ash borer, the bronze birch borer (Figure 69) is endemic (native to and only found in) North America. Based on public records and expert reports, Muilenburg and Herms (2012) constructed a low-resolution (to state) map of the birch borer’s distribution. The birch borer is native to the northern hardwood and boreal forest regions of North America, from Virginia to Colorado, south to Arizona and California, and north into most of Canada There are also records from Arkansas, Georgia and North Carolina.

The bronze birch borer’s natural hosts include white birch (*Betula papyrifera*), yellow birch (*Betula alleghaniensis*), the western North American water birch (*Betula occidentalis* Hook.), and two eastern North American species: sweet birch (*B. lenta* L.), gray birch (*B. populifolia* Marshall). Another native birch species, river birch (*Betula nigra*), appears to immune to the bronze birch borer (Nielsen et al. 2011). River birch is native to the eastern and central US, reaching the ceded territory in west central and central Wisconsin (Furlow 1993).

Notably, a number of birch species introduced by the horticultural trade are much less resistant to the birch borer, including European white birch (*Betula pendula*), downy birch (*Betula pubescens* Ehrh.), monarch birch (*Betula maximowicziana* Regel), and Szechuan white birch (*Betula szechuanica* Jansson) (Nielsen et al. 2011). When 100-200 individuals of each of these species were planted together with various native birch species in an experiment in Ohio, virtually all of the individuals of the non-native species were killed by the birch borer within 9 years, while those of most to nearly all of the native species were unscathed, despite the severe drought of 1988. This experiment demonstrated how host species (in this case native birch) that share a coevolutionary history with a native pest (the BBB) have evolved targeted defenses towards those pests. It also suggests that if the birch borer were introduced to Europe or Asia, it could threaten its new hosts, as the EAB and other introduced pests have done to native trees here.

The life cycle of the bronze birch borer is very similar to that of the EAB. The larvae go through 4 instars, during which time they tunnel just below the bark. The larvae usually take 2 years to develop into beetles, at least in the more northern parts of the range (Muilenburg and Herms 2012). Like EAB larvae, birch borer larvae are capable of girdling and eventually killing their host tree if they become abundant enough. The adults emerge in early to late summer, leaving frass-filled larval galleries and D-shaped exit holes. The birch borer may girdle branches as well, leading to crown dieback.

Figure 69. The bronze birch borer is a native relative of the EAB that primarily attacks stressed or dying birch trees. Like the EAB, it leaves D-shaped exit holes (but ONLY in BIRCH!). Steven Katovich, US Forest Service, Bugwood.org.

Muilenburg and Herms (2012) outline a “cohort senescence model” based on observations of a Hawaiian rainforest tree by Mueller-Dombois (1986), which may explain much of the dieback observed in even-aged white birch stands. A relatively short-lived, early successional species, white birch often forms even-aged, monospecific stands following disturbances such as fire, windstorms and logging. New stands experience a period of vigorous growth, followed by a stage of maturity. These mature trees eventually exhibit decreased vigor. At some point environmental factors such as drought or excessive heat stress the trees, leading to large-scale dieback and mortality (Jones et al. 1993). Stress can also trigger a birch borer outbreak, such as the one that occurred in the Upper Peninsula of Michigan in 1991, following the drought years of 1988 and 1989 (Jones et al. 1993). This severe drought resulted in mortality of over 105 million birch trees across the Great Lakes region of North America (Jones et al. 1993).

A number of other insects attack white birch (Marquis et al. 1969). These include leaf feeders and defoliators such as the forest tent caterpillar, *Malacoronza dintria*; the birch skeletonizer, *Bucculatrix canademirella*; the birch leaf miner, *Fenusa pusilla*; the birch leaf-mining sawfly, *Phyllotomu nemoruta*; and the birch casebearer, *Coleophowu sulmani*. Cambium miners such as *Agromyza pruinosu* and ambrosia beetles such as *Trypodendron betulae* may cause defects in birch wood. Insects such as *Apion walshii*, and their associated fungi, cause considerable damage to paper birch seeds during some years.

A NOTE ON THE JAPANESE CEDAR LONGHORNED BEETLE

Northern white cedar (*Thuja occidentalis; giizhikaandag*) occurs throughout the ceded territory, though it is more common in the north (Figure 70). It is tolerant of a wide variety of soil types, but doesn't occur on very dry soils. It is often associated with cool, moist, nutrient-rich sites, particularly on organic soils near streams or other drainage-ways, or on calcareous mineral soils (Johnston 1990).

The small Japanese cedar longhorned beetle *Callidiellum rufipenne* (Motschulsky) (Coleoptera: Cerambycidae), is native to East Asia and Japan (sources in Maier and Lemmon 2000). It is primarily a pest or scavenger of conifers in the family Cupressaceae (Maier 2007). In eastern North America and the ceded territory this plant family includes northern white cedar, common juniper (*Juniperus communis*) and eastern red cedar (*Juniperus virginiana*). In its native range it generally only attacks dead and dying trees (Shibata 1994).

The JCLB has repeatedly been intercepted in solid wood packing material at ports in North America dating back to at least the mid-1900s (Maier and Lemmon 2000, Maier 2007). But the beetle wasn't detected in the wild in North America until 1997, when an adult JCLB was collected from an eastern red cedar in eastern North Carolina (Maier and Lemmon 2000). Larvae were subsequently reared from dead red cedar wood nearby (Maier and Lemmon 2000). Populations have since been found in several nearby states on the Atlantic coast (Maier 2007) (Figure 71).

Similar to EAB larvae on ash trees, the larvae of the Japanese cedar longhorned beetle (JCLB) burrow through the inner bark of cedar and other members of the Cupressaceae. Burrowing by the growing larvae often causes the bark of the host tree to split open. The larvae pupate in the fall, and the adults emerge in the spring, leaving oval exit holes (Figures 72 and 73).

Maier and Lemmon (2000) transported live white cedar trees from several nurseries and garden centers in Fairfield and New Haven, Connecticut, to a double screened enclosure in New Haven. In March of 1999 emerging adults were collected from these trees, proving that the JCLB can reproduce on living white cedar. A subsequent experiment (Maier 2007) showed that the JCLB could NOT reproduce on eastern North American (and a few European) species of fir (*Abies*), tamarack (Larix), pine (*Pinus*), spruce (*Picea*), eastern hemlock, or western Douglas fir, *Pseudotsuga menziesii* (Mirbel) Franco.

The only suitable eastern North American hosts appeared to be Atlantic white cedar (*Chamaecyparis thyoides*), white cedar, red cedar, and common juniper (Maier 2007). Furthermore, except for stressed nursery or landscape white cedar plants, the JCLB has only been found to emerge from dying or dead wood of these suitable species. The JCLB also seems unable to reproduce in debarked poles of these suitable species.

The extensive trapping program of Maier (2008) has shown that the JCLB is well-established on the east coast and will likely continue to spread. While these investigations would seem to indicate that the JCLB will not become a serious pest of juniper and cedar in the ceded territory, it would be wise to take the same precautions recommended to avoid the spread of other forest pests.

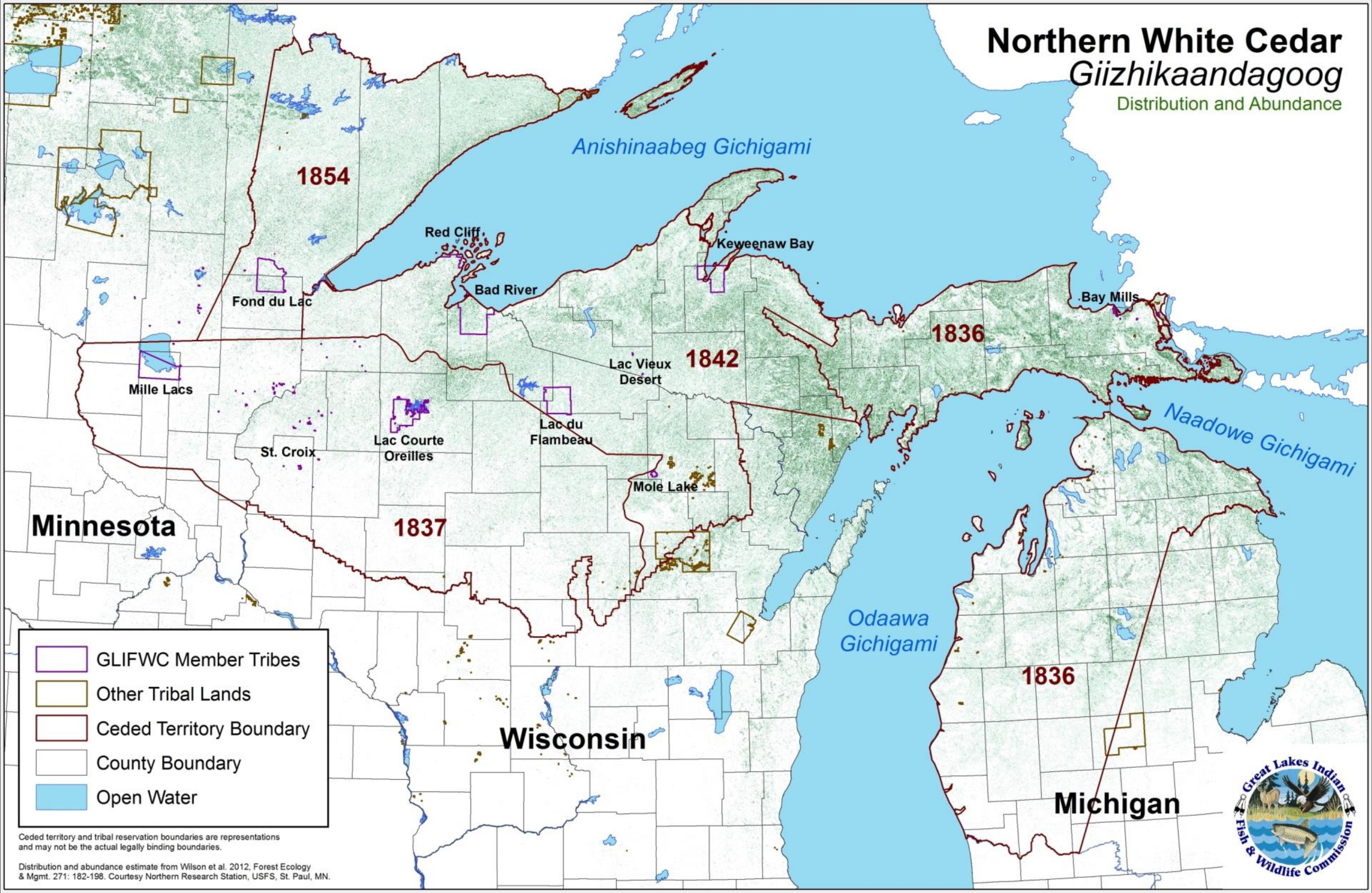

Figure 70. Estimated abundance and distribution of northern white cedar in the ceded territory. The green shading indicates white cedar abundance. Red polygons indicate approximate ceded territory boundaries. Estimates constructed by Wilson et al. (2012).

Figure 71. Known distribution of the Japanese cedar longhorned beetle. (USDA Forest Service, Forest Health Protection and partners: http://foresthealth.fs.usda.gov/portal/Flex/APE).

Figure 72. Adult JCLBs are 1/4 to 1/2 inch (6-14 mm) long. They emerge in early spring to start a new generation. (Connecticut Agricultural Experiment Station, Bugwood.org)

*Figure 73. Cracked bark and oval exit holes left by the JCLB on cultivated Alaska cedar (*Chamaecyparis nootkatensis *(D. Don) Spach. (Connecticut Agricultural Experiment Station, Bugwood.org)*

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