

# Mapping the Occurrence of Tree Damage in the Forests of the Northern United States

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## Abstract

The U.S. Forest Service Forest Inventory and Analysis Program uses visual inspections of trees from bottom to top to record damage that is likely to prevent survival, reduce growth, or hinder capability to produce marketable products. This report describes the types of damage and occurrence as measured across the 24-state northern region between 2009 and 2013. Descriptive statistics and spatial occurrence maps are presented by genus, species, and state. Inter- and intra-species variation, as well as biotic and abiotic disturbance agents, are issues that should be considered while analyzing and interpreting data from damage indicators.

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## Cover Photo

Beech nectria fruiting bodies. Photo by Elizabeth Morin, used with permission.

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# INTRODUCTION

Tree damage is an important visual indicator of tree and forest health. The agents that cause damage to trees can vary greatly in the type and severity of injury inflicted. Furthermore, the impact on health, vigor, and value can be quite different depending on the damaging agent and where the damage occurs. For example, decay on the stem of a tree may decrease its value for timber products, but it may have little impact on the tree's ability to survive. By contrast, a tree with a flooded root system is likely to suffer severe health impacts including potential mortality. Damaging agents fall into several general categories including insect, disease, decay, animal, weather, and human activity.

Assessment of damage to individual trees is conducted by the U.S. Forest Service Forest Inventory and Analysis (FIA) Program, and these results can be presented at a variety of geographic scales. Aerial detection surveys of biotic and abiotic damage to forest ecosystems are conducted as part of the U.S. Forest Service Forest Health Protection (FHP) Program, and they provide another source of information about tree damage (available for download here: <http://www.fs.fed.us/foresthealth/technology/adsm.shtml>). This combination of ground (FIA) and aerial (FHP) surveys provides critical and complementary information about tree damage across the United States. The results presented here are focused on observations from FIA plots.

At the state level, the primary outlet for reporting tree damage is through 5-year FIA reports mandated by the 1998 Farm Bill [Agricultural Research, Extension, and Education Reform Act of 1998] (Public Law 105-185). The current status and trends in forest extent and condition (including tree damage) are described in these reports (e.g., Morin et al. 2015). The purpose of this summary report is to document the occurrence of damage across the northern region (Fig. 1) so state-level summaries have some context within their broader geographic area.

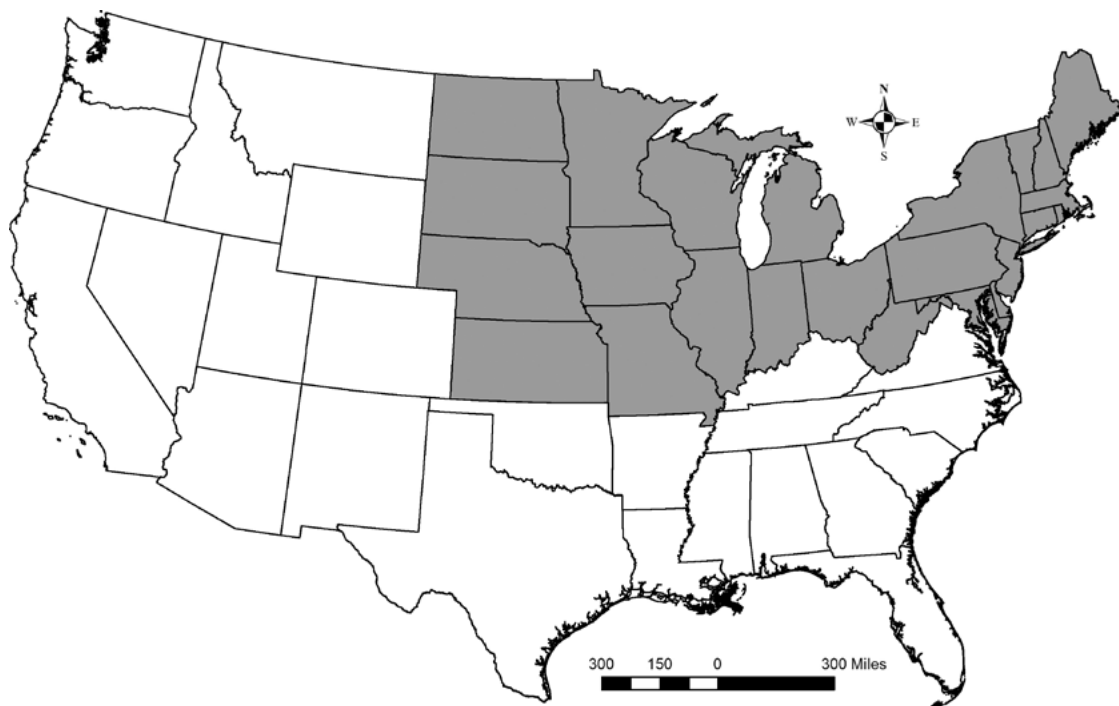


Figure 1.—Northern region states included in the tree damage summary are shaded gray.



## METHODS

The FIA program conducts an inventory of forest attributes nationwide (Bechtold and Patterson 2005). The current FIA sampling design is based on a tessellation of the United States into hexagons approximately 6,000 acres in size with at least one permanent plot established in each hexagon. Tree and site attributes are measured on plots falling in forest land; at each plot, measurements are taken in four 24-foot fixed-radius subplots. We summarized the damage data collected on 41,430 FIA plots sampled between 2009 and 2013 in the 24-state Northern Research Station FIA (NRS-FIA) region to serve as a baseline in comparisons of future data (Fig. 1, Table 1).

Tree damage is collected on all trees  $\geq 5.0$  inches in diameter at breast height (d.b.h.) on each subplot (U.S. Forest Service 2013). Up to three damaging agents may be recorded per tree. In general, a recorded damage is likely to: (1) prevent the tree from surviving more than 1 to 2 years, (2) reduce the growth of the tree in the near term, or (3) negatively affect a tree's marketable products. If there are more than three damage agents observed, the most

**Table 1.—Number of FIA plots with at least one accessible forested condition by state and year**

State	Year					Total
	2009	2010	2011	2012	2013	
Connecticut	64	62	59	66	67	318
Delaware	23	27	26	26	30	132
Illinois	210	193	199	225	189	1,016
Indiana	406	407	367	407	196	1,783
Iowa	121	143	129	116	119	628
Kansas	92	117	126	130	114	579
Maine	639	638	631	627	628	3,163
Maryland	99	95	82	80	84	440
Massachusetts	115	110	103	110	104	542
Michigan	720	884	876	855	820	4,155
Minnesota	1,197	1,242	1,170	1,294	1,267	6,170
Missouri	668	614	662	613	612	3,169
Nebraska	62	58	71	66	64	321
New Hampshire	162	163	197	215	208	945
New Jersey	70	82	76	65	65	358
New York	656	634	638	639	657	3,224
North Dakota	40	34	43	29	37	183
Ohio	325	337	328	307	329	1,626
Pennsylvania	590	589	607	618	577	2,981
Rhode Island	22	26	23	22	28	121
South Dakota	67	70	77	84	79	377
Vermont	145	157	181	187	180	850
West Virginia	386	364	430	422	413	2,015
Wisconsin	1,272	1,245	1,259	1,311	1,247	6,334
Total	8,151	8,291	8,360	8,514	8,114	41,430

important ones are recorded based on the list of impacts above (i.e., agents threatening survival are more important than agents that reduce wood quality). In general, agents that affect the roots or bole tend to be the most threatening because they have the capacity to affect the entire tree; damage to peripheral parts of the tree may be temporary because leaves, shoots, and reproductive structures can be replaced.

The damage codes used for this variable come from a January 2012 Pest Trend Impact Plot System (PTIPS) list from the Forest Health Technology Enterprise Team (FHTET) (U.S. Forest Service 2015). The list has been modified to meet FIA needs and is made up of general damaging agents and then subdivided into specific agents. Not all PTIPS codes are used because some do not cause tree damage as defined above while others are better recorded as a general agent. The NRS-FIA region identifies some specific agents within their area, and this may be different in other FIA regions. For this report, all occurrences of specific agents were collapsed into seven general categories: insect, canker, decay, animal, weather, logging, and other. For example, a tree that was observed to have emerald ash borer (EAB; *Agrilus planipennis* Fairmaire) damage was reclassified as insect damage, and a tree that was observed to have a flooded root system due to a beaver dam was reclassified into the animal damage category.

Results are presented for the top 20 tree genera sampled within the NRS-FIA region. Additional analyses are presented for species and damaging agents within those genera where substantial damage was observed.

## RESULTS

### Regional Summary

Tree damage was assessed for 1,414,919 trees on 41,430 forested plots. A total of 186 species in 61 genera was observed; 20 species had 20,000 or more observations and 20 genera had 9,000 or more observations.

The majority of trees were observed to have no damage present (76 percent). The most commonly observed types of damage were decay (16 percent) and insects (4 percent). Decay was observed across the study region, but the area with the highest percentage of trees with damage was in the Plains States where tree cover is sparse (Fig. 2). Insect damage was also observed across the study area, but hotspots include southern New England, southern Michigan, and the Plains States (Fig. 3).



Decay fungi on rotting stem. Photo by Randall Morin, U.S. Forest Service.

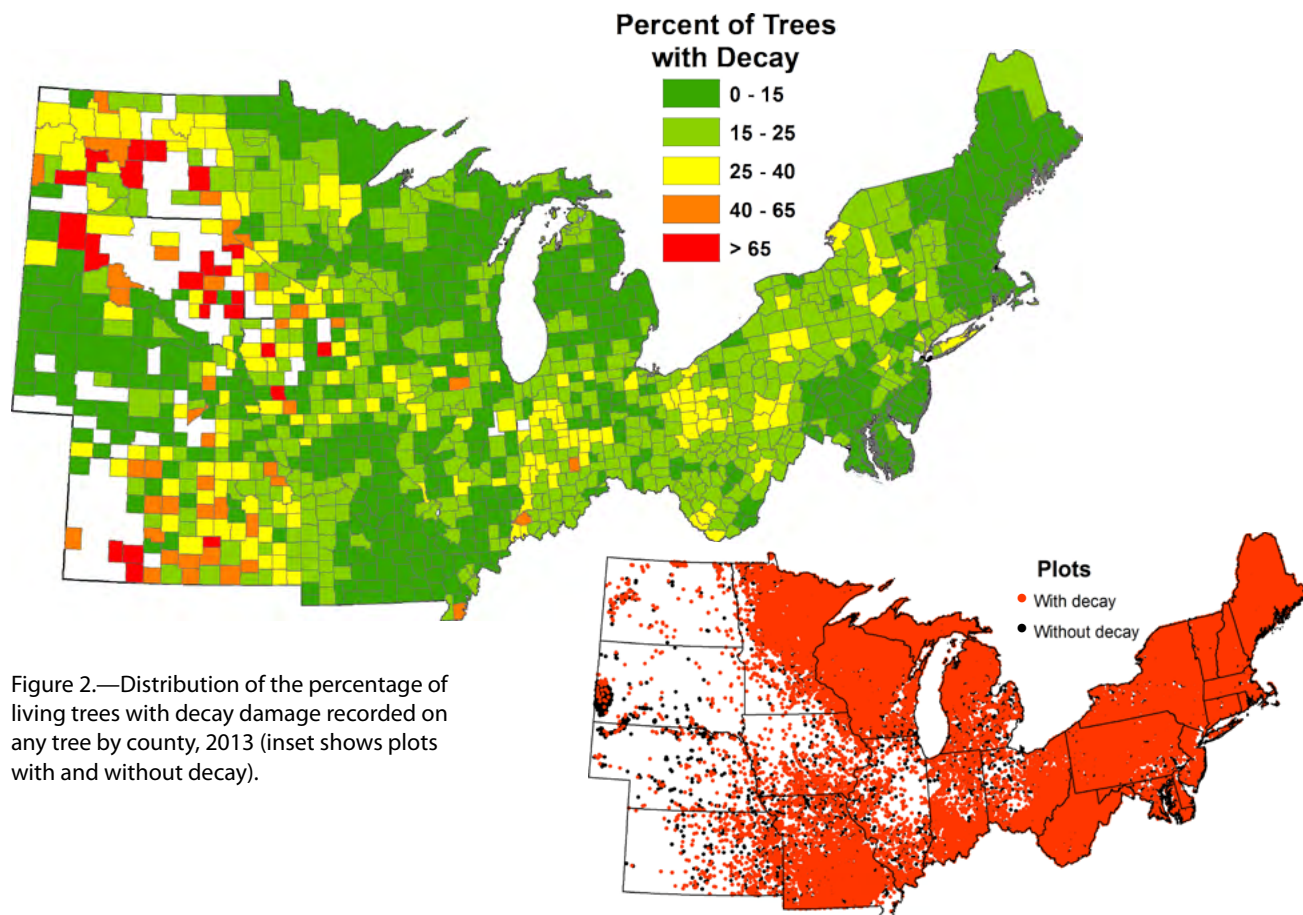


Figure 2.—Distribution of the percentage of living trees with decay damage recorded on any tree by county, 2013 (inset shows plots with and without decay).

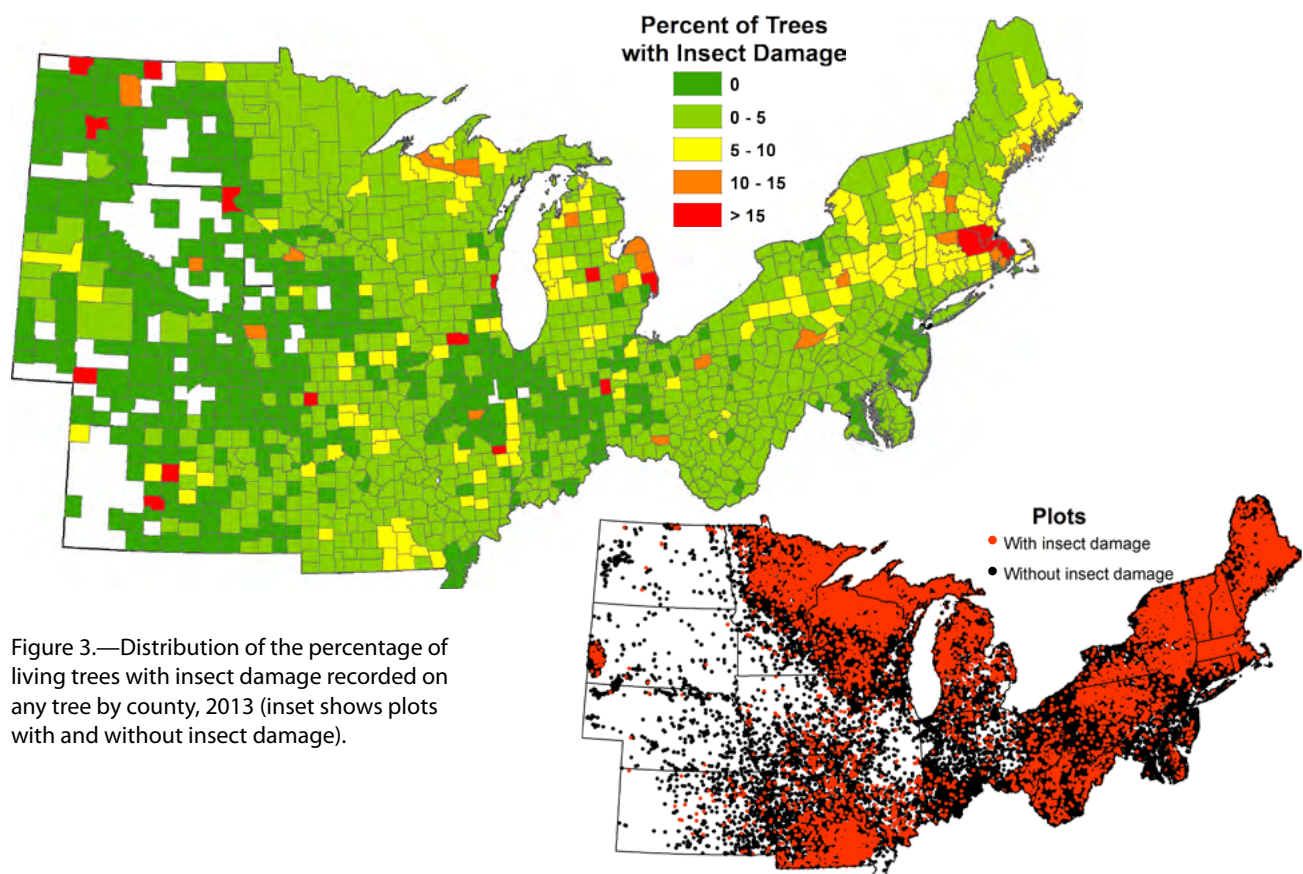


Figure 3.—Distribution of the percentage of living trees with insect damage recorded on any tree by county, 2013 (inset shows plots with and without insect damage).

The majority of trees were observed to have no damage present, but this varied greatly by genus (Fig. 4). Hardwoods generally had a higher occurrence of damage observed than softwoods. The percentage of hardwood trees observed without damage by genera ranged from 30 percent for *Fagus* to 83 percent for *Quercus*, and the percentage of softwood trees observed without damage by genera ranged from 75 percent for *Thuja* to 93 percent for *Picea*. The types of damage that were recorded also differed greatly among genera (Fig. 5).

By a large margin, the most common type of damage observed was decay (16 percent of all trees). However, the occurrence of decay varied greatly by genus and, similar to overall damage, softwood species were generally less likely than hardwoods to be observed with decay. The percentage of hardwood trees observed with decay by genera ranged from 10 percent for *Ulmus* to 35 percent for *Fagus*, and the percentage of softwood trees observed with decay by genera ranged from 3 percent for *Picea* to 22 percent for *Thuja* (Fig. 6).

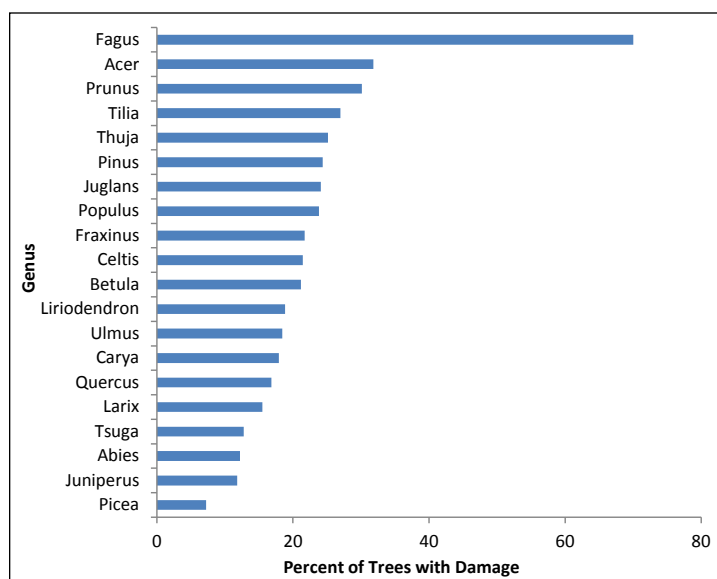


Figure 4.—Percentage of trees with damage observed by genera, 2013.

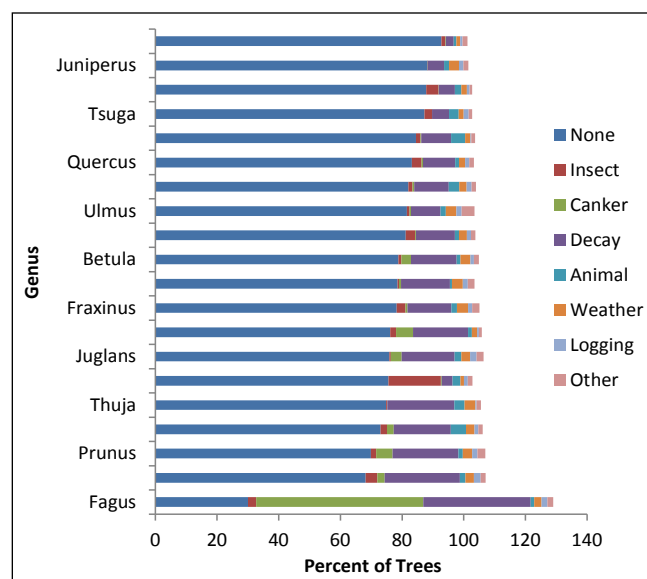


Figure 5.—Percentage of trees observed by genera and damage type, 2013. Percentage totals can be above 100 due to the possibility of multiple damages being recorded on individual trees.

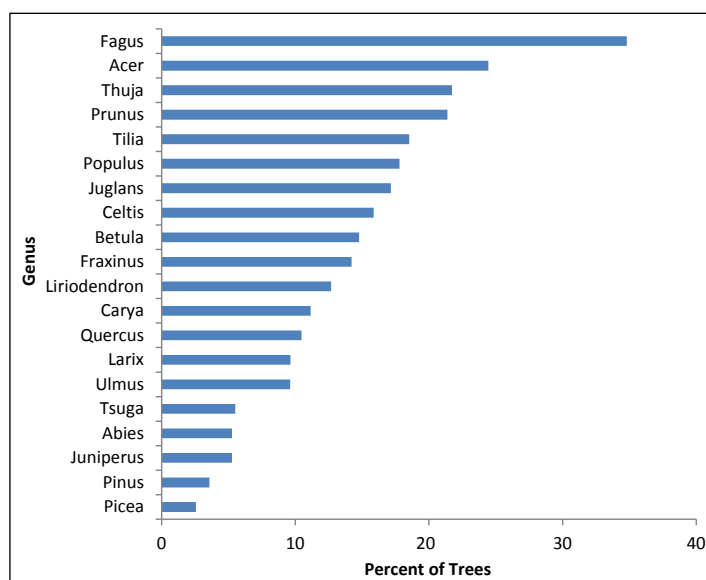


Figure 6.—Percentage of trees observed with decay by genera, 2013.



Although not nearly as common as decay, insect damage was observed on approximately 4 percent of all trees. The tree genus most often observed with insect damage was *Pinus* (17 percent of trees). Insect damage was recorded on less than 5 percent of trees in each remaining genus (Fig. 7). However, when individual species were examined, it was noted that sugar maple (*Acer saccharum*) and eastern white pine (*Pinus strobus*) had insect damage recorded on 9 and 40 percent of trees, respectively (Fig. 8).

The only other damage category that was observed on more than 3 percent of all trees was cankers. The tree genus most often observed with canker damage was *Fagus* (54 percent of trees). Cankers were also recorded on over 5 percent of trees each for *Populus* and *Prunus*. The incidence of cankers on each remaining genus was 3 percent or lower (Fig. 9).

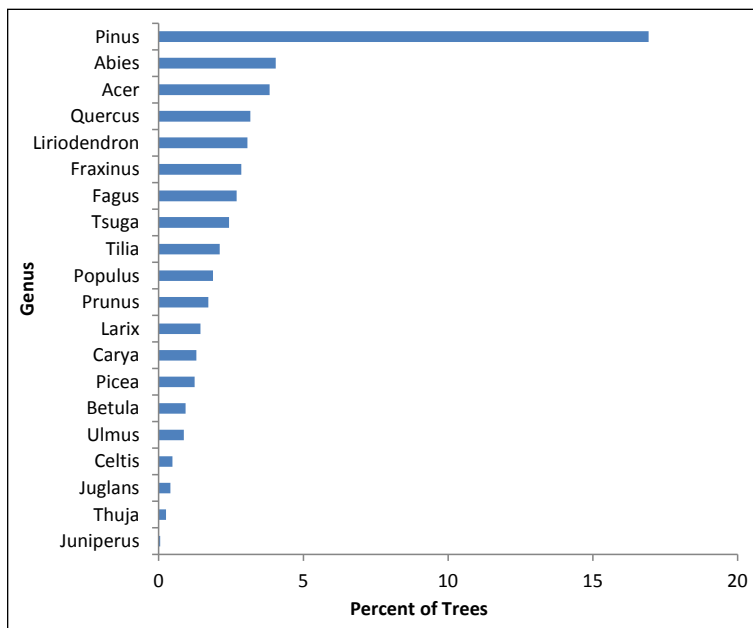


Figure 7.—Percentage of trees observed with insect damage by genera, 2013.

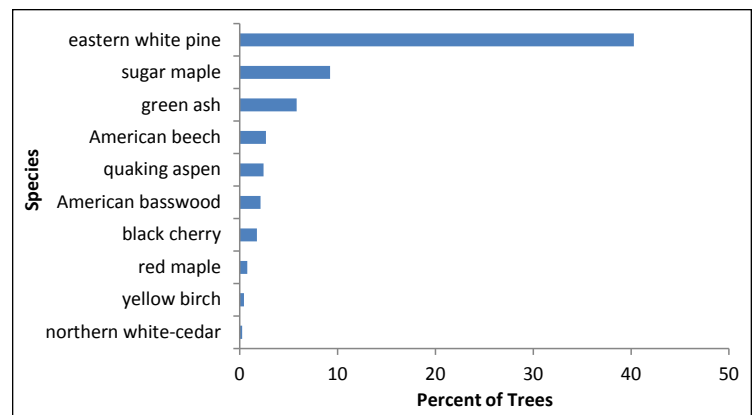


Figure 8.—Percentage of trees observed with insect damage by species, 2013.

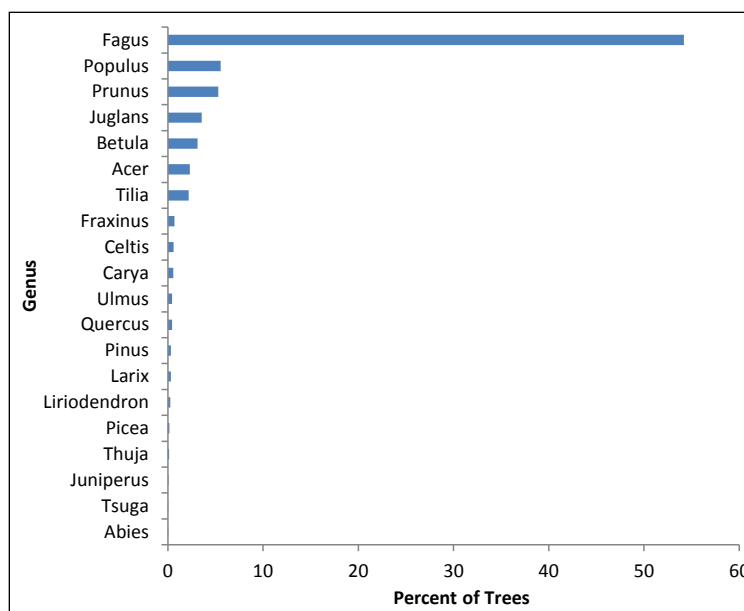


Figure 9.—Percentage of trees observed with cankers by genera, 2013.



The other damage categories were rarely observed (3 percent or less of all trees) (Fig. 5). However, animal damage was recorded on 5 percent of trees each for American basswood (*Tilia americana*) and tamarack (*Larix laricina*) (Fig. 10), and weather damage was recorded on 5 percent of trees each for black ash (*Fraxinus nigra*), green ash (*Fraxinus pennsylvanica*), and paper birch (*Betula papyrifera*) (Fig. 11).

Although *Fagus* was clearly the genus with the highest occurrence of damage, it makes up a relatively small proportion of the total number of trees across the study region. By contrast, *Acer* is the most dominant genus in the study area and also has the highest occurrence of damage after *Fagus* (Fig. 12).

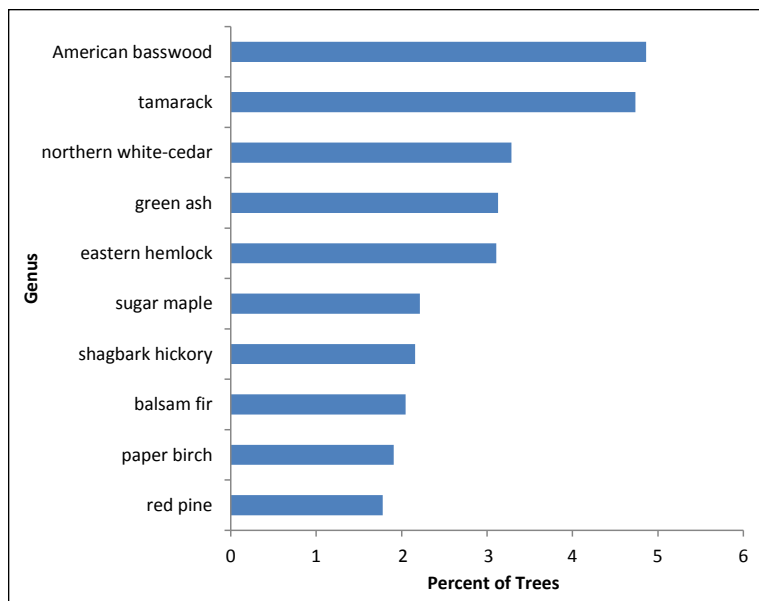


Figure 10.—Percentage of trees observed with animal damage by species, 2013.

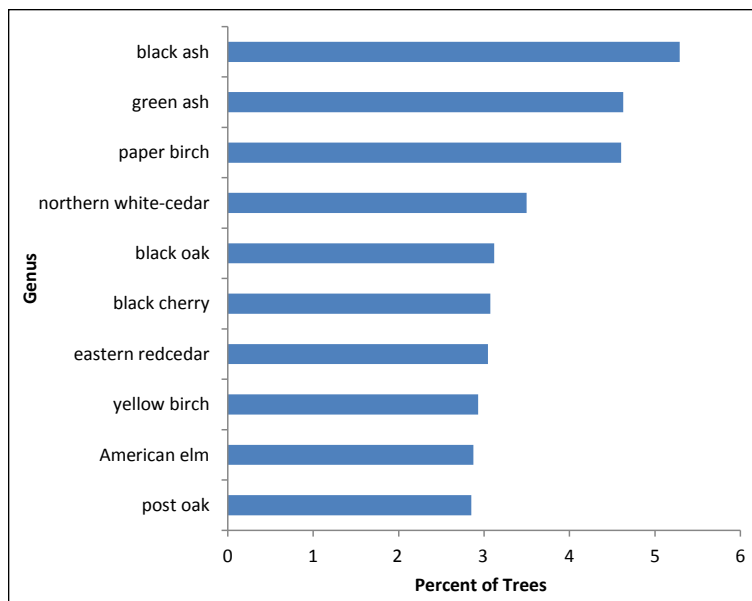


Figure 11.—Percentage of trees observed with weather damage by species, 2013.

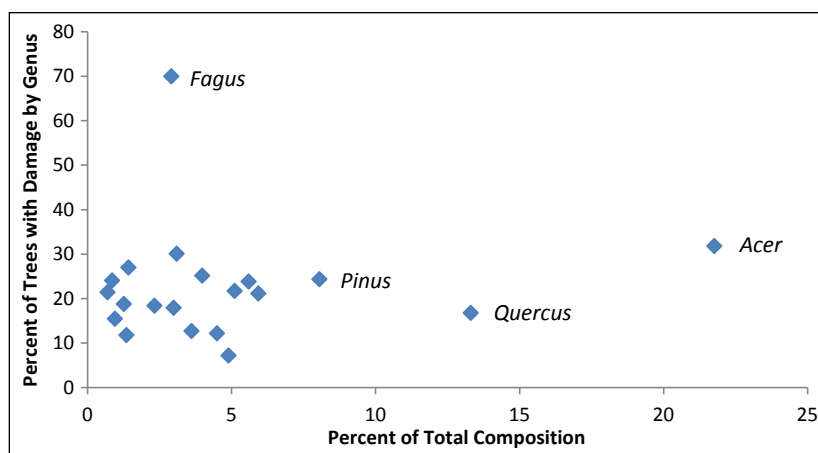


Figure 12.—Percentage of total species composition based on number of trees plotted against percentage of trees within a genus with damage, 2013. Genera that make up more than 5 percent of the total number of trees are labelled.

## Sugar Maple

Sugar maple is widely distributed across the northern region and is a major component of the maple/beech/birch forest-type group. It is also one of the most prominent and important hardwoods supplying valuable saw logs, pulpwood, and firewood. Additionally, it is the principal source of maple sugar. It comprises about 9 percent of the total volume across the northern United States. Insect damage was recorded on 9 percent of sugar maple trees (Fig. 8). The incidence of insect damage is more common across the northern range of the species, particularly in Minnesota, Wisconsin, New York, New Hampshire, and northern Pennsylvania (Fig. 13). The majority of the damage is caused by sugar maple borer (*Glycobius speciosus*), which can cause lumber defects but rarely causes mortality (Hoffard and Marshall 1978).

## American Beech

American beech is a major component of the maple/beech/birch forest-type group that comprises 25 percent of the forest resource across the study area. It is an important pulpwood and firewood species and is also important for wildlife due to the hard mast that it produces. Decay was recorded on 35 percent of American beech, and the incidence of decay is well distributed across the range of the species but is generally lower in New England (Fig. 14). By contrast, cankers were recorded on 54 percent of American beech trees, but the spatial distribution of occurrence is concentrated in the northern portion of its range (Fig. 15). The high frequency of cankers on American beech is due to the long history of beech bark disease (BBD) in the region.

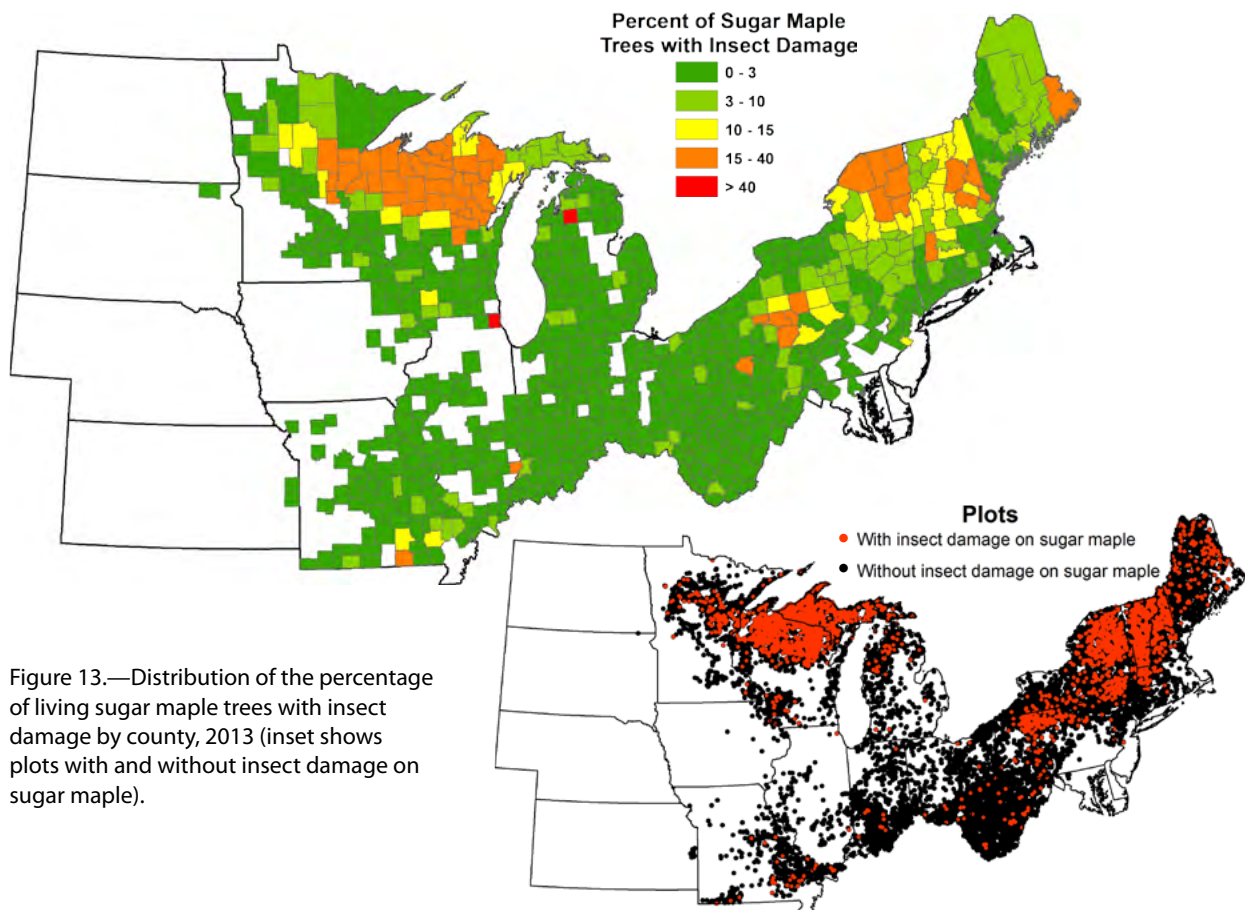


Figure 13.—Distribution of the percentage of living sugar maple trees with insect damage by county, 2013 (inset shows plots with and without insect damage on sugar maple).

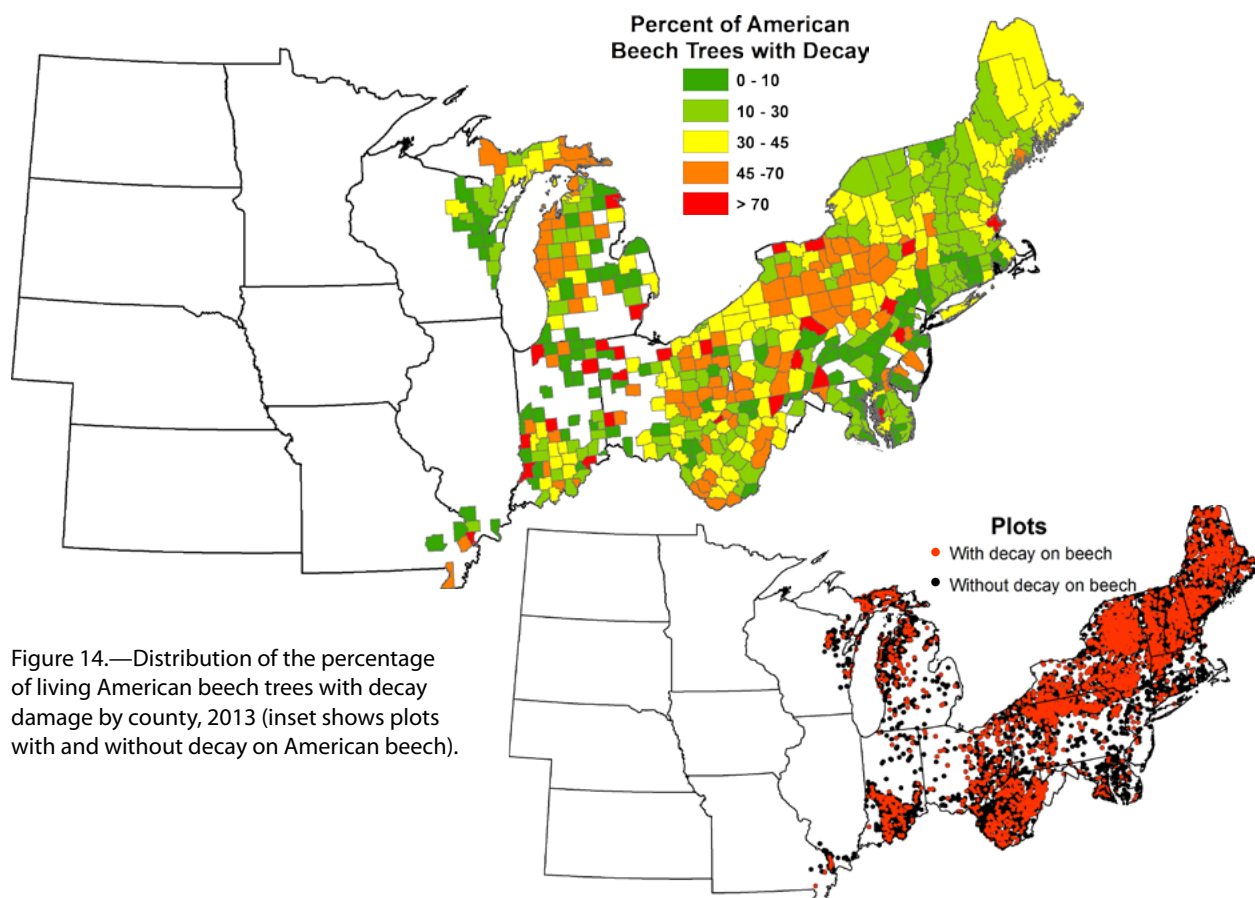


Figure 14.—Distribution of the percentage of living American beech trees with decay damage by county, 2013 (inset shows plots with and without decay on American beech).

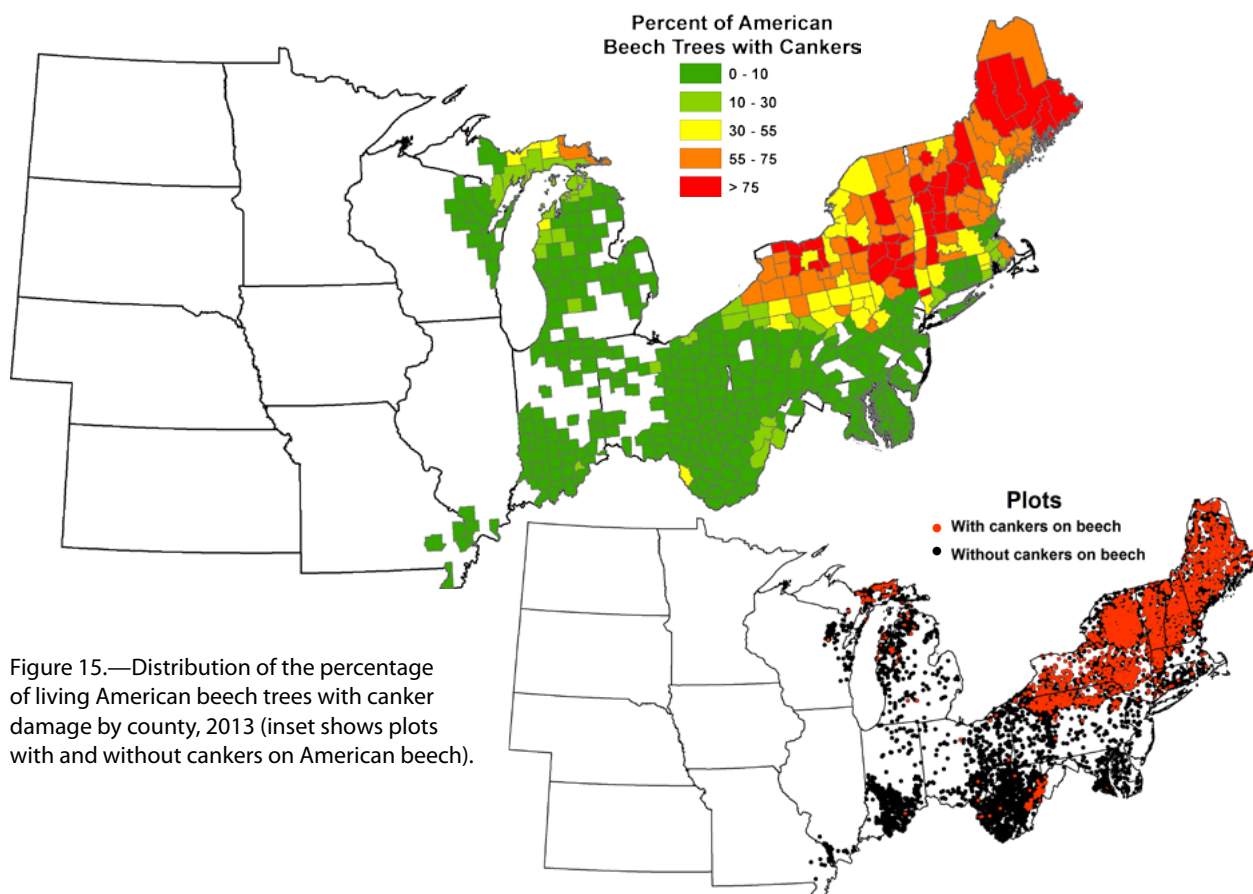


Figure 15.—Distribution of the percentage of living American beech trees with canker damage by county, 2013 (inset shows plots with and without cankers on American beech).

BBD is an insect-fungus complex involving the non-native beech scale insect, *Cryptococcus fagisuga*, which feeds on bark fluids from stems of American beech, providing an opportunity for the native canker fungi *Neonectria coccinea* var. *faginata* and *Neonectria ditissima* to invade the inner living bark and cambium leading to dieback and mortality (Houston 1994, Mize and Lea 1979). The beech scale insect was accidentally introduced with live plants imported to Halifax, Nova Scotia, from Europe in the 1890s (Houston 1994). The scale insect has since slowly spread (~9 miles/year) into the New England states, New York, Pennsylvania, and West Virginia, and a discontinuous “jump” has transported it into Michigan (Fig. 16) (Morin et al. 2007, Wieferich et al. 2013). Three phases of BBD are generally recognized: (1) the “advancing front,” which corresponds to areas recently invaded by scale populations; (2) the “killing front,” which represents areas where fungal invasion has occurred and tree mortality begins (typically 3-5 years after the scale insects appear, but sometimes as long as 20 years); and (3) the “aftermath forest,” which are areas where the disease is endemic (Houston 1994, Shigo 1972).

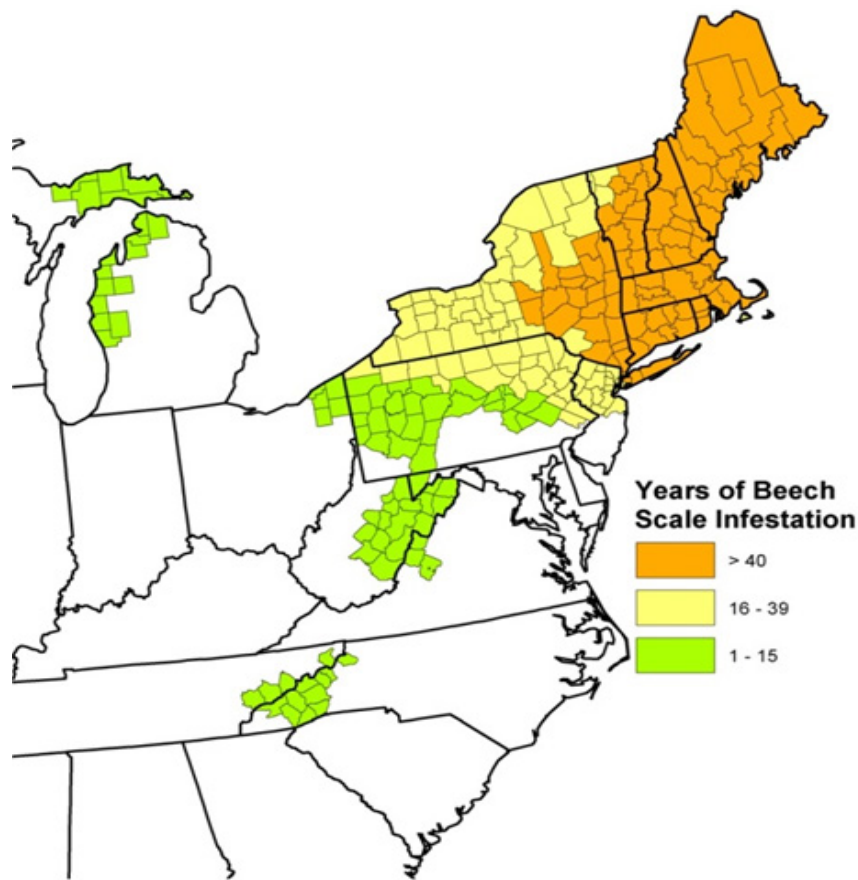


Figure 16.—Map of the historical spread of the beech scale insect in the eastern United States, 2010.



## Quaking Aspen

Quaking aspen (*Populus tremuloides*) is the most widely distributed tree in North America and is a major component of the aspen/birch forest-type group that comprises 9 percent of the forest resource across the study area. It is primarily used as pulpwood and many kinds of wildlife benefit from this species. Cankers were recorded on 7 percent of quaking aspen trees, and the incidence of the damage is most common in the Great Lake States, particularly Minnesota and Wisconsin, North Dakota, and Vermont (Fig. 17). The incidence of cankers on quaking aspen is due to *Hypoxyylon* canker, caused by the fungus *Hypoxyylon mammatum* (Wahl.), which is one of the most important killing diseases of aspen in eastern North America (Anderson and Anderson 1997).

## Eastern White Pine

Eastern white pine is the most important species in the white/red/jack pine forest-type group that comprises 5 percent of the forest resource across the study area. It is one of the most valuable timber species in eastern North America. Insect damage was recorded on 40 percent of eastern white pine trees, and the incidence of the damage is highest in New York, New England, and Michigan (Fig. 18). The high incidence of white pine insect damage is due to the accumulation of deformed stems caused by the native white pine weevil, *Pissodes strobi* (Peck). Although the weevil damage does not typically kill trees, the form and quality of saw logs is often impacted severely.

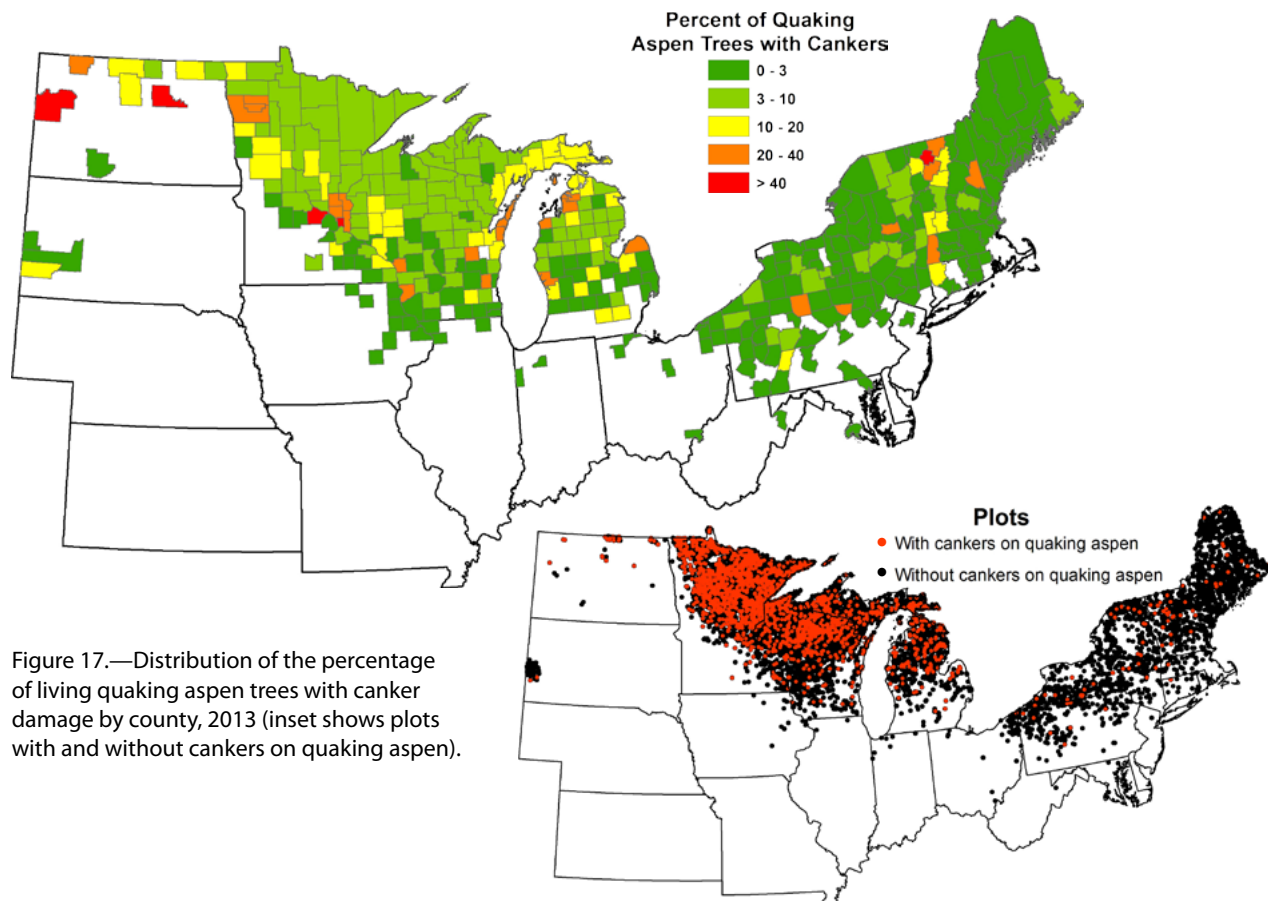


Figure 17.—Distribution of the percentage of living quaking aspen trees with canker damage by county, 2013 (inset shows plots with and without cankers on quaking aspen).

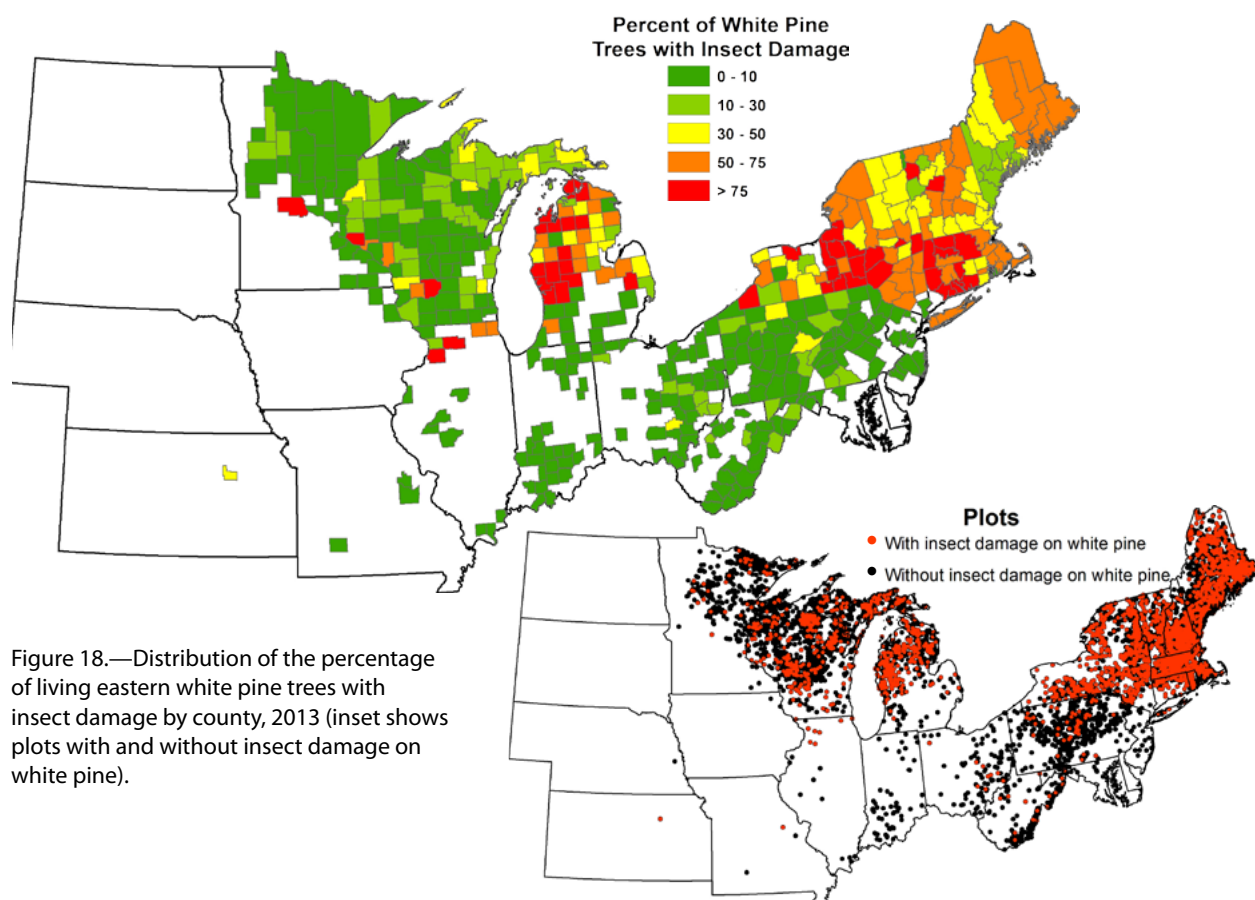


Figure 18.—Distribution of the percentage of living eastern white pine trees with insect damage by county, 2013 (inset shows plots with and without insect damage on white pine).

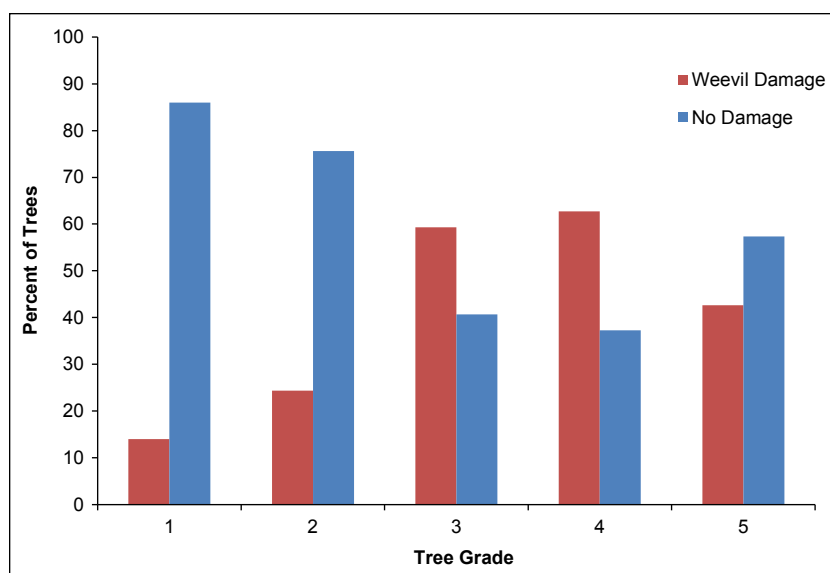


Figure 19.—Percentage of white pine trees of sawtimber size by tree grade and white pine weevil status, 2013.

FIA assigns tree grades to sawtimber-size trees as a measure of quality. Tree grade is based on tree diameter and the presence or absence of defects such as knots, decay, and curvature of the bole. These grades have parallels to log grades used by sawmills, but they are not identical. The grades decrease in quality from grade 1 (high grade lumber) to grade 3. Grade 4 is assigned to tie/local use material. The substantial impact of white pine weevil damage is illustrated by the increasing proportion of damaged trees that fall into tree grades 3 and below (Fig. 19).

## Ash Species

Ash species (*Fraxinus* spp.) are widely distributed geographically in the northern United States, but they are minor components in many forest-type groups. Ash represents only about 5 percent of the total volume across the northern region, and the majority of this is white (*Fraxinus americana*) and green ash. White ash is particularly sought after for handles and baseball bats.

Insect damage was recorded on 3 percent of ash trees overall, and this proportion was higher on green ash (6 percent). The vast majority of insect damage on ash is due to EAB. This exotic beetle was first discovered in the United States in southeastern Michigan near Detroit in the summer of 2002. Since then it has spread into many other states. As of 2012, EAB had been discovered in about 15 percent of the counties in the 37 states that comprise the natural range of ash species in the eastern United States (Fig. 20). EAB probably arrived in the United States on solid wood packing material carried in cargo ships or airplanes originating in its native Asia. The highest incidence of insect damage on ash is in Michigan (Fig. 21) where 21 percent of ash trees were damaged.

Weather damage was recorded on 5 percent of green and black ash trees. Most of this weather damage is likely due to flooding of black ash in swampy areas and green ash in riparian areas. Weather damage on green and black ash was distributed across the range of the two species in the northern United States (Figs. 22, 23).

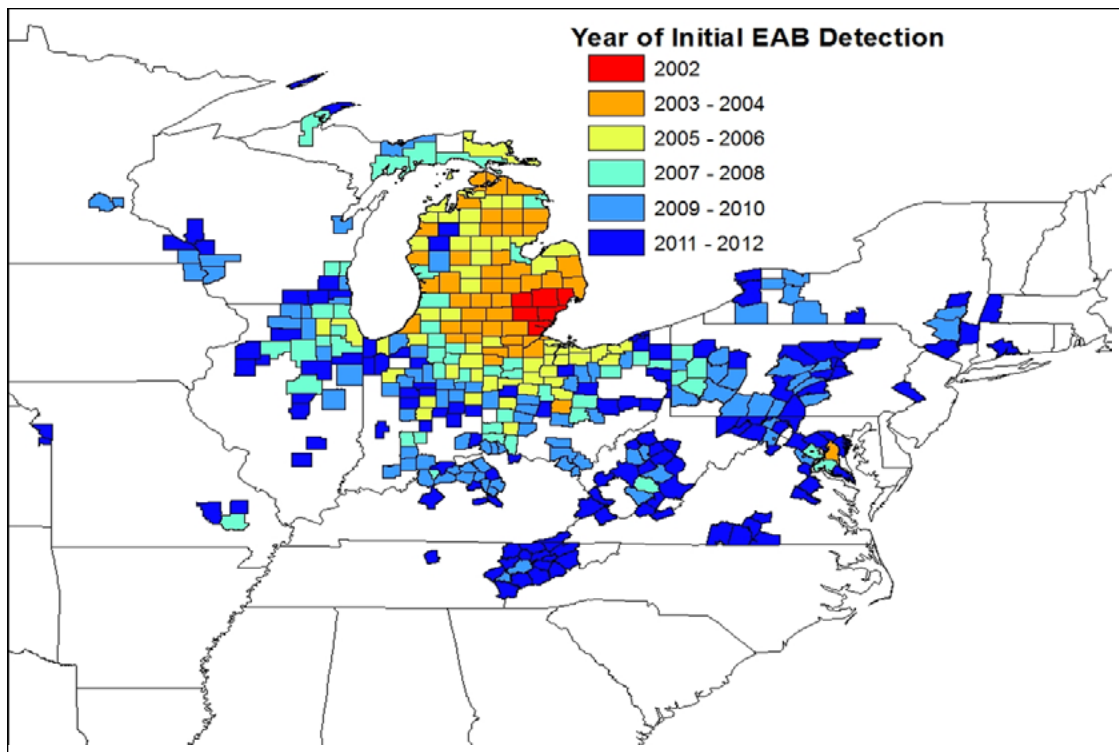


Figure 20.—Year of initial EAB detection by county, 2012.



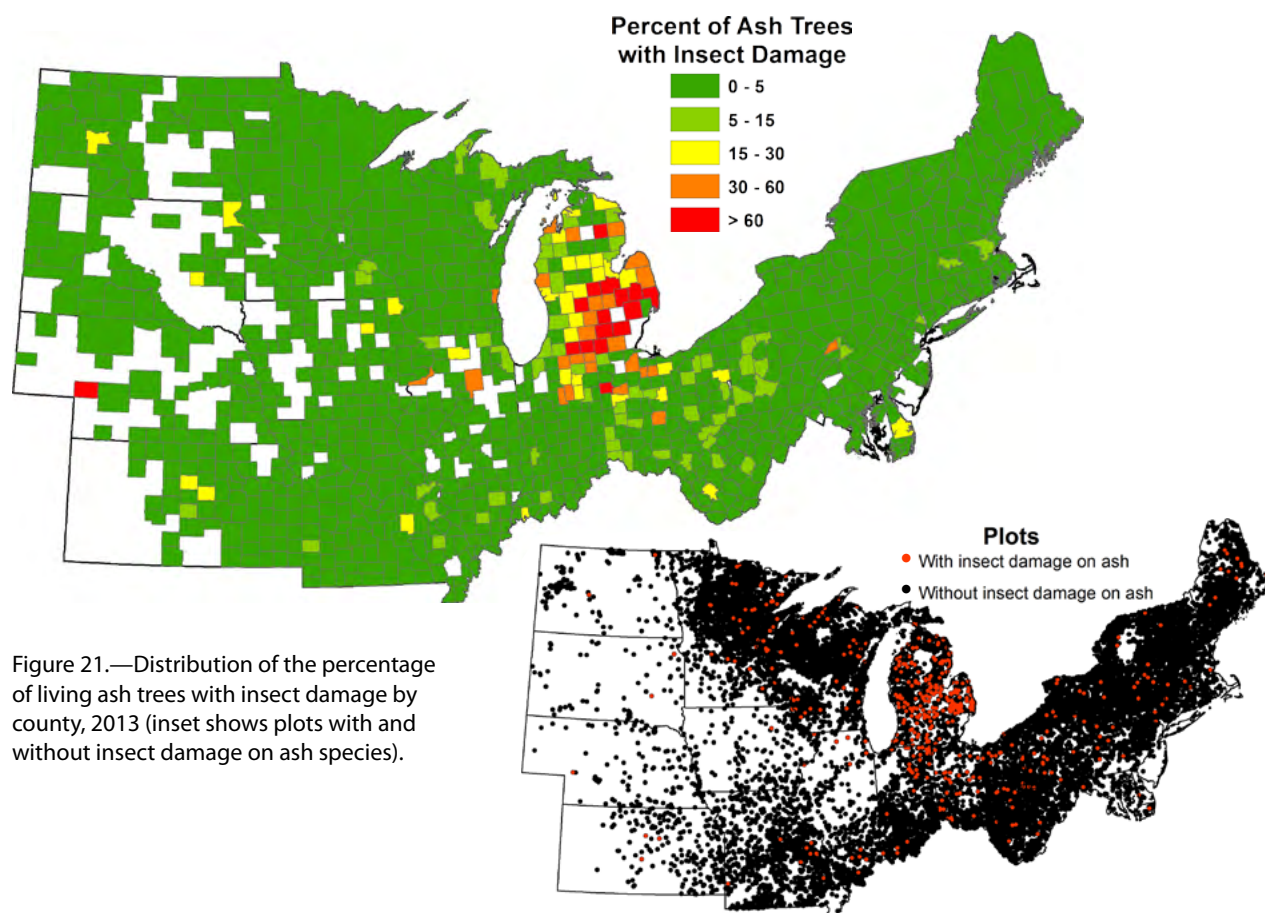


Figure 21.—Distribution of the percentage of living ash trees with insect damage by county, 2013 (inset shows plots with and without insect damage on ash species).

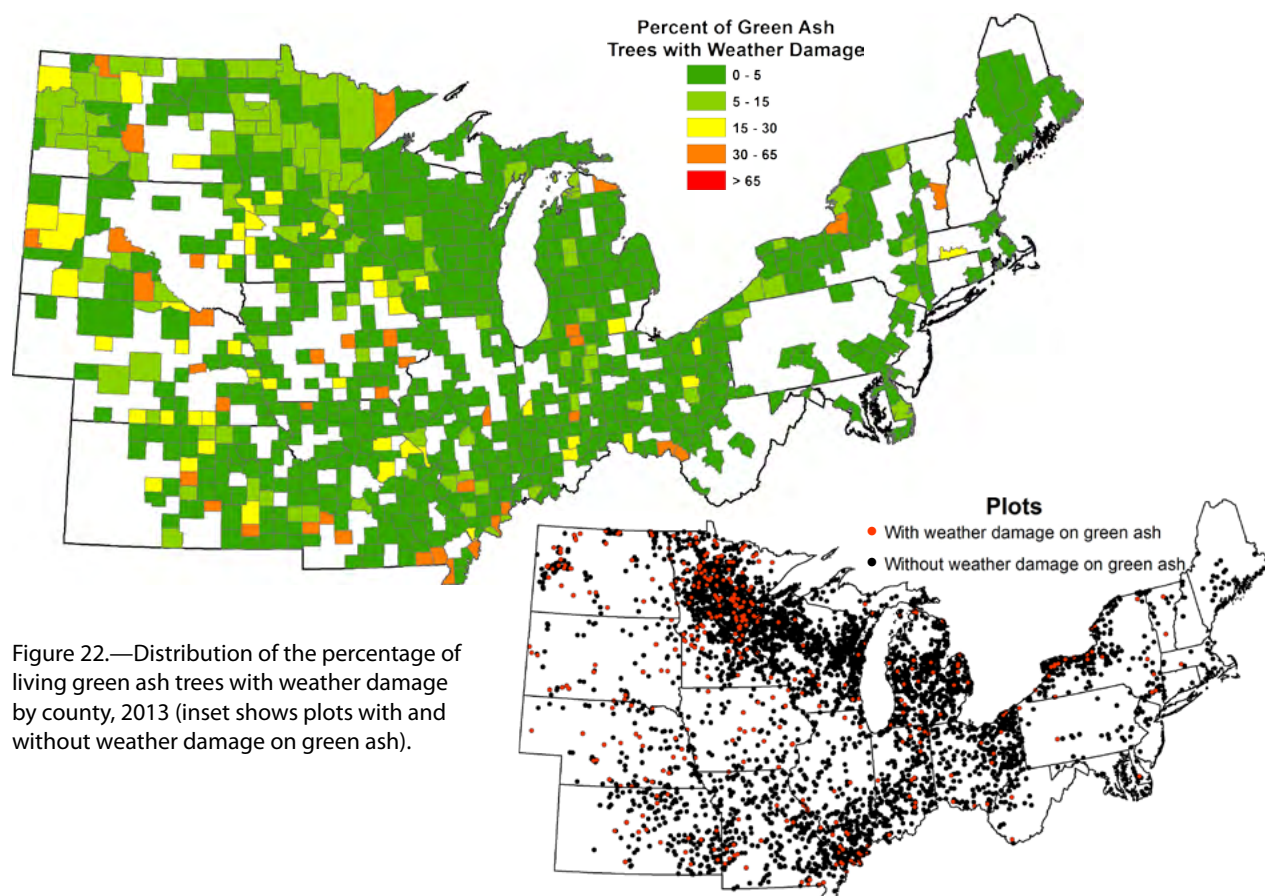


Figure 22.—Distribution of the percentage of living green ash trees with weather damage by county, 2013 (inset shows plots with and without weather damage on green ash).



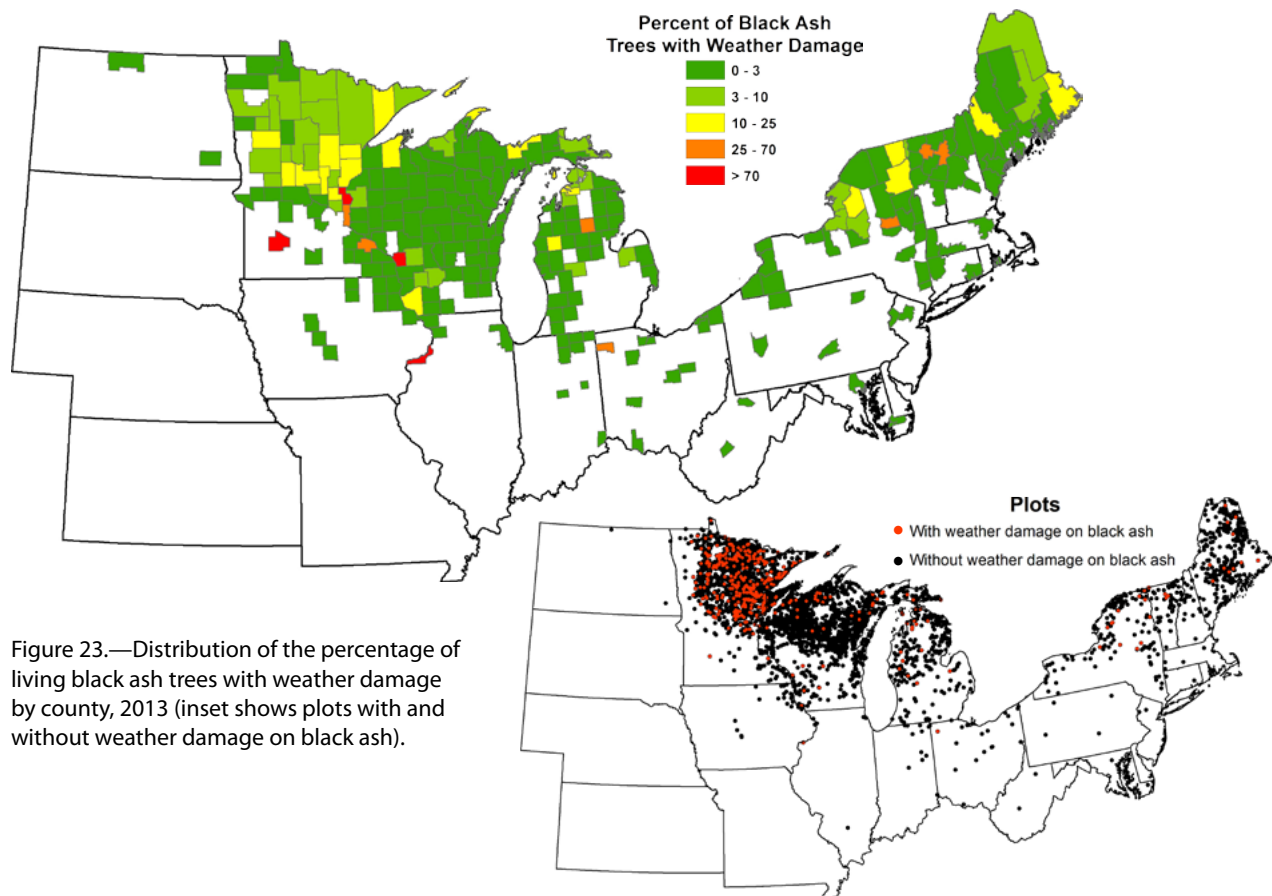


Figure 23.—Distribution of the percentage of living black ash trees with weather damage by county, 2013 (inset shows plots with and without weather damage on black ash).

## American Basswood

American basswood is widely distributed across the northern region, but it grows in association with other species and rarely forms pure stands. It is an important timber species, especially in the Great Lake States, and its seeds and twigs are eaten by wildlife. Basswood only comprises about 2 percent of total volume across the northern United States. Animal damage was recorded on 5 percent of American basswood trees (Fig. 10) and was distributed across its range in the northern United States (Fig. 24). The majority of the damage is probably girdling by rodents.

## Tamarack

Tamarack is distributed across the northern portion of the northern United States including the Great Lake States and northern New England. It is primarily used for pulpwood, but the heavy, durable wood is also used for posts, poles, and firewood. Wildlife also use this species for food and nesting. Tamarack forms pure stands in northern Minnesota, but in most other areas it is found in mixed stands with black spruce. Tamarack only comprises about 0.5 percent of the total volume across the northern United States. Animal damage was recorded on 5 percent of tamarack trees (Fig. 10). This damage was most often recorded in the Great Lake States, especially in Michigan and Wisconsin (Fig. 25). The majority of damage is likely due to North American porcupines (*Erethizon dorsatum*) feeding on the inner bark of trees, which can cause deformities or mortality (Burns and Honkala 1990).

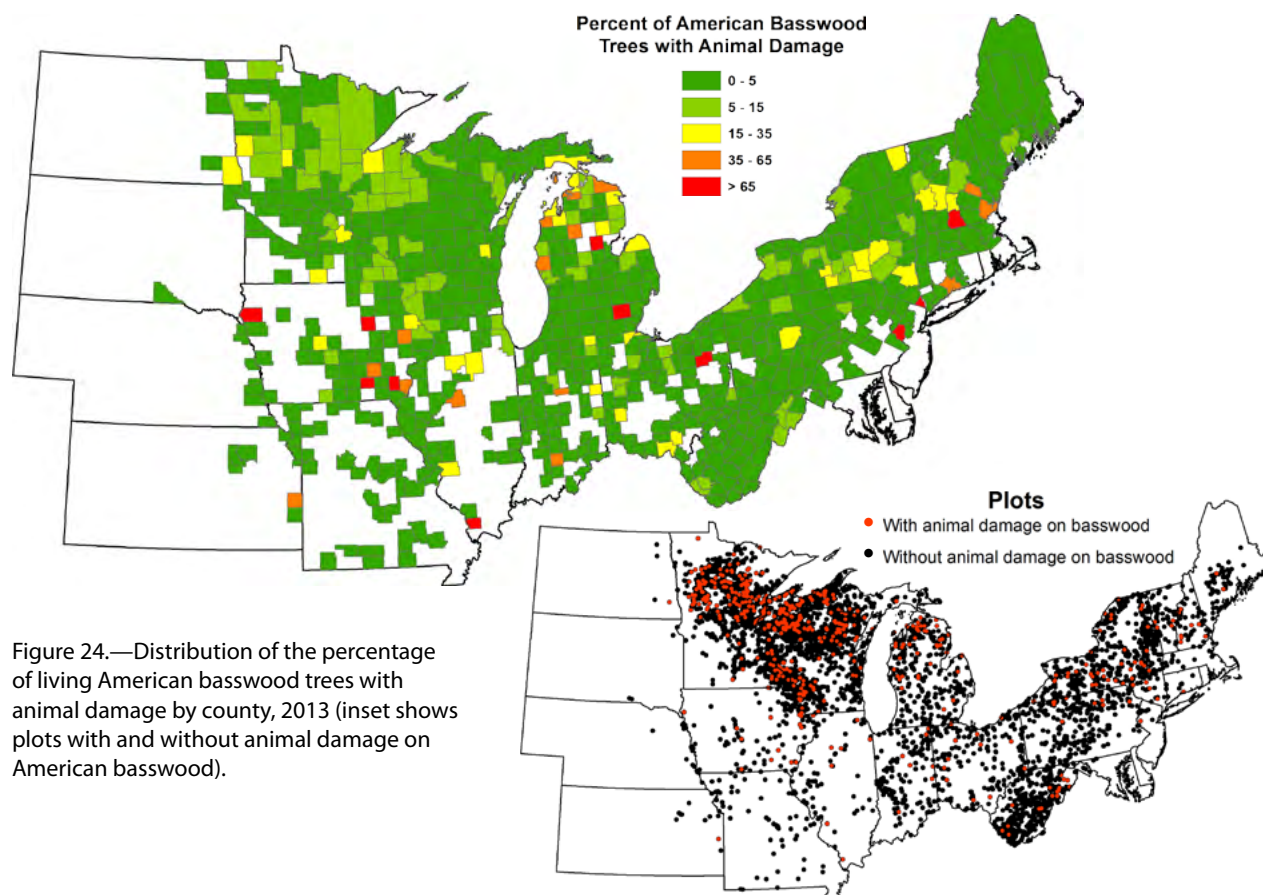


Figure 24.—Distribution of the percentage of living American basswood trees with animal damage by county, 2013 (inset shows plots with and without animal damage on American basswood).

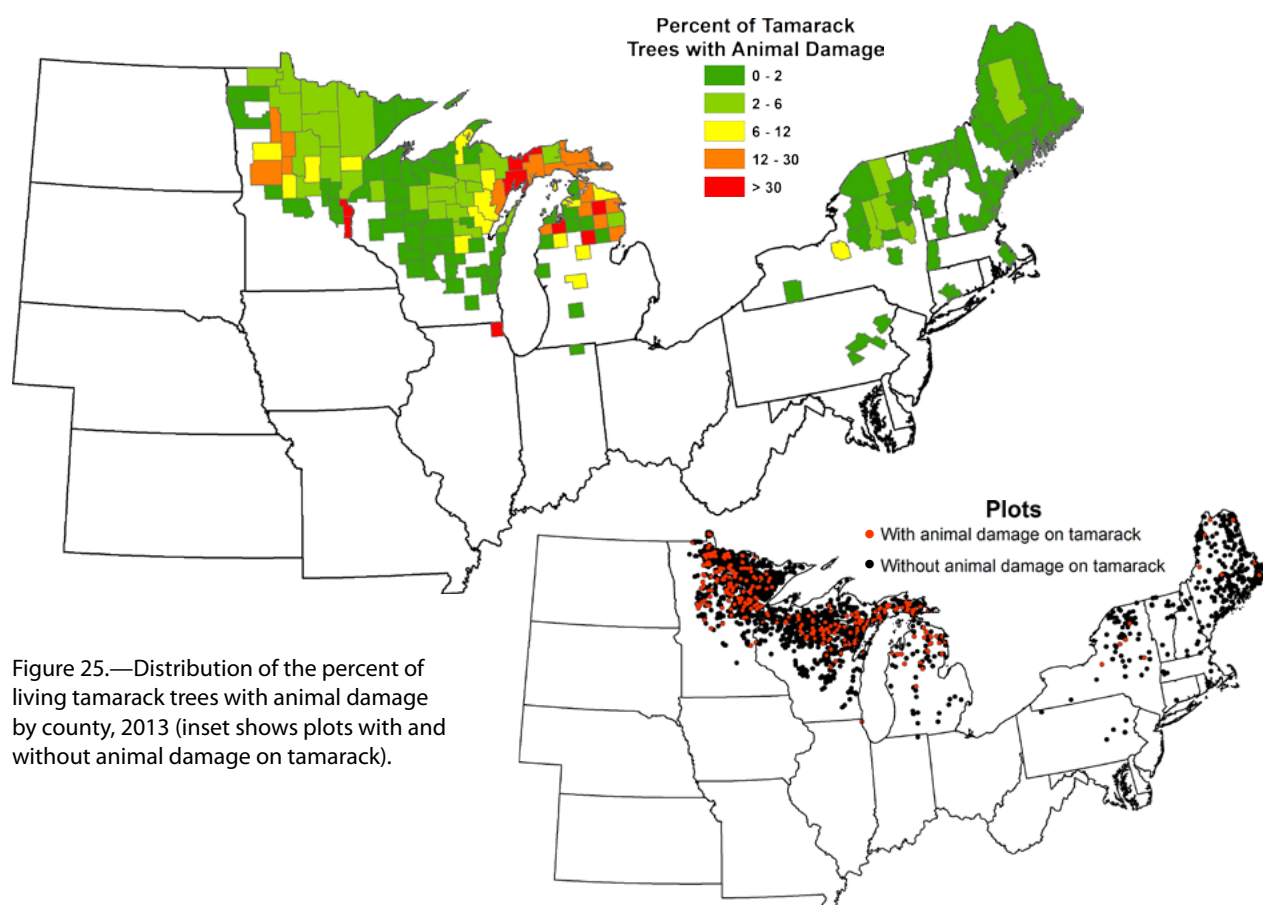


Figure 25.—Distribution of the percent of living tamarack trees with animal damage by county, 2013 (inset shows plots with and without animal damage on tamarack).

## DISCUSSION

Several factors need to be considered when analyzing and interpreting the damage data: variations between species, site differences, and impacts of biotic and abiotic damage agents. Here, we present a brief synopsis of each of these factors.

### Variations Due to Genus and Species Differences

The occurrence of damage is expected to vary by genus and species due to differences in susceptibility and vulnerability to damaging agents as well as differences in tree and branch morphology and silvical characteristics. This is illustrated across the northern region where the occurrence of damage ranged from 7 to 70 percent by genera (Fig. 4). Decay drives the overall occurrence of damage because it is the most commonly observed damage type by a large margin (Fig. 5). Hardwoods had a higher occurrence of damage observed than softwoods due to softwoods being generally more rot-resistant.

The other types of damage also varied by genus or species. For example, *Pinus* is the tree genus most often observed with insect damage by a large margin (17 percent of trees). This is due to the widespread impacts of the native white pine weevil, but the high occurrence is increased further because the deformed stems are visible for many years. Therefore, the number of damaged trees can continue to increase in white pine stands over time.

### Variations Due to Site Differences

The occurrence of damage can also vary within genus and species due to site differences such as variations in weather, soil conditions, animal populations, and presence of native or invasive insects and diseases. For example, trees in the northern portion of a species' range may be more vulnerable to snow and ice damage or trees in a riparian area may be more likely to suffer flood damage. Variation related to animal populations is illustrated across the northern region where the occurrence of animal damage on tamarack is observed most often in the Great Lake States (Fig. 25) where the range of porcupines overlaps the range of the tree species (Fig. 26). Similarly, although the sugar maple borer is found throughout the range of sugar maple, the occurrence of damage is concentrated in the northern range of the species, particularly in Minnesota, Wisconsin, New York, New Hampshire, and northern Pennsylvania (Fig. 13).



Figure 26.—Distribution of the porcupine in North America.

## CONCLUSION

An important indicator of tree and forest health is outwardly visible damage on trees. This report documents the occurrence of damage across the northern region so that summaries for smaller areas have some context within their broader geographic area. Given the ever increasing number of alien forest pests (Aukema et al. 2010) and potential increases in forest disturbances such as fire, hurricanes, and windstorms due to climate influences (Dale et al. 2001), monitoring tree damage is increasingly important. Future forest resource assessments will include trends of abundance and proportion of trees with damage.

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Red oak crack. Photo by Randall Morin, U.S. Forest Service.

Morin, Randall S.; Pugh, Scott A.; Steinman, Jim. 2016. **Mapping the occurrence of tree damage in the forests of the northern United States**. Gen. Tech. Rep. NRS-GTR-162. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 19 p.

The U.S. Forest Service Forest Inventory and Analysis Program uses visual inspections of trees from bottom to top to record damage that is likely to prevent survival, reduce growth, or hinder capability to produce marketable products. This report describes the types of damage and occurrence as measured across the 24-state northern region between 2009 and 2013. Descriptive statistics and spatial occurrence maps are presented by genus, species, and state. Inter- and intra-species variation, as well as biotic and abiotic disturbance agents, are issues that should be considered while analyzing and interpreting data from damage indicators.

**KEY WORDS:** tree damage, FIA, forest health, disturbance agents, invasive pest, damage map

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