CHAPTER 6

Crown Dieback and Damages in the Eastern United States

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INTRODUCTION

The Forest Inventory and Analysis (FIA) program of the Forest Service, U.S. Department of Agriculture, visually assesses tree crown conditions as an indicator of forest health. These assessments are useful because individual tree photosynthetic capacity is dependent upon the size and condition of the crown. In general, trees with full, vigorous crowns are associated with more vigorous growth rates (Zarnoch and others 2004); when trees undergo stress, e.g., from an insect attack or extreme weather event, the first symptoms are often visible in the crown. Furthermore, tree crowns form the overstory structure of the forest and directly influence the composition and structure of the understory thereby making them an integral component of the forest ecosystem.

Initially implemented by the Forest Health Monitoring (FHM) program, crown conditions have been measured in the United States since 1990 (Randolph 2013). After a series of field tests and reviews in the early 1990s, the crown condition indicator was formalized to include a set of eight variables: vigor class, uncompacted live crown ratio, crown light exposure, crown position, crown density, crown dieback, foliage transparency, and crown diameter (Schomaker and others 2007). When the FHM detection monitoring plots were incorporated into FIA in the year 2000, assessment of these variables was continued by FIA (Woodall and others 2011). Over time, the crown assessment protocols have been refined to address client needs, field logistics, and budgetary demands (USDA Forest Service 2016). Presently, FIA assesses uncompacted live crown ratio and crown dieback as the primary crown condition metrics.

This chapter represents the fourth national summary of crown condition in the United States. Previous summaries were included in Forest Health Monitoring: 2006 National Technical Report (Randolph 2009), Forest Health Monitoring: National Status, Trends, and Analysis 2013 (Randolph 2015), and Forest Health Monitoring: National Status, Trends, and Analysis 2017 (Randolph 2018). In like manner, the objective of this report is to summarize current crown dieback, current crown-damaging agents, and 20-year crown dieback trends for the most common genera and species ("species groups") in the Eastern United States (fig. 6.1) with the goal of identifying species in decline and geographical areas of concern, e.g., Randolph and others (2012).

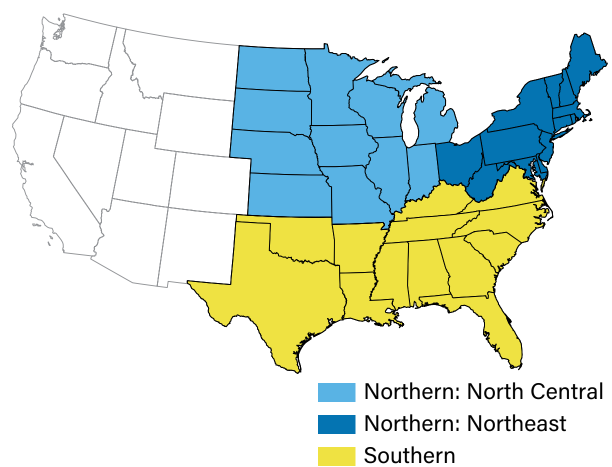

Figure 6.1—Regional breakdown of the Eastern United States for the crown condition analysis.

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METHODS

Data

The FIA program assesses crown dieback and damage on live trees with diameter at breast height (d.b.h.) ≥12.7 cm on its network of nationwide plots (Bechtold and Patterson 2005). Crown dieback is defined as the recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds toward the trunk (Schomaker and others 2007). Crown dieback is measured by means of ocular estimation and coded as 0, 05, 10, … 95, 99, where the code represents the upper limit of the class, e.g., 1–5-percent crown dieback is code 05. Crown dieback for live trees with complete defoliation, i.e., 100-percent crown dieback, is coded as 99. Biotic and abiotic agents causing tree damage above specific thresholds are observed by means of visual inspection successively from the bottom of the tree to the top, i.e., roots, bole, branches, and foliage. Up to three damage agents can be recorded per tree. Damage agents fall into one of 23 classes and may be recorded generally, e.g., abiotic agent, or specifically, e.g., wind. Typically, damage to the crown must meet or exceed 20 percent of the branches, stems, or foliage in order for a damage agent to be noted. However, any damage to the terminal leader or any evidence of a successful attack is sufficient for other agents (USDA Forest Service 2015). When trees have died or been cut since the previous inventory, FIA field crews assign a single cause of death from a list of eight possible agents: insect, disease, fire, animal, weather, vegetation (suppression, competition, vines), silvicultural or land clearing activity, and unknown.

The FIA plot network consists of permanently monumented plots located at a sampling intensity of approximately one plot per 6,000 acres (2428 ha) across the country. Plots are divided into spatially balanced panels and one panel of plots is measured each year on a rotating and ongoing basis. The time it takes to measure all panels within a State is referred to as a cycle. The majority of States in the Eastern United States are on 5- or 7-year cycles. Exceptions are Oklahoma and Texas, which have 5-year cycles in their eastern regions and 10-year cycles in their central and western regions. The FIA program dates its inventories according to the year of the most recently collected panel of plots. For example, the 2021 inventory for Arkansas, which is on a 5-year cycle, includes data collected in FIA inventory years 2017 through 2021.

To summarize current crown conditions in the Eastern United States, I utilized various subsets of the crown dieback, damage agent, and cause of death data collected by FIA in the Northern and Southern regions (fig. 6.1, table 6.1) (Burrill and others 2021). Data collection during 2020 and 2021 was sporadic and imbalanced across the country due to the COVID-19 pandemic. Therefore, the most recent data included in this summary were from the 2019 inventory for most States (table 6.1). I calculated changes in crown dieback over time by pairing the most recent observations with those made on the same trees in the previous measurement cycle. I also incorporated crown dieback estimates for prior years as reported previously by Randolph (2006, 2018) and Randolph and others (2010a, 2010b).

Table 6.1—Most recent Forest Inventory and Analysis inventory year for data included in the crown condition summary, by region and State

Region	Inventory year	State
Northern	2019	Connecticut, Delaware, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Dakota, Vermont, West Virginia, Wisconsin
Southern	2018	Florida, Louisiana, Kentucky, Tennessee, Texas
Southern	2019	Alabama, Arkansas, Georgia, Mississippi, North Carolina, Oklahoma, South Carolina, Virginia

Analyses

Survivorship—I evaluated the relationship between past crown dieback and current tree status, i.e., survivorship, by matching individual tree observations made with the most recent data, i.e., the 2018 or 2019 inventory year (table 6.1) (current assessment) with those made in the immediately preceding inventory. Measurement intervals for individual trees assessed during these time periods ranged from 4.2 to 7.4 years (mean = 5.6, SD = 0.7) in the Northern region and from 3.0 to 12.2 years (mean = 6.1, SD = 1.5) in the Southern region; however, to reduce variation, I only included trees with a remeasurement period within one standard deviation of their respective regional mean in the survivorship analysis. I calculated the proportion of trees by previous crown dieback class (0 percent, >0–10 percent, >11–20 percent, and >20 percent) and current tree status (live or dead) for each region. In addition, I calculated the proportion of mortality, i.e., trees with current tree status = dead, among trees with 0-percent crown dieback at the previous inventory for each species group by region. This calculation exposed species groups potentially affected by the occurrence of acute stressors between the previous and current assessments.

The FIA damage collection protocol is crafted in such a way that damage agents are recorded only when symptoms exceed predefined thresholds that indicate the tree is likely to (1) die within 1 to 2 years, (2) have reduced growth in the near term, or (3) have diminished marketability (USDA Forest Service 2015). Therefore, to identify damage agents that may contribute to imminent tree mortality, I calculated the frequency of each general damage agent by region and species class (softwood, hardwood) for trees in the >20-percent dieback class.

Current crown dieback and damage—I summarized current crown dieback conditions by region for all trees combined, species class (softwood, hardwood), and species groups measured on at least 100 plots by region. I calculated mean crown dieback using the ratio of means estimator (Cochran 1977, Woodall and others 2011). I also calculated the frequency of trees in each crown dieback class (0 percent, >0–10 percent, >10–20 percent, and >20 percent). In the past, crown dieback has been more prevalent in the Northern region than in the Southern region (Randolph 2015, 2018). Therefore, to compare species groups present in both regions, I ranked the species groups according to mean crown dieback, proportion of trees in the 0-percent dieback class, and proportion of trees in the >20-percent dieback class within each region. I based cross-regional comparisons of crown condition by species group on the average of the three rankings.

To identify geographical areas with excessive crown dieback, I calculated the proportion of trees with >20-percent crown dieback for each FIA plot condition[1] by species class, species group, and for all species combined. I mapped the proportions according to the approximate plot locations provided by FIA and examined the proportions visually. I only mapped conditions with at least three tally trees. For plot locations with multiple conditions, the greatest proportion of trees with >20-percent crown dieback among the conditions was displayed.

I calculated the frequency of each general damage agent by region and species group. For each plot condition, I calculated the proportion of trees with damage agents considered especially injurious to tree crowns by damage agent and species class. I mapped the condition-level proportions according to the approximate plot locations provided by FIA and examined the proportions visually. I only mapped conditions with at least three tally trees. For plot locations with multiple conditions, the greatest proportion of damaged trees among the conditions was displayed. The damage agents included in the spatial analysis were defoliating insects; sucking insects; chewing insects; decline complexes/dieback/wilts; foliage diseases; wind, snow, and ice; and parasitic/epiphytic plants (USDA Forest Service 2015). All these agents except wind, snow, and ice are general categories and include multiple specific agents.

Crown dieback trends—Using graphs, I compared current mean crown dieback to mean crown dieback from four prior time periods (1996–1999, 2001–2005, 2006–2010, and 2011–2015), by region, for all species combined and by species group. In addition, I compared current crown dieback (d_2) to previous crown dieback (d_1) by region and species group for all trees measured during both assessments. The hypothesis that the average ratio between d_2 and d_1 equaled 1 was tested with a paired *t*-test under a log transformation:

$$H_0: \bar{\delta} = 0 \text{ versus } H_A: \bar{\delta} \neq 0$$

where

$\bar{\delta}$ is the mean of $\log(d_{ij2} + c) - \log(d_{ij1} + c)$

where

c is a constant equal to 0.1

d_{ij2} is current crown dieback on tree i on plot j

d_{ij1} is previous crown dieback on tree i on plot j

The log transformation was necessary to accommodate crown dieback's severely skewed distribution and the addition of c was needed to adjust 0-percent crown dieback to a log transformable value. I used the R package SURVEY (Lumley 2004, R Core Team 2022)

[1] *An FIA plot is stratified into homogeneous condition classes based on ownership, forest type, stand size, stand density, stand origin, and reserved status (USDA Forest Service 2015).*

to accommodate the inventory design in which trees are nested on plots. I performed the hypothesis test for surviving trees only and for surviving trees plus mortality trees. Crown dieback is not assessed for dead trees; therefore, d_2 for mortality trees was set to the maximum possible dieback, i.e., 99 percent. I did not include harvested trees because it was not known if the trees were alive or dead at the time they were cut. As with the survivorship analysis, I only included trees with a remeasurement period within one standard deviation of their respective regional mean remeasurement period in this analysis. I considered crown dieback between the current and previous assessments to be statistically significantly different if the 95-percent confidence interval for $\bar{\delta}$ did not include zero. I back transformed results and present them under the original hypothesis such that 95-percent confidence intervals including 1 indicate no statistical difference; intervals with an upper confidence limit <1 indicate a statistically significant decline in crown dieback; and intervals with a lower confidence limit >1 indicate a statistically significant increase in crown dieback.

RESULTS AND DISCUSSION

Relationship Between Crown Dieback and Survivorship

Crown dieback is strongly correlated with tree survivorship such that trees with greater amounts of dieback are more likely to die within 5 years than those with little or no dieback (Morin and others 2015, Steinman 2000). Therefore, as expected, the likelihood of mortality tended to increase with increasing crown dieback in both regions (fig. 6.2). Although high levels of crown dieback are a good indicator of impending mortality, there are instances when trees with no crown dieback die before they are remeasured. This is most likely to happen when trees die quickly as the result of an acute stressor, e.g., wildfire, or when the effects of less acute stressors coincide with a lengthy remeasurement period. Overall, mortality among the trees with 0-percent crown dieback at the previous inventory was low (5.2 percent in the Northern region; 7.8 percent in the Southern region). Such was the case for most individual species groups except ash (*Fraxinus* spp.) and elm (*Ulmus* spp.) in the Northern region and ash, black cherry (*Prunus serotina*), and Virginia pine (*Pinus virginiana*) in the Southern region (fig. 6.3). An inspection of reported causes of death indicated that insects, most likely emerald ash borer (*Agrilus planipennis*) (Morin and others 2017), and diseases, most likely Dutch elm disease (*Ophiostoma novo-ulmi)* (Karnosky 1979, USDA Forest Service 2011), were the most frequently reported agents for northern ash and elm, respectively. Though no single agent dominated the causes of death recorded for ash and black cherry in the Southern region, insects, diseases, weather, and vegetation (suppression, competition, vines) were recorded frequently. Vegetation was the most frequently reported cause of death among the Virginia pines.

Damage agents observed on trees with >20-percent crown dieback suggest possible causes of death for trees most at risk of mortality. Stem decay, defined as rot occurring in the tree bole or stems above the roots and stump and recorded by

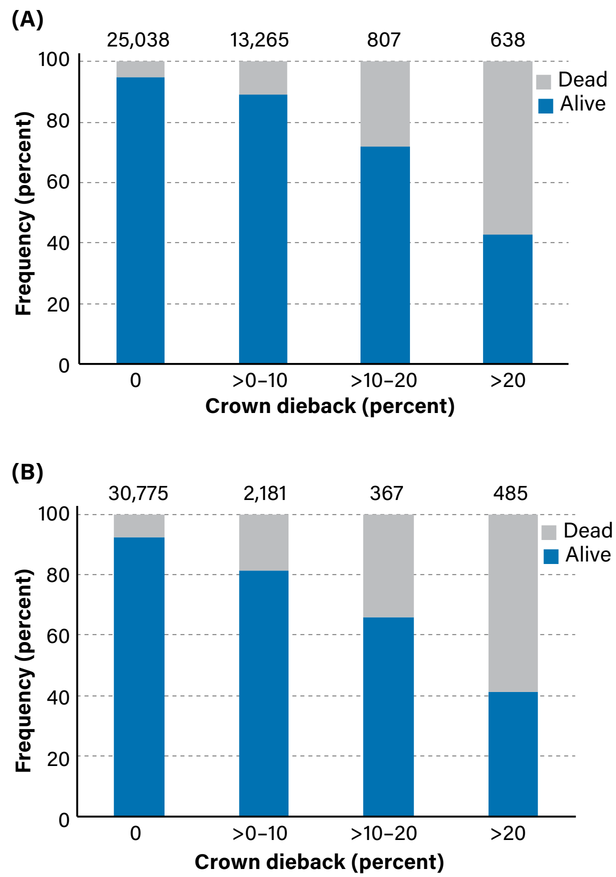

Figure 6.2—Proportion of remeasured trees in the (A) Northern and (B) Southern regions of the Eastern United States, by previous crown dieback and current tree status. The number of trees in each dieback class is listed above the column. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program)

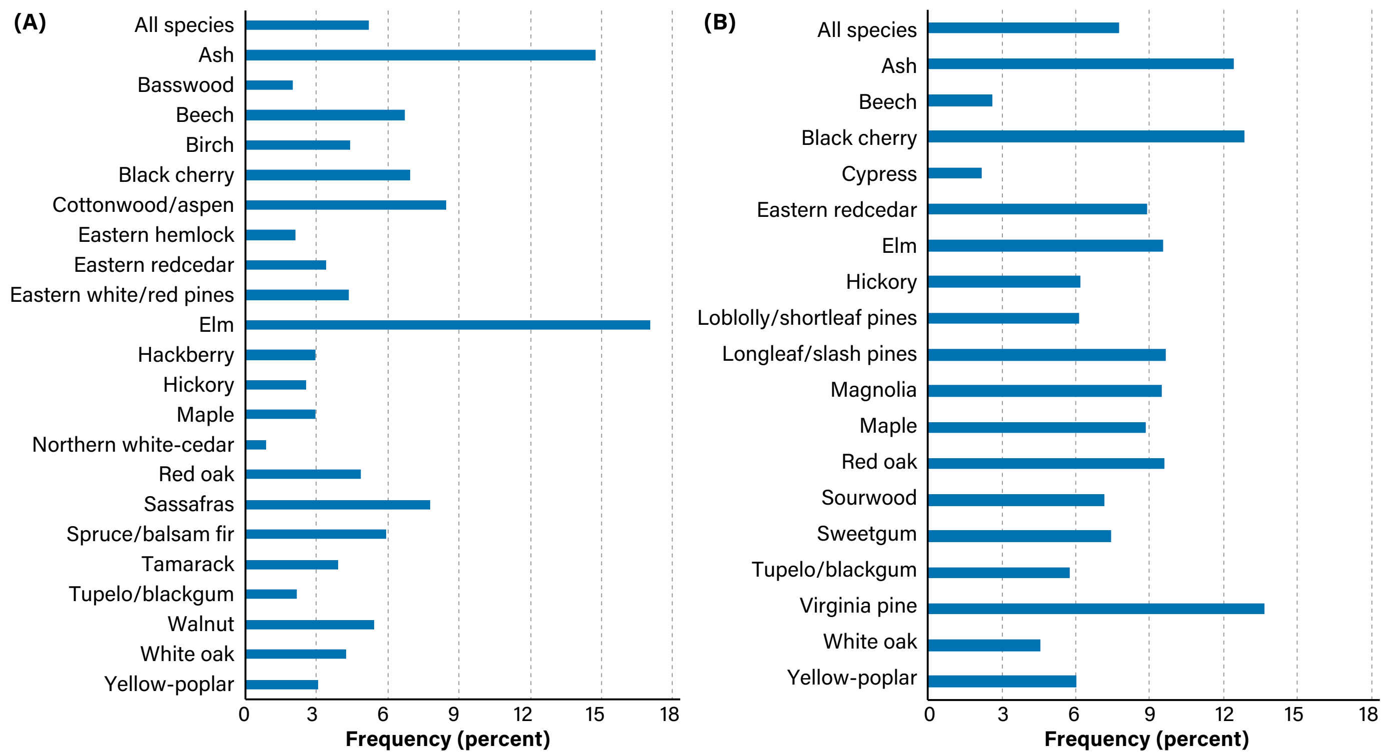

Figure 6.3—Proportion of trees with 0-percent crown dieback during the previous assessment that were dead upon remeasurement during the current assessment in the (A) Northern and (B) Southern regions of the Eastern United States, by species group. All species groups shown are based on at least 200 observations. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program)

FIA when there is any evidence of rotten wood, conks, or fungal fruiting bodies (USDA Forest Service 2015), is the most frequently recorded damage agent in the Eastern United States (Randolph and others 2021). As such, it was no surprise that stem decay was the most frequently recorded damage agent among trees with >20-percent crown dieback in both the Northern region (25.7 percent for softwoods; 42.5 percent for hardwoods) and Southern region (66.2 percent for softwoods; 72.6 percent for hardwoods). Other damage agents frequently associated with >20-percent crown dieback were boring insects in the Northern region and cankers and decline complexes/dieback/wilts in the Southern region (fig. 6.4).

Current Crown Dieback and Damage

The expectations that hardwoods typically have more crown dieback than softwoods and that crown dieback is more prevalent in the Northern region than in the Southern region held true (tables 6.2 and 6.3). Among the softwood species groups, the overall best crown conditions were observed for eastern white and red pines (*P. strobus, P. resinosa*) in the Northern region and loblolly and shortleaf pines (*P. taeda, P. echinata*) in the Southern region. Likewise, the overall best crown conditions among the hardwood species groups were observed for tupelo and blackgum (*Nyssa* spp.), basswood (*Tilia americana*), birch (*Betula* spp.), cottonwood and aspen (*Populus* spp.) in the Northern region, and birch, yellow-poplar (*Liriodendron tulipifera*), beech (*Fagus grandifolia*), and tupelo and blackgum in the Southern region. The overall poorest crown conditions in the

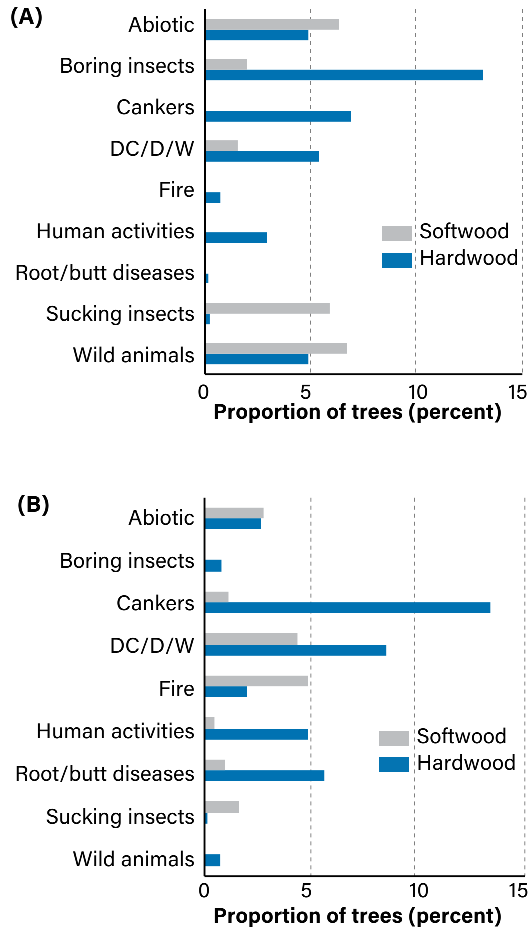

Figure 6.4—Frequency of common damage agents among trees with crown dieback >20 percent in the (A) Northern and (B) Southern regions of the Eastern United States, by species class. DC/D/W = decline complexes/dieback/wilts. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program)

Table 6.2—Current mean crown dieback and proportion of trees by dieback class for species groups in the Northern region

Species group	Number of plots	Number of trees	Mean	SEM	Dieback class 0	>0–10	>10–20	>20
			percent		*percent*			
Softwood	1,909	26,064	1.4	0.1	84.7	13.1	1.2	1.0
Eastern hemlock	428	3,077	1.0	0.1	90.4	8.1	0.7	0.8
Eastern redcedar	223	1,192	1.8	0.2	71.3	27.1	1.2	0.4
Eastern white and red pines	617	4,442	0.6	0.1	93.2	6.2	0.3	0.3
Northern white-cedar	285	4,092	3.6	0.4	68.4	24.4	4.2	3.1
Spruce and balsam fir	883	9,603	1.1	0.1	87.2	11.4	0.7	0.6
Tamarack	127	741	1.1	0.3	88.3	9.4	1.6	0.7
Hardwood	3,569	60,930	3.3	0.1	65.1	31.0	1.7	2.1
Ash	984	3,811	6.9	0.9	59.1	30.5	3.6	6.8
Basswood	353	1,325	1.7	0.2	77.0	21.7	0.5	0.8
Beech	629	2,700	3.3	0.2	66.8	28.0	2.9	2.3
Birch	1,159	5,159	2.2	0.1	72.8	24.8	1.3	1.2
Black cherry	711	2,206	4.0	0.3	59.5	35.6	2.4	2.5
Cottonwood and aspen	749	4,984	2.2	0.2	80.5	16.6	1.1	1.9
Elm	744	1,907	6.3	0.4	44.0	48.1	2.8	5.0
Hackberry	239	715	3.8	0.4	48.7	48.3	1.1	2.0
Hickory	755	2,619	2.3	0.2	65.0	33.9	0.4	0.6
Maple	2,364	18,581	2.5	0.1	72.8	24.0	1.7	1.6
Red oak[a]	1,301	5,129	3.6	0.2	53.1	43.6	1.7	1.6
Sassafras	201	616	4.9	0.7	51.5	43.3	2.1	3.1
Tupelo and blackgum	239	559	1.6	0.3	75.5	24.0	0.2	0.4
Walnut	327	740	3.8	0.4	52.3	44.7	1.4	1.6
White oak[b]	1,023	5,334	3.6	0.2	48.3	49.3	1.1	1.3
Yellow-poplar	250	1,089	2.8	0.4	69.5	28.0	0.9	1.6

SEM = standard error of the mean.

[a] *Quercus* section *Lobatae*.

[b] *Quercus* section *Quercus*.

Table 6.3—Current mean crown dieback and proportion of trees by dieback class for species groups in the Southern region

Species group	Number of plots	Number of trees	Mean	SEM	Dieback class 0	>0–10	>10–20	>20
			percent		- - - percent - - -			
Softwood	4,194	57,963	0.9	0.1	94.9	3.6	0.5	1.1
Cypress	138	1,048	0.3	0.1	98.9	0.4	0.2	0.6
Eastern redcedar	589	2,226	0.9	0.2	96.7	1.4	0.6	1.2
Loblolly and shortleaf pines	2,339	37,769	0.1	0.0	99.6	0.3	0.0[a]	0.1
Longleaf and slash pines	309	3,912	0.3	0.1	98.0	1.4	0.3	0.3
Pinyon-juniper	1,102	11,405	3.7	0.3	77.4	16.3	2.1	4.3
Virginia pine	156	783	0.6	0.3	98.0	1.1	0.4	0.5
Hardwood	6,511	71,206	2.1	0.1	84.8	11.6	1.6	2.0
Ash	662	2,135	3.0	0.5	88.5	6.2	1.6	3.7
Beech	219	468	0.7	0.3	97.9	1.1	0.0	1.1
Birch	137	418	0.4	0.2	97.6	1.9	0.0	0.5
Black cherry	434	829	1.6	0.3	91.6	5.2	1.7	1.6
Elm	1,544	4,521	1.4	0.1	89.5	8.1	0.9	1.4
Hickory	1,066	2,908	1.0	0.1	93.9	4.0	1.0	1.1
Honey mesquite	1,817	10,530	4.6	0.4	61.9	31.4	2.8	3.8
Magnolia	221	629	1.3	0.4	95.5	1.9	0.6	1.9
Maple	1,153	3,976	1.4	0.2	94.1	2.8	1.2	1.9
Red oak[b]	2,631	10,398	1.4	0.1	91.5	5.9	1.1	1.5
Sourwood	234	655	1.4	0.4	93.1	4.7	0.8	1.4
Sugarberry	486	1,539	1.1	0.2	90.1	8.2	0.6	1.1
Sweetgum	1,750	6,865	1.2	0.1	94.8	2.4	1.4	1.5
Tupelo and blackgum	888	3,001	0.7	0.1	96.3	2.0	0.9	0.8
Walnut	136	288	3.9	1.3	77.4	14.6	4.5	3.5
White oak[c]	2,531	13,176	2.6	0.2	76.2	19.3	2.4	2.1
Yellow-poplar	556	2,296	0.6	0.1	97.5	1.3	0.6	0.6

SEM = standard error of the mean.

[a] Value is >0.0 but <0.1.

[b] *Quercus* section *Lobatae*.

[c] *Quercus* section *Quercus*.

Northern region were observed for northern white-cedar (*Thuja occidentalis*), elm, ash, and sassafras (*Sassafras albidum*). In the Southern region, the overall poorest crown conditions were observed for pinyon-juniper,[2] honey mesquite (*Prosopis glandulosa*), walnut (*Juglans* spp.), and ash.

Potential causes for the poor crown conditions varied by species group. Reported damage agents on ash and elm support the effect of known stressors, i.e., emerald ash borer and Dutch elm disease, respectively. Northern white-cedar trees often grow in areas inundated by water (Boulfroy and others 2012), and pinyon-juniper trees typically grow in environments where moisture is scarce (Shaw and others 2005). Both water-related stresses can lead to crown dieback (Bréda and others 2006, Kozlowski 1986). In addition, reported damage agents suggest wild animals, possibly beaver (*Castor canadensis*), may have contributed to northern white-cedar crown dieback and fire may have contributed to pinyon-juniper crown dieback. Root/butt and other general diseases were commonly reported damage agents on honey mesquite and are likely contributors to its crown dieback. Similarly, root/butt diseases and heart rot were common among walnut. In addition to stem decay, damage by cankers, wild animals, and vines was commonly reported for sassafras.

Though crown dieback was more prevalent in the Northern region than in the Southern region, most of the species groups found throughout the Eastern United States ranked similarly within the two regions. On average, birch, tupelo/blackgum, and hickory (*Carya* spp.) ranked among the species groups with the best crown conditions. Ash, black cherry, and eastern redcedar (*Juniperus virginiana*) ranked among the species groups with the poorest crown conditions, and maple (*Acer* spp.) and red oak (*Quercus* section *Lobatae*) ranked in the middle. Crown conditions for beech, elm, walnut, white oak (*Quercus* section *Quercus*), yellow-poplar and two *Celtis* species, hackberry (*C. accidentalis*) and sugarberry (*C. laevigata*), ranked differently within the two regions. For best crown conditions, beech and yellow-poplar ranked in the top third among species groups in the Southern region and in the middle third among species groups in the Northern region. Elm ranked in the middle third among species groups in the Southern region and in the bottom third among species groups in the Northern region. Sugarberry ranked in the middle third among species groups in the Southern region and hackberry ranked in the bottom third among species groups in the Northern region. Walnut and white oak ranked in the bottom third among species groups in the Southern region and in the middle third among species groups in the Northern region. No species groups ranked in the top third in one region and bottom third in the other region.

Spatially, FIA plot locations where >25 percent of the trees had >20-percent crown dieback were scattered throughout the Northern region, whereas in the Southern region, they were concentrated primarily in Texas (fig. 6.5). Further

[2] *Woodland pinyon pines (* Pinus cembroides, P. edulis, P. remota*) and woodland junipers (* Juniperus ashei, J. coahuilensis, J. deppeana, J. flaccida, J. monosperma, J. pinchotii, J. scopulorum*).*

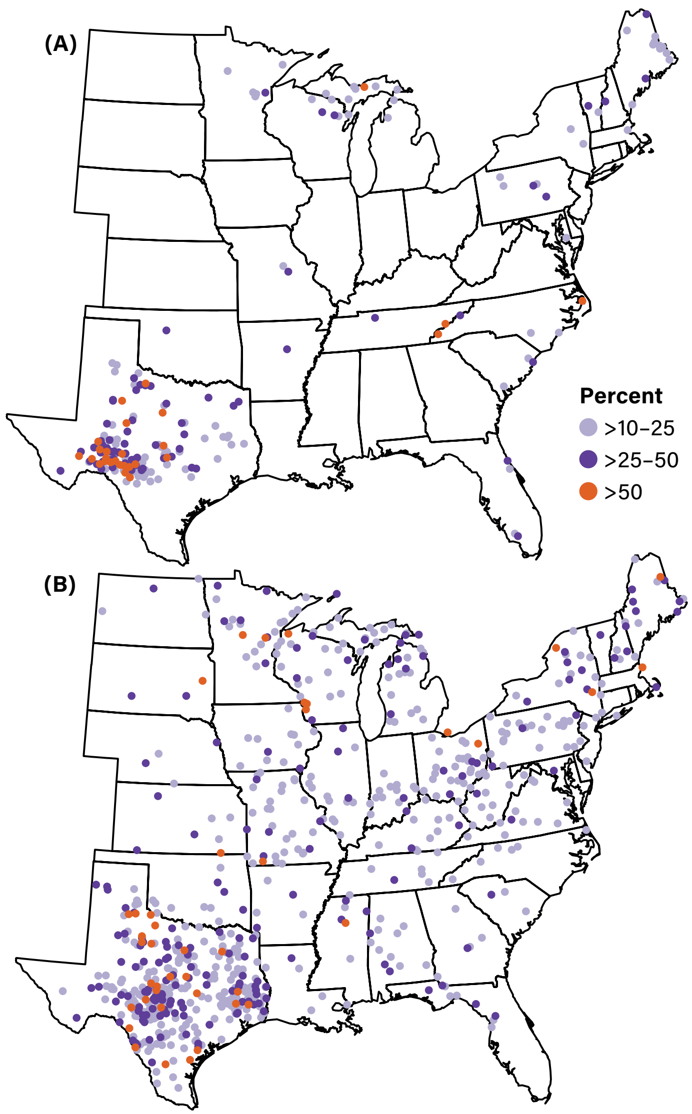

Figure 6.5—Proportion of (A) softwood and (B) hardwood trees with crown dieback >20 percent, by Forest Inventory and Analysis (FIA) plot location. Plot locations are approximate. (Data source: U.S. Department of Agriculture, Forest Service, FIA program)

examination indicated that the Texas plots where >25 percent of the trees had >20-percent crown dieback were composed of Ashe juniper (*J. ashei*), Pinchot juniper (*J. pinchotii*), honey mesquite, and live oak (*Q. virginiana*) and had evidence of weather- and fire-related disturbances. Other than ubiquitous stem decay, the most frequently recorded damage agents among trees with >20-percent crown dieback in Texas were heart rot and decline complexes/dieback/wilts.

Four agents stood out among those considered especially damaging to tree crowns: defoliators, chewing/sucking insects, parasitic/epiphytic plants, and wind. Plots with defoliating insect damage to >25 percent of the trees were concentrated in the Northeast and the Lake States (fig. 6.6). Eastern spruce budworm (*Choristoneura fumiferana*) was the most common insect recorded in the Lake States, and spongy moth (*Lymantria dispar*), primarily, and eastern tent caterpillar (*Malacosoma americanum*), secondarily, were the predominant specific insects recorded in the Northeast. Sucking insects and chewing insects were combined because only a few instances of chewing insect damage were observed. Though some sucking insect damage was noted on hardwood trees, e.g., beech scale (*Cryptococcus fagisuga*), the majority of sucking insect damage was observed on softwood trees throughout Appalachia and New England (fig. 6.7) for which balsam woolly adelgid (*Adelges piceae*) and hemlock woolly adelgid (*A. tsugae*) were the most frequently cited culprits. Parasitic/epiphytic plant damage was scattered across the Northern region and consisted primarily of vine damage on hardwood trees (fig. 6.8). Vine damage was distributed throughout the canopy in

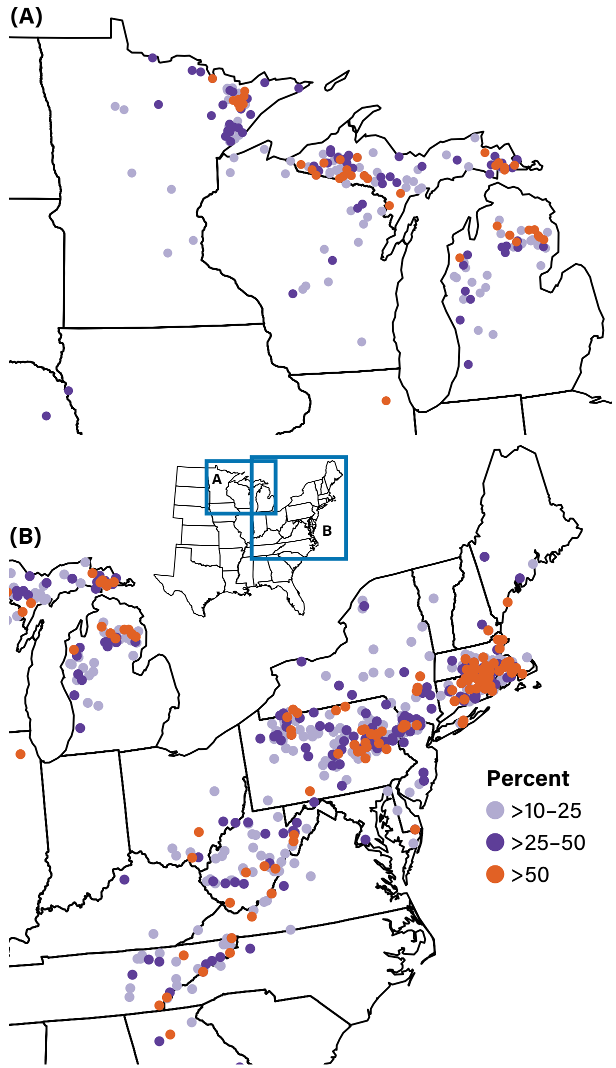

Figure 6.6—Forest Inventory and Analysis (FIA) plot locations in the (A) Lake States and (B) Northeastern regions of the Eastern United States where trees were frequently damaged by defoliating insects, by proportion of trees affected. Plot locations are approximate. (Data source: U.S. Department of Agriculture, Forest Service, FIA program)

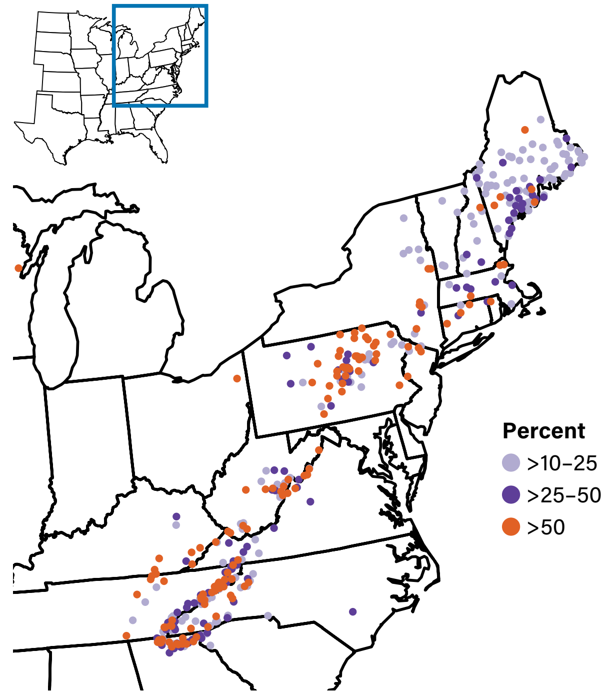

Figure 6.7—Forest Inventory and Analysis (FIA) plot locations in the Eastern United States where softwood trees were frequently damaged by chewing or sucking insects, by proportion of trees affected. Plot locations are approximate. (Data source: U.S. Department of Agriculture, Forest Service, FIA program)

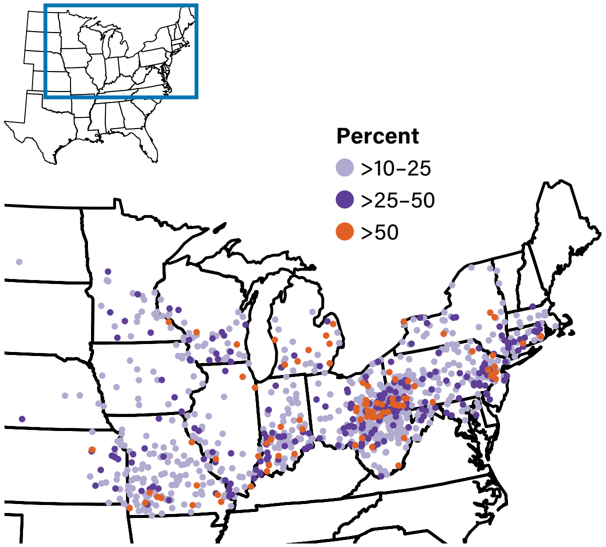

Figure 6.8—Forest Inventory and Analysis (FIA) plot locations in the Eastern United States where hardwood trees were frequently damaged by vines, by proportion of trees affected. Plot locations are approximate. (Data source: U.S. Department of Agriculture, Forest Service, FIA program)

a manner consistent with the distribution of trees. That is, the majority of trees tallied were in the codominant crown class and the majority of all vine-damaged trees were in the codominant crown class. However, the proportion of vine-damaged trees within each crown class was greatest for the intermediate crown class. Except for wind damage in the Lake States (fig. 6.9), most likely due to major storm events in the summer of 2016 (Minnesota Department of Natural Resources 2016, Wisconsin Department of Natural Resources 2016), there were no concentrations of damage from the other agents considered especially damaging to tree crowns.

I did not include a comparison of mean crown dieback between damaged and undamaged trees because up to three damage agents are allowed to be recorded for an individual tree, which confounds the effect of any particular damage agent. Sample sizes of damaged and undamaged trees became increasingly imbalanced once the subset of trees with only one damage agent was further divided by those for which crown dieback was assessed, and even more so when trees were classed by species group.

Trends in Crown Dieback

Tree crown dieback may be caused by agents acting directly on the crown or by agents affecting the movement of water and nutrients to the crown, or both. In some cases, crown dieback may be ephemeral such that tree growth returns to normal once the causal agent is no longer present (Smith and Conkling 2004). In other cases, crown dieback may continually worsen if the causal

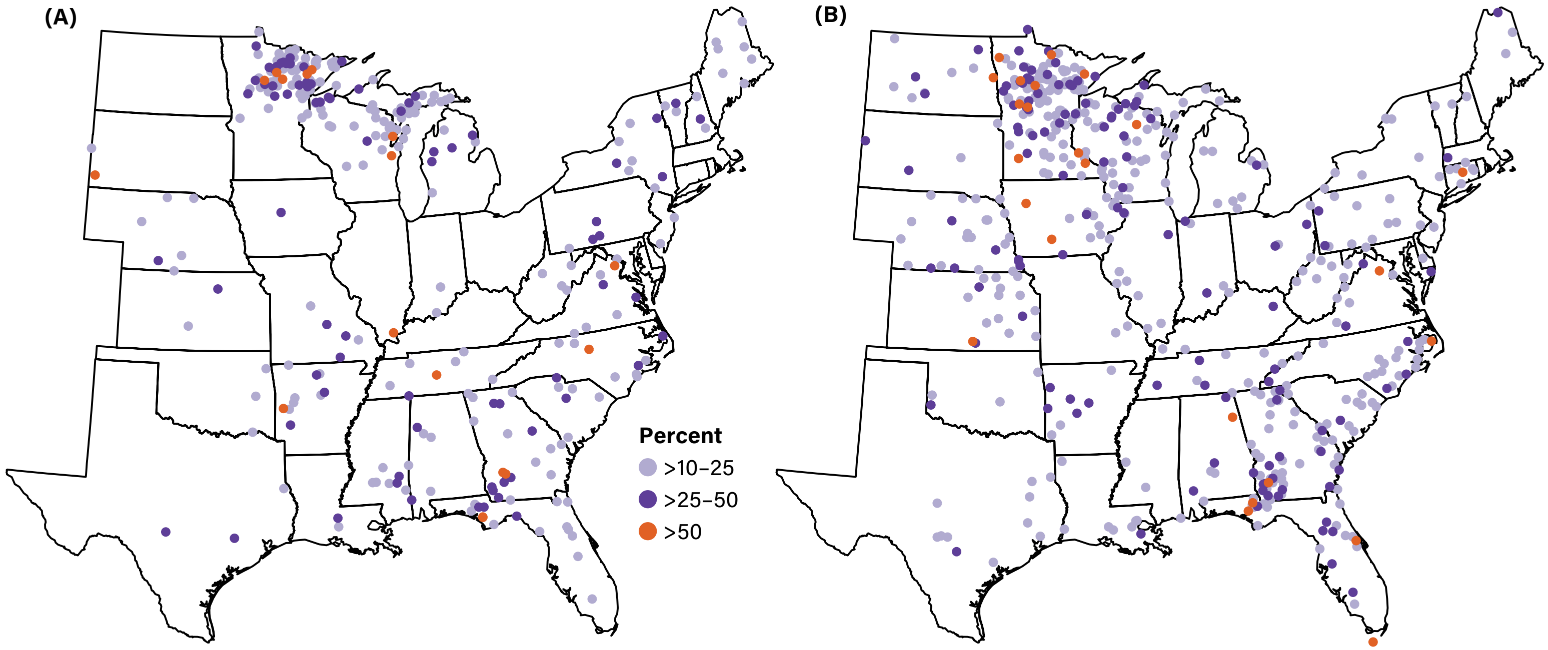

Figure 6.9—Forest Inventory and Analysis (FIA) plot locations in the Eastern United States where (A) softwood and (B) hardwood trees were frequently damaged by wind, by proportion of trees affected. Plot locations are approximate. (Data source: U.S. Department of Agriculture, Forest Service, FIA program)

agent persists. Some fluctuation in average crown dieback is expected over time; however, increasing or ongoing high levels of crown dieback are cause for concern, especially for individual species groups with no known stressors.

There has been an overall downward trend in mean crown dieback for all species combined in both the Northern and Southern regions since the late 1990s (fig. 6.10). Yet the degree to which average crown dieback changed varied by species group. Mean crown dieback for most species groups either declined or exhibited no change. This was true for all softwood species groups examined in the Northern and Southern regions (fig. 6.11). The same was also true for almost all hardwood species groups considered in the Southern region (fig. 6.12). The only hardwood species group in the Southern region with a ratio of current mean crown dieback to mean crown dieback in 1999 that was >1 was ash (ratio = 1.1). This is likely due to emerald ash borer, which was detected in the Southern region (Fairfax County, VA) in 2008 and in all Southern States except Florida and Mississippi by the end of 2020 (Emerald Ash Borer Information Network 2022). Among the hardwood species groups in the Northern region, mean crown dieback during the current inventory period was at least 1.2 times greater than it was during the earliest inventory period for ash, elm, sassafras, walnut, yellow-poplar, and hackberry (fig. 6.13). Despite the overall increases for these groups, current mean crown dieback was less than mean crown dieback observed during previous years for some species groups. For example, mean crown dieback peaked for sassafras in 2010 and in 2015 for hackberry. In contrast, declines in mean crown dieback in the Northern region have been steady since 1999 (fig. 6.13A).

The test comparing the ratio of d^2 to d^1 indicated that, on average, crown dieback on surviving trees either declined or remained steady for all species groups in the Northern (table 6.4) and Southern (table 6.5) regions. This may be because trees with crown dieback dropped out of the population due to mortality or because crown dieback was either not present or no longer recordable by definition, i.e., the dieback was no longer "recent" and consisting of fine twigs (Schomaker and others 2007). Including mortality trees in the comparison of d^2 to d^1 indicated that most of the species groups with declines in mean crown dieback from 2015 to 2019 in the Southern region (figs. 6.11B and 6.12) may have been due, at least in part, to trees dropping out of the inventory because of mortality (table 6.5). Likewise in the Northern region, declines in mean crown dieback from 2015 to 2019 for birch and cottonwood and aspen (*Populus* spp.) (fig. 6.13) may also have been due, at least in part, to mortality (table 6.4).

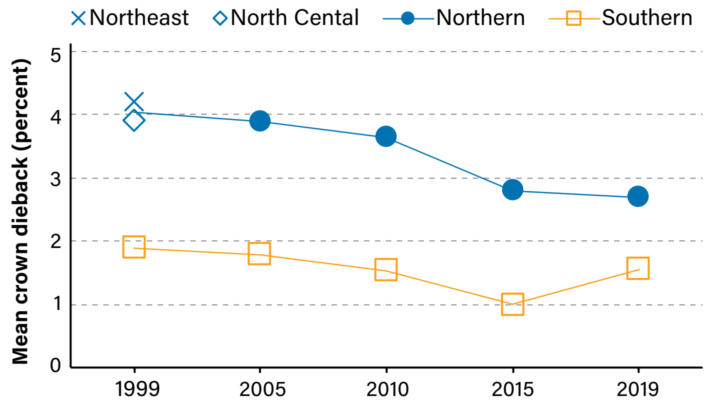

Figure 6.10—Mean crown dieback for trees ≥5.0 inches diameter at breast height in the Eastern United States, by region and year. Crown dieback in the 1990s was collected by the Forest Service Forest Health Monitoring program and reported by Randolph (2006) and Randolph and others (2010a, 2010b). NC = North Central; NE = Northeastern. (Additional data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program)

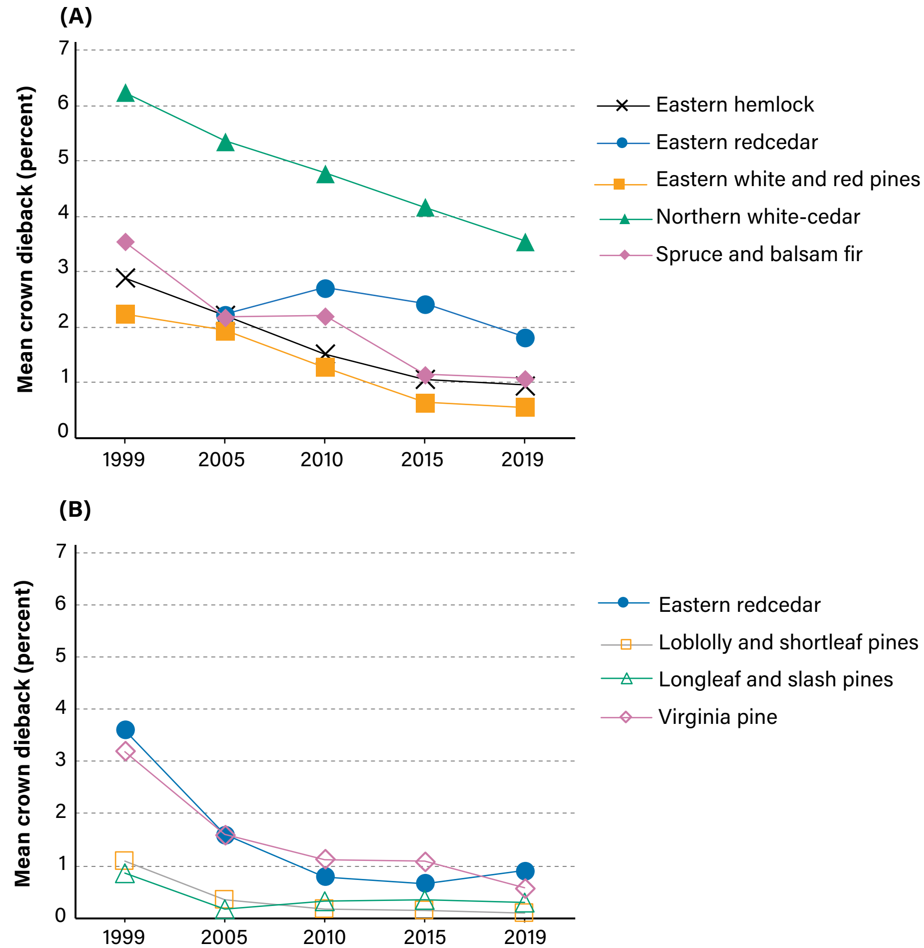

Figure 6.11—Mean crown dieback for softwood species groups in the (A) Northern and (B) Southern regions of the Eastern United States, by species group and year. (Data Source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program)

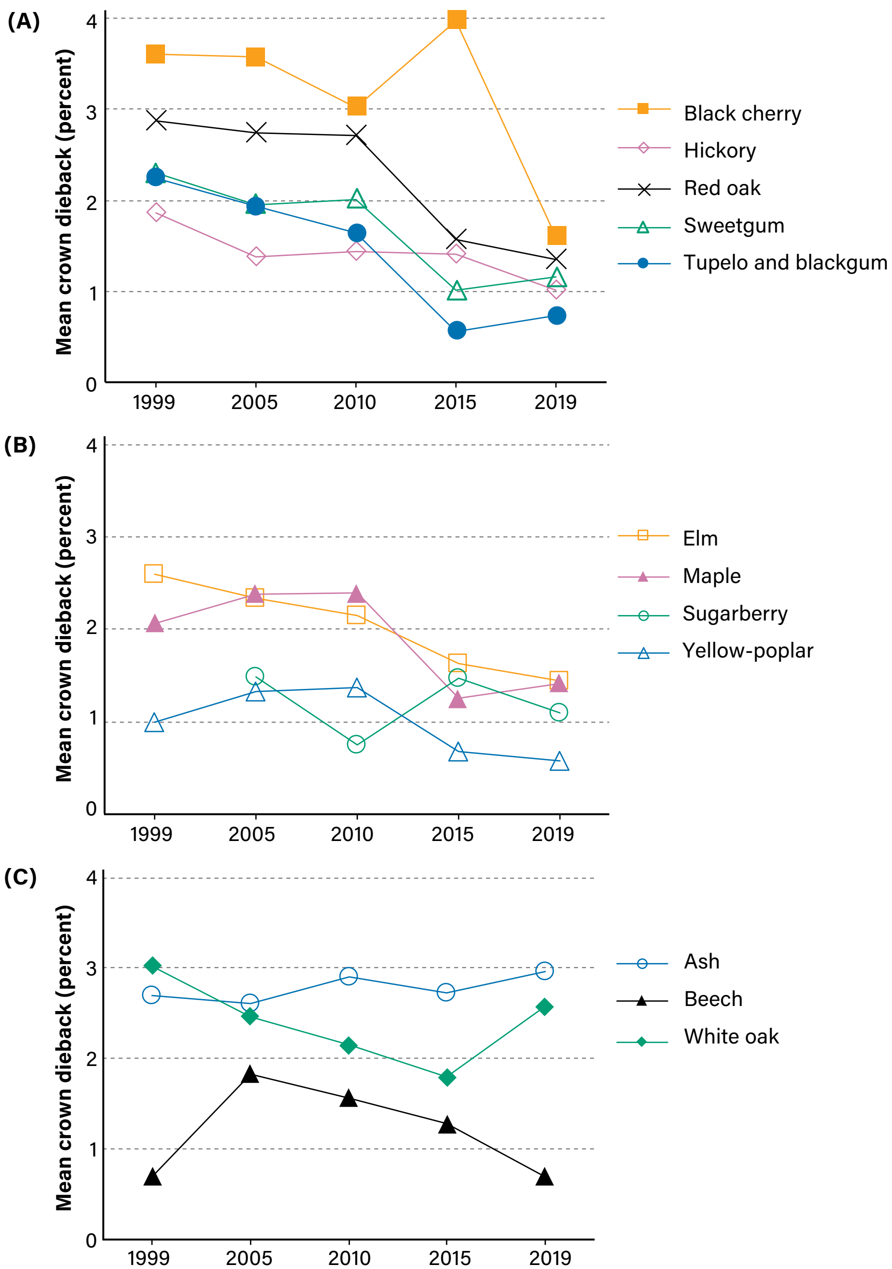

Figure 6.12—Mean crown dieback for hardwood species groups in the Southern region of the Eastern United States for which the ratio between current mean crown dieback and the earliest mean crown dieback was (A) ≤0.5, (B) >0.5 and <0.8, and (C) ≥0.8. (Data Source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program)

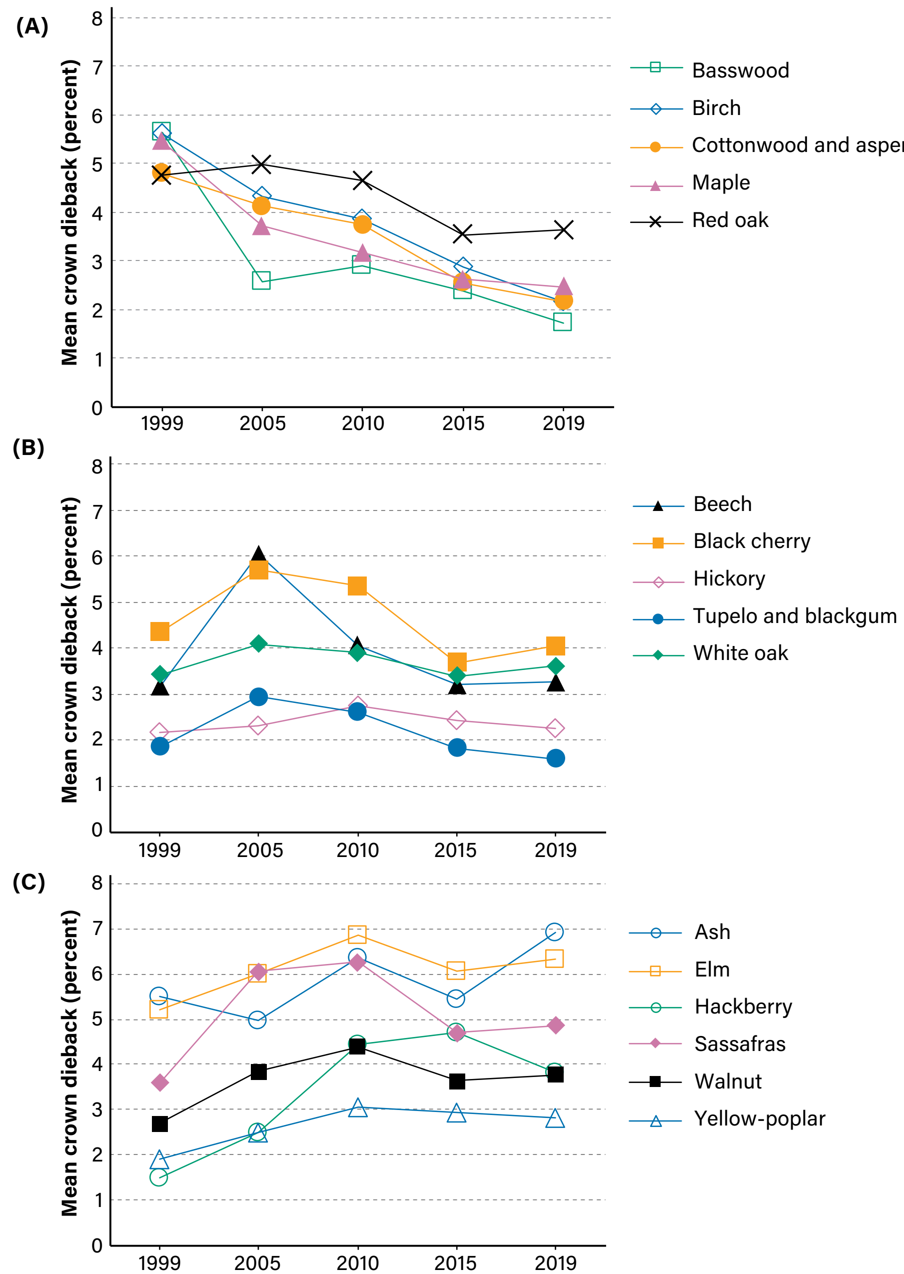

Figure 6.13—Mean crown dieback for hardwood species groups in the Northern region of the Eastern United States for which the ratio between current mean crown dieback and the earliest mean crown dieback was (A) <0.8, (B) ≥0.8 and <1.2, and (C) ≥1.2. (Data Source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program)

Table 6.4—Mean ratio between current and previous crown dieback, and 95-percent upper (UCL) and lower (LCL) confidence limits, for paired trees in the Northern region, by species group

	Surviving trees and mortality trees					Surviving trees only				
Species group	Number of plots	Number of trees	Mean	LCL	UCL	Number of plots	Number of trees	Mean	LCL	UCL
Softwood	888	12,033	1.2	1.1	1.3	866	11,231	0.9	0.8	1.0
Eastern hemlock	190	1,321	1.1	0.9	1.4	188	1,288	0.9	0.8	1.2
Eastern redcedar	86	458	1.2	0.7	1.9	82	431	0.9	0.5	1.5
Eastern white and red pines	266	2,087	1.1	0.9	1.2	264	1,984	0.8	0.7	0.9
Northern white-cedar	155	2,062	0.9	0.7	1.3	154	2,001	0.9	0.6	1.2
Spruce and balsam fir	451	4,487	1.3	1.1	1.6	440	4,088	0.9	0.7	1.0
Tamarack	67	399	1.1	0.6	1.9	66	382	0.8	0.6	1.2
Hardwood	1,644	26,113	1.2	1.1	1.3	1,574	23,652	0.8	0.8	0.9
Ash	459	1,797	2.4	1.8	3.2	394	1,463	1.12	0.9	1.4
Basswood	156	576	0.6	0.4	0.8	152	559	0.5	0.4	0.7
Beech	282	1,137	1.5	1.1	2.1	273	1,030	1.0	0.8	1.3
Birch	534	2,267	1.2	1.0	1.4	515	2,064	0.8	0.7	1.0
Black cherry	294	961	1.4	1.1	1.8	273	858	0.9	0.7	1.2
Cottonwood and aspen	354	2,164	1.5	1.2	1.8	330	1,870	0.8	0.7	1.0
Elm	336	887	2.1	1.6	2.8	288	695	1.0	0.8	1.2
Hackberry	94	250	0.9	0.5	1.6	88	228	0.7	0.4	1.2
Hickory	299	1,040	1.2	0.9	1.5	287	985	0.9	0.7	1.2
Maple	1,056	8,037	0.9	0.8	1.0	1,036	7,579	0.7	0.6	0.8
Red oak[a]	565	2,234	1.1	0.9	1.4	530	2,032	0.8	0.7	1.0
Sassafras	94	268	1.5	0.8	2.8	82	228	0.9	0.5	1.6
Tupelo and blackgum	107	235	1.1	0.8	1.6	104	230	1.0	0.7	1.4
Walnut	132	292	1.0	0.7	1.6	119	269	0.8	0.5	1.1
White oak[b]	427	2,298	1.4	1.1	1.9	404	2,111	1.1	0.8	1.4
Yellow-poplar	97	401	1.2	0.8	1.7	92	365	0.9	0.6	1.3

[a] *Quercus* Section *Lobatae*.

[b] *Quercus* Section *Quercus*.

Table 6.5—Mean ratio between current and previous crown dieback, and 95-percent upper (UCL) and lower (LCL) confidence limits, for paired trees in the Southern region, by species group

	Surviving trees and mortality trees					Surviving trees only				
Species group	Number of plots	Number of trees	Mean	LCL	UCL	Number of plots	Number of trees	Mean	LCL	UCL
Softwood	986	12,020	1.6	1.5	1.7	920	11,097	1.0	0.9	1.0
Cypress	59	387	1.1	0.9	1.3	58	378	0.9	0.8	1.0
Eastern redcedar	150	548	1.7	1.3	2.2	140	497	1.0	0.9	1.1
Loblolly and shortleaf pines	668	8,347	1.5	1.4	1.6	630	7,795	1.0	1.0	1.0
Longleaf and slash pines	163	1,697	1.9	1.5	2.6	148	1,518	1.0	0.8	1.2
Virginia pine	95	523	2.1	1.4	3.3	87	444	0.8	0.7	1.0
Hardwood	1,350	17,296	1.5	1.4	1.6	1,202	15,403	0.8	0.8	0.9
Ash	192	575	1.9	1.4	2.6	162	482	0.8	0.6	1.1
Beech	76	176	0.8	0.6	1.1	74	166	0.7	0.5	0.9
Black cherry	196	386	1.5	1.0	2.2	166	322	0.6	0.5	0.9
Elm	287	613	1.5	1.2	1.9	259	534	0.8	0.7	0.9
Hickory	405	1,237	1.2	1.0	1.5	379	1,129	0.8	0.7	0.9
Maple	512	1,889	1.7	1.4	1.9	463	1,665	0.9	0.8	1.0
Red oak[a]	803	3,041	1.6	1.4	1.8	737	2,664	0.8	0.8	0.9
Sourwood	133	358	1.3	0.9	1.7	118	317	0.8	0.6	1.0
Sugarberry	52	161	1.7	1.0	2.6	48	145	0.9	0.7	1.2
Sweetgum	483	1,801	1.4	1.2	1.7	459	1,638	0.9	0.8	0.9
Tupelo and blackgum	317	1,058	1.2	1.0	1.4	294	989	0.8	0.7	0.9
White oak[b]	620	2,706	1.0	0.8	1.1	585	2,516	0.7	0.6	0.8
Yellow-poplar	284	1,096	1.3	1.1	1.5	272	1,019	0.9	0.8	1.0

[a] *Quercus* Section *Lobatae*.
[b] *Quercus* Section *Quercus*.

CONCLUSIONS

In general, crown conditions were as expected for most species groups and overall exemplified the presence of known stressors in the Eastern United States, such as beech bark disease, emerald ash borer, hemlock woolly adelgid, spongy moth, and eastern spruce budworm. Damage by wind and vines was also common; however, damage by foliage diseases, decline complexes/dieback/wilts, and snow and ice was less frequent. With only a few exceptions, average crown dieback has remained stable or declined over the last 20 years. Among the softwood species groups included in this summary, crown dieback was greatest among northern white-cedar trees in the Northern region and pinyon-juniper trees in the Southern region. Among the hardwood species groups, crown dieback was greatest among ash and elm trees in the Northern region and honey mesquite trees in the Southern region. Favorably, a downward trend in crown dieback was observed for northern white-cedar over the last 20 years and within the last 10 years for elm; however, crown dieback continued to trend upward for ash. The first remeasurement of trees in central and western Texas is only partially complete; therefore, it is unclear if the high levels of crown dieback for pinyon-juniper and honey mesquite are characteristic for these species groups or trending in one direction or the other.

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