United States
Department of
Agriculture

Forest Service

Northeastern Area

Morgantown, WV

NA-TP-04-99

Changes in Composition of the Mixed Mesophytic Forest: Effects of Succession and Disturbance

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Acknowledgments

I wish to thank Gerry Hertel and Dan Twardus of the USDA Forest Service for sponsoring this study and providing expert advice. I am deeply grateful to a number of my colleagues for their helpful reviews of the draft – from the Forest Service: Bob Anderson, Bill Burkman, Andy Gillespie, Will McWilliams, Manfred Mielke, and Dave Randall; from the Ohio Department of Natural Resources: Dan Balser; and from the West Virginia Department of Agriculture: Sherri Hutchinson and Clark Haynes. Special thanks to Tom Hall and John Quimby of the Pennsylvania Bureau of Forestry for their thorough critique.

Jim Steinman

Credits

Editors: *Lennie Eav and Brenda Wilkins*

Format and layout: *Nancy Lough*

Printing and production: *Patty Dougherty and Tinathan Coger*

Cover Photo: *Courtesy of Dan Balser of Ohio Department of Natural Resources*

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January 1999

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Abstract

This study investigated the hypothesis that air pollution is causing mortality of the larger overstory trees, which results in a shift in species composition. To determine if the theorized shifts in species composition have occurred, this study compared historical changes in forest composition as described by Braun (1940) with more recent changes as quantified by the Forest Inventory Analysis (FIA) program of the USDA Forest Service. FIA estimated recent composition changes using records of live, dead, and cut trees from 5,404 randomly sampled plots.

Analyses suggest that the forest overstory consisted mostly of late-successional species in the 1940s and early- and mid-successional species in the 1980s. Thus, differences were most likely due to disturbances (insects and diseases, fire, weather, pollution) that killed trees, which allowed pioneer species to occupy openings. Forest succession may account for the 6 percent of dead trees in the 1980s since the percentages of dead trees were significantly greater among early-successional species. Percentages and spatial gradients of dead trees of species tolerant to air pollutants were similar to dead trees of intolerant species. Most of the 4 percent of all trees cut in the 1980s were not late-successional species, which may have favored successional trends.

Keywords: mixed mesophytic forest, tree mortality, succession, disturbances, air pollutants

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Introduction

The mixed mesophytic forest was described by E. Lucy Braun (1950) as the portion of the Appalachian region of the United States (Figure 1) that contains a diverse *mixture* of *mesophytes.* Mesophytes are plants that grow best on moist sites. Field studies conducted by Braun in the 1940s included descriptions of the many tree species observed in the overstory (see Appendix Table A-1), including counts of overstory trees along sampled transects. Summaries of Braun's published counts (see Appendix Table B-1) show species in the following order of abundance:

1. American beech
2. Sugar maple
3. Yellow-poplar
4. Eastern hemlock
5. American chestnut
6. White oak
7. Basswood
8. Chestnut oak
9. Hickory
10. Yellow buckeye

Various stress factors have contributed to modify the distribution and species composition (Martin 1992) of the forest. As with all forest ecosystems, trees compete for light, water, and nutrients; species tolerant of competition tend to succeed while intolerant species die (Spurr and Barnes 1992). This relatively slow process of competition and survival is often abruptly interrupted by disturbances that kill trees, create forest openings, alter species composition, and modify forest succession trends (Abrams and Downs 1990; Abrams and Nowacki 1992). Disturbances in the mixed mesophytic forest include urban development, agriculture, logging, fire, drought, wind storms, forest insects, and diseases (Hicks and Mudrick 1993). The most influential tree disease in recent years has been chestnut blight [*Cryphonectria parasitica* (Murr.) Barr]. Chestnut blight has virtually eliminated the American chestnut tree from the forest overstory.

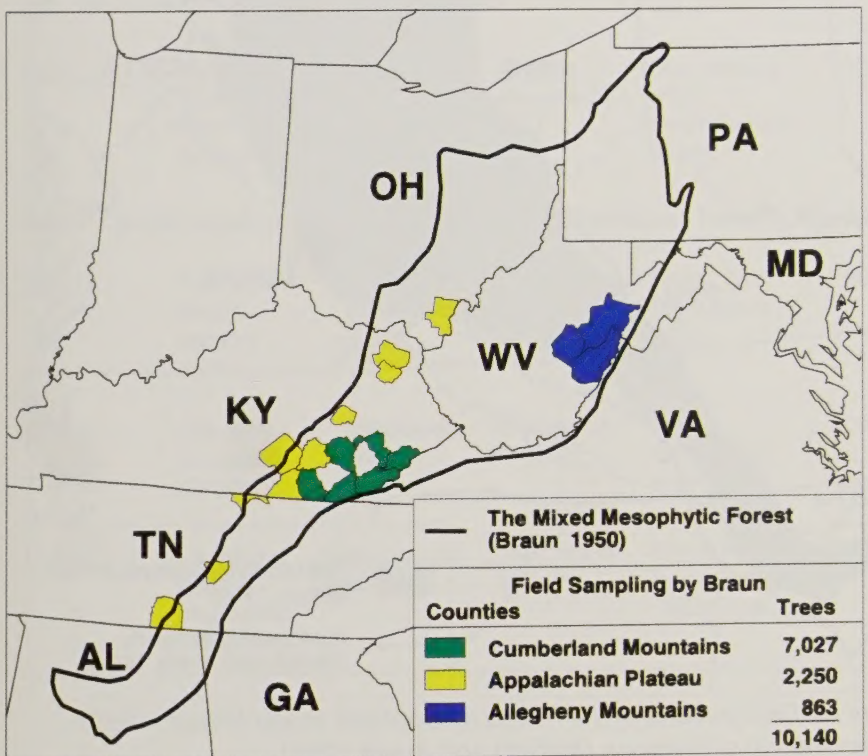


Figure 1. States containing the mixed mesophytic forest and counties sampled by Braun (1950).

Role of Air Pollution

Air pollutants consisting of nitrogen, sulfur, and ozone have been present in the United States forests throughout the latter half of the 20th century. However, most studies to determine the effects of ambient air pollutants on mature forest trees have shown inconclusive results due to the following factors:

- Difficulty and expense involved in conducting controlled "cause and effect" field experiments.
- Lack of reference or benchmark data with which to compare increases in air pollution data.
- Reliance on evaluations that associate tree mortality and ambient air pollution along spatial gradients (Shriner and others 1990).

Studies of tree mortality and ambient air pollution in the northern Appalachian region have only been able to demonstrate a relationship between mortality of red spruce and concentrations of air pollutants at high elevations. Even so, two hypotheses exist for the mixed mesophytic forest. These hypotheses state that: (1) larger trees of some species are dying at an accelerated rate, and (2) mortality is due to the deposition of airborne nitrogen and exposure to ozone, which predispose trees to root pathogens (Little 1995).

Study Design

The current analysis focused on testing the hypothesis that trees of some species are dying at accelerated rates. Supportive analyses used quantitative data from the Forest Inventory and Analysis (FIA) program of the USDA Forest Service (Hansen and others 1992). FIA provides the best available source of high-quality and unbiased information obtained from an extensive system of randomly selected locations. Initial analyses were conducted to compare the overstory composition observed by Braun in the 1940s with the composition observed in the 1980s as gleaned from the FIA data. Subsequent analyses identified tree species and geographic locations with percentages of dead trees or cut trees that deviate from forest-wide averages. These results were then used to infer historical differences in species composition between the 1940s and 1980s, and the recent changes in species composition and forest succession trends.

While this study did not directly address the hypothesis that air pollutants cause trees to die, FIA data were utilized to identify likely causes of mortality based on the differential proportions of dead trees among species and locations. More rigorous hypothesis testing would require collection of data to frequently monitor the variability in tree health over time across the study region, and account for changes in health and mortality due to coincident effects of tree competition and disturbances such as forest insects and diseases. Such data are currently not available for the mixed mesophytic forest although they have been collected in other regions by the ongoing Forest Health Monitoring and North American Maple Projects (Twardus and Mielke 1995).

Methods

Study Area

The location of the mixed mesophytic forest as described by Braun (1950) closely corresponds to delineations of ecological subregions (Table 1 and Figure 2) defined by McNab and Avers (1994). Use of subregion boundaries was desirable to facilitate comparisons among natural physiographic and climatic zones instead of political entities (e.g., states and counties). The southern extension of the forest in ecological subregion 231C of Alabama was retained for analyses, although it has a warmer climate and more loblolly pine than the other subregions. Likewise, the northern extension in 212G of Pennsylvania was retained although it represents a cooler climate than the rest of the forest and has a higher proportion of black cherry.

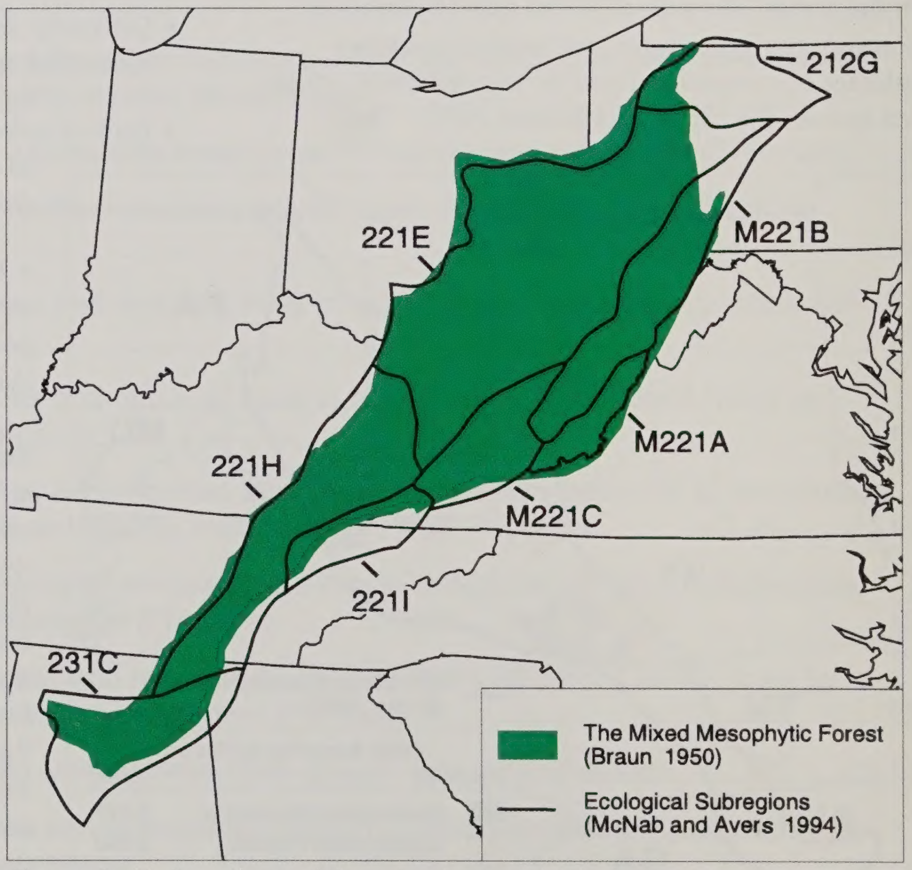


Figure 2. Delineations of the mixed mesophtyic forest (Braun 1950) and ecological subregions (McNab and Avers 1994).

Table 1
Characteristics of Ecological Subregions that Contain the Mixed Mesophytic Forest (McNab and Avers 1994)

Ecological Subregion	Geo-morphology	Paleozoic Parent Materials	Soil Taxa	Potential Forest Vegetation	Elevation (ft)	Precip (in) Temp (F)	Growing Season (days)	Disturbance and Land Use
212 Laurentian Mixed Forest Province								
212G	dissected plateau	sandstone, siltstone, shale	Ultisols Inceptisols	Hemlock- N. hardwoods Appal. oak-pine	1000-2400	40-50 46-48	120-150	Fire; forestry, oil, agriculture
221 Eastern Broadleaf Forest Province								
221E	dissected plateau	sandstone, siltstone, shale, coal	Ultisols Inceptisols	Appalachian hardwoods	660-1350	35-45 39-55	120-170	Fire, clearing; agriculture, urban
221H	dissected plateau	sandstone, shale, coal	Ultisols Inceptisols	Mixed; mesophytic, Appal. oak	650-980	46-55	175	Fire; forestry
221I	Faulted/ folded monoclinal mountains	sandstone, shale, llimestone	Ultisols Inceptisols	Appal. oak, Mixed Mesoph.	800-1000	46-55	175	Fire; forestry
231 Southeastern Mixed Forest Province								
231C	Faulted/ folded monoclinal mountains	stratified marine deposits	Ultisols Inceptisols	Oak-hickory-pine, Southeastern mixed	330-1330	50-55 60-62	200-210	Fire, drought; forestry
M221 Central Appalachian Broadleaf Forest - Coniferous Forest - Meadow Province								
M221A	Faulted/ folded parallel ridges	limestone, sandstone, shale	Inceptisols Ultisols	Appal. oak, oak-hickory, pine	300-4800	35-50 46-60	120-170	Fire; agric., forestry, urban
M221B	Severely dissected plateau	sandstone, shale	Inceptisols Ultisols	Mixed hardwoods, spruce-fir	1000-4600	40-60 39-54	110-160	Fire; forestry
M221C	Faulted/ folded monoclinal mountains	sandstone, shale	Inceptisols Ultisols	Mixed mesophytic, Appal. oak	2000-2600	40-47 45-50	140-160	Fire; agriculture, forestry

Braun Historical Data

Reports by Braun (1940; 1950) include a valuable historical record of the characteristics of the mixed mesophytic forest during the 1940s. Field studies conducted by Braun included sampling along transects averaging 1 mile in length to obtain counts of living overstory trees. Braun sampled a total of 10,140 trees from 19 counties with most trees (7,027) located in the Cumberland Mountains of southeastern Kentucky (see Figure 1). Published data from the various sampled areas provide a means to estimate the species composition of the forest during the 1940s.

Diameters and spacing in tree stands were not provided in the Braun reports, which precluded estimation of how trees of different sizes were distributed in stands. However, descriptions and within-stand photographs indicate an uneven aged forest with trees of various sizes. Some trees were reported to be at least 40 inches dbh (diameter at 4.5 feet above the ground), but photographs often depict one or two of these large diameter trees surrounded by trees of smaller sizes.

Counts of dead trees were also not collected in the Braun data, which prevented comparison with estimates derived from recent FIA data used in this study. Although Braun mentioned that American chestnut was disappearing due to chestnut blight, Braun did not mention the occurrence of mortality of other tree species.

FIA Data

The Northeastern Research Station FIA Eastwide Database (Hansen and others 1992) was used to estimate recent species composition and percentages of dead and removed trees, which represent cumulative amounts of mortality and cutting during a probable period of 10 to 15 years. Data were collected from an extensive network of randomly sampled plots measured over a span of four years in the following states: Alabama (1990), Kentucky (1988), Ohio (1991), Pennsylvania (1989), Tennessee (1989), and West Virginia (1989). A few plots in the FIA data included sample plots from Maryland (1986) and Virginia (1992).

The area of each sample plot was commonly 1/5 acre, but varied among locations (1/6 to 1/4 acre) as a function of different sampling designs. Variables used from plot records included approximate locations (latitude and longitude), forest type, stand size (trees dominated by saplings 1 to 5 inches dbh), poletimber (5 to 10 inches dbh), or sawtimber (>10 inches dbh), and stand basal area (total cross-sectional area of trees at 4.5 feet above the ground). Plot sizes were used to estimate the equivalent number of trees per acre of each tallied tree. Variables used from each tree record included species, diameter at breast height (dbh), crown position (dominant, codominant, intermediate, or suppressed), and status (live, standing or fallen dead, or cut). Records of dead trees and cut trees from previous inventories were used to determine diameter at breast height and crown position values 10 to 15 years earlier.

All tree species within the study area were of interest for evaluation. This comprehensive approach avoided bias towards any given species and facilitated more robust comparisons among a variety of species groups. However, greater emphasis was placed on species that Braun described as predominant in the overstory than on other species. Thus, analyses were confined to FIA plots within oak-hickory, northern hardwood, and oak-pine forest types that mostly contain representative species of the mixed mesophytic forest.

Of the selected FIA plots, 68 percent was from oak-hickory types and 19 percent was from northern hardwood forest types. Oak-hickory forest types were predominant in all ecological subregions except 212G, which had a majority of plots in northern hardwood forest types. Oak-pine forest types were represented by less than 10 percent of the plots in most subregions, and therefore some analyses were not conducted for these types.

Analyses were also confined to FIA plots within poletimber- and sawtimber-sized stands and to dominant and codominant trees at least 10 inches dbh. Trees of this size were chosen because they represent most of the relative stocking of mature stands and most of the removals from logging in the region (Birch and others 1992). With this criterion, a total of 5,404 FIA plots and 86,654 overstory trees at least 10 inches dbh was chosen from the database (Table 2 and Table 3). Of this total, 32 groups of species were each represented by at least 150 trees, with an additional 12 species placed in a miscellaneous category. Each species was commonly represented by only one or two trees on a sample plot, and rarely by more than five trees.

Analytical Procedure

Analytical procedures to evaluate species composition, dead trees, and removed trees used percentages of numerical counts of trees in the overstory that were at least 10 inches dbh. Counts of trees were used because this measure can be interpreted and collected for later comparison with other data, and species composition from tree counts can be compared to historical estimates by Braun (1950). Although Braun did not include measurements of tree diameters in reported data, it was assumed in this study that overstory trees were greater than 10 inches in diameter and located in mature stands.

Species were analyzed individually and in groups based on whether they were intolerant, moderately tolerant, or tolerant of competition (Burns and Honkala 1990a; 1990b). The tolerance ratings of species generally correspond to the successional stage in which they predominate, where tolerant species characterize a late successional forest. A previous study showed differences in stocking among species that vary in tolerance to competition and different successional stages of the forest (USDA Forest Service 1995).

Species composition of the forest was evaluated by combining tree data from all FIA plots within a given forest type or ecological subregion. Percentages of trees in each species were tabulated for each stratum. Tabulations were used to rank species by their abundance and to determine if any differences exist among forest types and ecological subregions. Species composition was also evaluated at six counties in southeastern Kentucky (counties of Bell, Clay, Harlan, Letcher, Perry, and Whitley) that correspond to a primary area sampled by Braun. A combined total of 3,618 trees from 206 FIA plots in these counties was used to determine percentages of each species and compared to those reported by Braun. Data from FIA plots were then used to estimate the composition of the forest in the same counties existing in 1988 and to interpret differences between surveys as temporal changes.

Proportions of dead trees and removed trees were analyzed separately using FIA data. Percentages of all live, dead, and removed trees were used to express the amount of dead and removed trees among species in a given stratum. Expressing the amount of dead and removed trees for all species in each stratum allowed comparison of averages (higher or lower) among species.

Table 2
Distribution of FIA Sample Plots with Trees at least 10 inches DBH
(by Forest Type and Ecological Subregion)

			Ecological Subregion							
Forest Type		**All**	**212G**	**221E**	**221H**	**221I**	**M221A**	**M221B**	**M221C**	**231C**
			Percent of plots							
Oak-Hickory		68.1	30.3	72.4	75.6	82.7	72.5	63.4	89.8	49.3
Northern Hardwood		18.5	62.6	16.5	2.2	5.5	12.8	31.9	8.1	0.0
Oak-Pine		5.1	1.1	2.7	11.2	7.2	8.3	0.6	0.8	23.5
Mixed Mesophytic		91.7	93.0	91.6	89.0	95.4	93.6	95.9	98.7	72.8
Types	**n =**	**5404**	**527**	**1974**	**844**	**226**	**204**	**832**	**521**	**276**
Softwood and		8.3	6.1	8.4	11.0	4.6	6.4	4.1	1.3	27.2
Other Types	**n =**	**490**	**34**	**181**	**104**	**11**	**14**	**36**	**7**	**103**
All Types	**n =**	**5894**	**561**	**2155**	**948**	**237**	**218**	**868**	**528**	**379**

Table 3
Distribution of all trees (live, dead, and cut) at least 10 inches DBH from 5404 FIA sample plots located in oak-hickory, northern hardwood, and oak-pine forest types

Species	Trees	Number of trees per sample plot					Plots with at least:	
		0	1-2	3-5	6-10	11 +	1 tree	3 trees
	n =	*Percent of 5404 plots*					*n =*	*n =*
Ash sp.	2157	80.7	15.2	2.9	1.0	0.2	1044	221
Aspen sp.	594	95.4	3.0	1.2	0.2	0.1	246	82
Basswood sp.	1457	89.5	6.9	2.6	0.8	0.2	568	193
Beech	4446	77.2	12.2	5.8	3.7	1.1	1233	575
Birch sp.	1791	86.7	9.4	2.7	1.0	0.2	717	211
Black cherry	5240	77.4	12.0	5.2	3.2	2.2	1221	571
Black locust	1350	88.9	8.3	2.0	0.7	0.1	601	153
Black walnut	617	93.0	6.0	0.9	0.1	0.0	380	55
Blackgum	791	89.2	9.9	0.8	0.1	0.0	581	45
Buckeye sp.	280	97.2	2.3	0.4	0.1	0.0	149	25
Cucumbertree	766	91.8	6.8	1.1	0.2	0.0	441	73
Elm sp.	869	91.9	6.3	1.5	0.3	0.0	440	100
Hemlock sp.	923	93.5	4.0	1.8	0.6	0.1	350	133
Hickory sp.	5208	60.7	26.5	9.7	2.7	0.4	2124	692
Magnolia sp.	156	98.3	1.5	0.2	0.1	0.0	94	15
Maple, red	8047	58.2	24.7	10.1	4.1	2.9	2259	925
Maple, sugar	4624	73.1	16.7	5.9	2.9	1.3	1452	547
Oak, black	5236	65.9	21.0	8.9	3.6	0.7	1845	711
Oak, chestnut	8114	65.2	15.1	10.4	6.6	2.7	1883	1066
Oak, northern red	7626	56.2	25.9	11.4	4.6	1.9	2367	969
Oak, other red	555	95.6	3.3	0.9	0.2	0.1	239	60
Oak, scarlet	3277	77.6	14.5	5.4	2.1	0.4	1210	429
Oak, other white	429	95.7	3.4	0.8	0.1	0.0	233	47
Oak, white	8069	56.4	23.2	12.6	5.8	1.9	2356	1100
Pine, loblolly	468	97.7	1.0	0.7	0.4	0.1	124	68
Pine, pitch	281	97.2	2.2	0.5	0.0	0.0	149	32
Pine, shortleaf	598	95.4	3.3	0.9	0.3	0.1	247	70
Pine, Virginia	1171	92.3	4.9	1.8	0.8	0.2	417	152
Pine, white	433	97.1	1.9	0.6	0.4	0.1	157	55
Sassafras	463	95.4	3.9	0.5	0.1	0.1	249	38
Sweetgum	263	98.0	1.3	0.5	0.1	0.0	107	35
Yellow-poplar	9280	58.0	20.2	11.8	6.8	3.1	2267	1174
Other species	1075	87.7	2.1	0.3	0.0	0.0	663	16
All Species	**86654**	**0.0**	**1.6**	**5.7**	**17.9**	**74.8**	**5404**	**5319**

Statistical tests of independence were used to compare percentages among species and ecological strata to determine if differences were significant ($p < 0.05$) (Agresti 1990). In this procedure, the Chi-square test statistic was used to determine if there is significant difference in percentage of dead or removed trees in a given stratum and the percentage of dead or removed trees in all observations.

To compare percentages of dead trees in sampled FIA plots at different locations, only plots with at least three live, dead and/or removed trees of a subject species were used. Percentages of plots with dead trees present or absent among forest types and ecological subregions were compared.

To determine if dead trees and removed trees on the same plot were associated, each plot was designated as having removals present or absent depending on evidence of at least one removed tree of any species. To facilitate statistical tests of association, analyses were confined to species represented on at least 50 sample plots. The percentages of plots with dead trees of individual species were determined for the groups of plots with and without removals, and tests of independence were used to determine if percentages were significantly different ($p < 0.05$) for groups that were compared.

Maps of plot locations and their corresponding attributes were also used to show where dead trees were present or absent for individual tree species. Spatial distributions of plots containing dead trees were visually interpreted to determine if plots occurred in groups or if they appeared to be randomly scattered.

Results and Discussion

1. Differences in Species Composition in the Last 50 Years

Historical Changes in Southeastern Kentucky

In the 1940s, Braun (1950) reported that 84 percent of the overstory trees in the Cumberland Mountains of southeastern Kentucky consisted of 10 species (see Figure 3 and Appendix Table B-1). Data collected from FIA plots in the same counties during

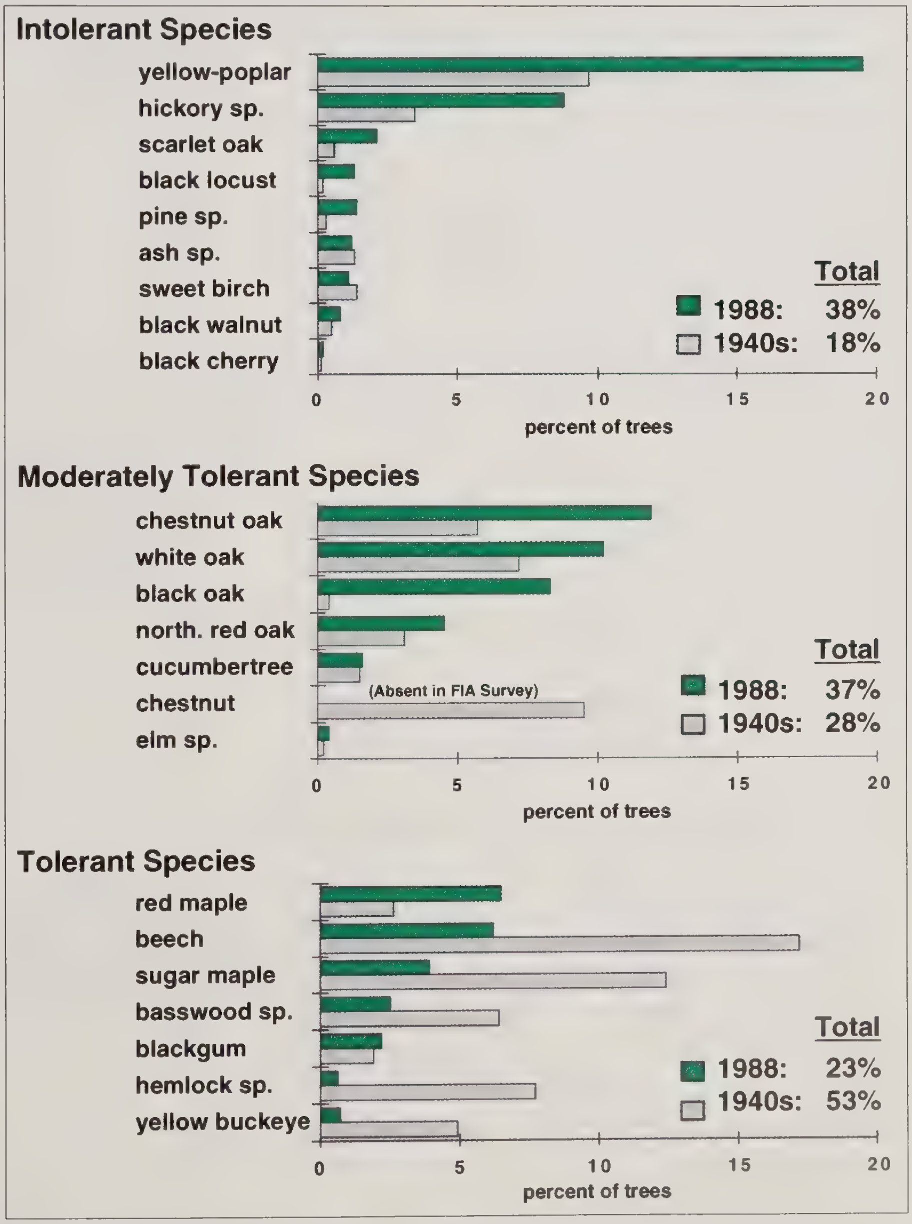


Figure 3. Species composition in southeastern Kentucky during the 1940s and 1988 as estimated by Braun (1950) and from FIA sample plots, respectively.

1988 showed that a different set of 10 species accounted for 83 percent of the overstory. Oak, hickory, red maple, and yellow-poplar were more abundant; beech, sugar maple, hemlock, basswood, and buckeye were less frequent. American chestnut was notably absent.

Braun estimated that the American chestnut comprised 10 percent of the overstory and observed that trees were dying from chestnut blight. The eventual loss of chestnut from the overstory is a well-known event. However, corresponding decreases in American beech, sugar maple, eastern hemlock, and yellow buckeye did not coincide with any disease or insect pest outbreak (e.g., beech bark disease [*Nectria coccinea* var. faginata (Pers.:Fr.)] or hemlock woolly adelgid [*Adelges tsugae* Annand]). Because these species are tolerant of limited growing conditions and therefore predominate late successional forests, it is not likely that they were outcompeted by other species. It is more likely that disturbances such as logging and land clearing created forest openings that were rapidly colonized by early successional species well adapted to increased light, moisture, and nutrient availability.

FIA data show that early successional species, including yellow-poplar, scarlet oak, hickory, black locust, Virginia pine, and red maple, were more abundant in 1988. The increase of red maple also corresponds to the capability of this species to easily regenerate and out-compete other species on a range of hydric to xeric sites (Burns and Honkala 1990a; 1990b).

FIA Data: Composition of Mixed Mesophytic Forest

Two-thirds of all FIA plots measured throughout the mixed mesophytic forest between 1986 and 1992 were within oak-hickory forest types, while only 19 percent of the plots represented northern hardwood types (see Table 1). Figure 4 (derived from Appendix Table C-1) shows that the oak-hickory types throughout the forest had a composition similar to southeastern Kentucky in 1988 (see Figure 3).

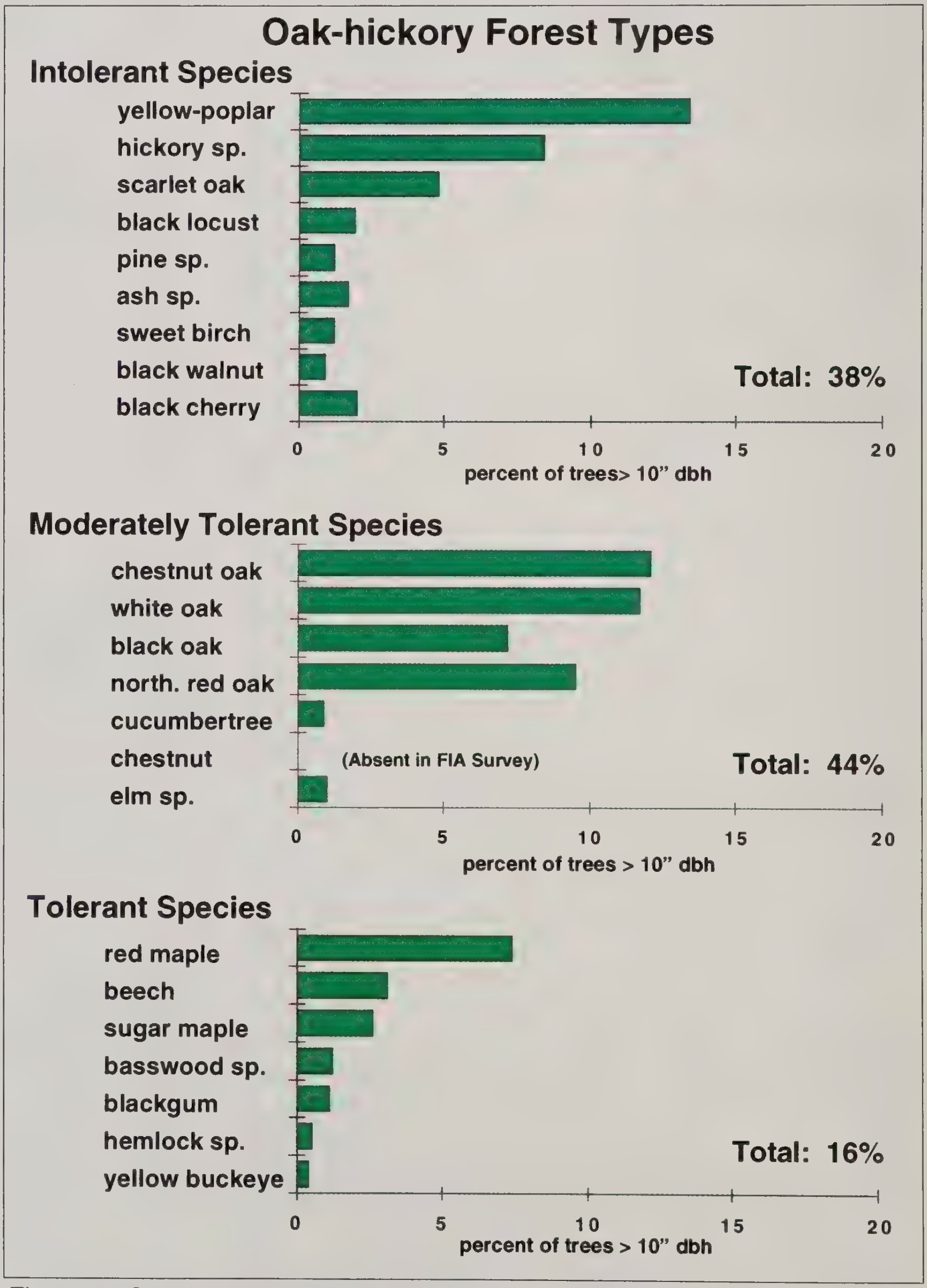


Figure 4. Species composition of oak-hickory forest types by tolerance to competition (FIA data).

Conversely, Figure 5 shows that the composition of northern hardwood forest types more closely resembled the composition of southeastern Kentucky in the 1940s. These results suggest that the mixed mesophytic forest region in the late 1980s were at an earlier stage of succession than that observed by Braun in the 1940s.

By definition, the oak-hickory forest types contain fewer tree species tolerant of competition than the northern hardwood types. FIA data show that only 16 percent of the trees in the oak-hickory type were of tolerant species as compared to 49 percent of the trees in the northern hardwood type. Most of this difference was due to greater percentages of red maple, sugar maple, American beech, basswood, and hemlock in the northern hardwood type. Conversely, high percentages of oak species in the oak-hickory type explain why 44 percent of the trees are moderately tolerant of competition, while only 9 percent of the trees in the northern hardwood type were moderately tolerant. The two groups of forest types are similar in that at least 40 percent of their trees were intolerant of competition. However, intolerant species in the oak-hickory type were mostly yellow-poplar, scarlet oak, and hickory species, and those in the northern hardwood type are mostly black cherry, sweet birch, and ash species.

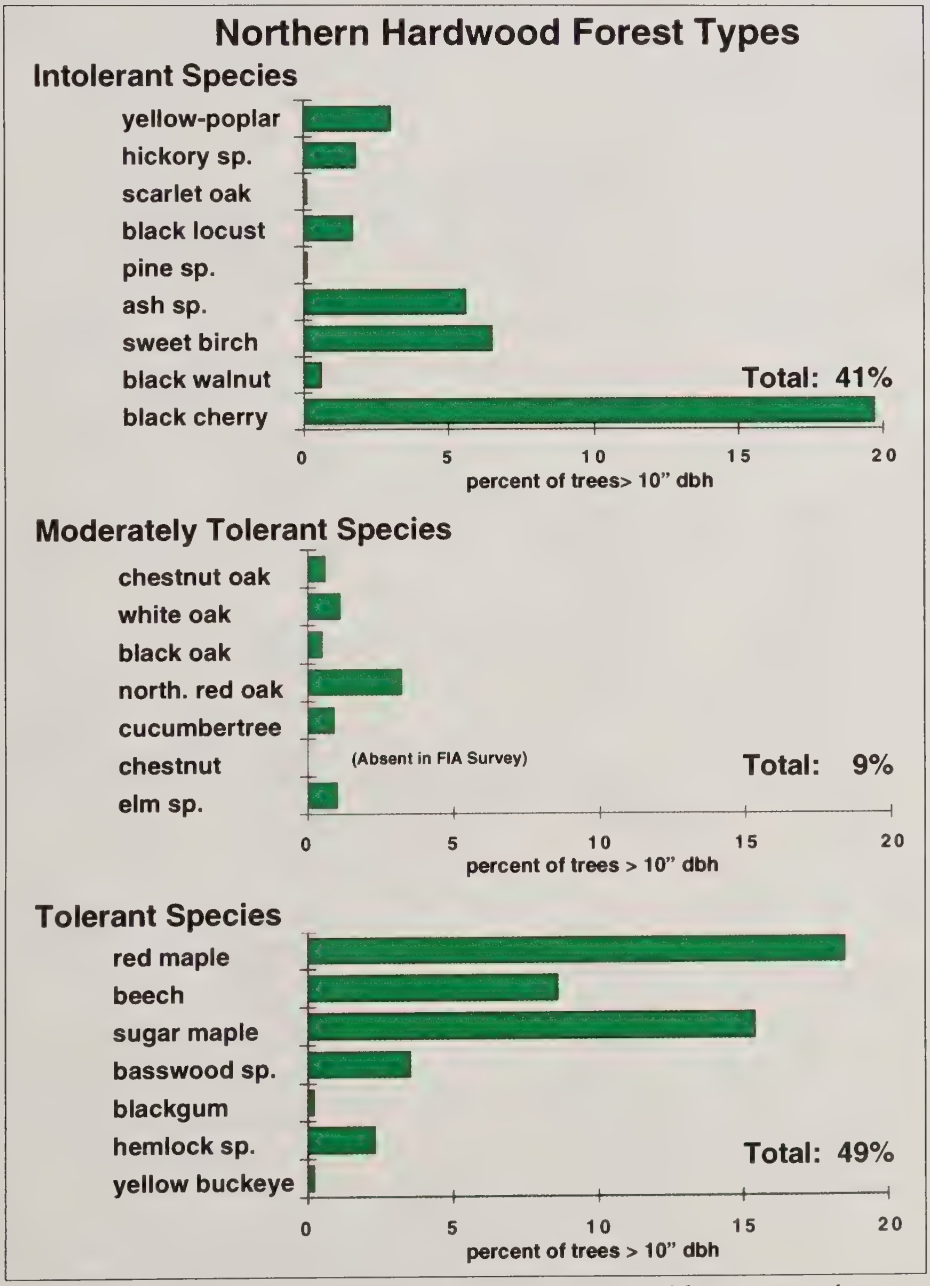


Figure 5. Species composition of northern hardwood forest types by tolerance to competition (FIA data).

Various pine and other oak species were not common and mostly found in the minor component of oak-pine forest types (see Appendix Table C-1). Pine species comprised about 40 percent of the oak-pine forest and consisted of Virginia pine, shortleaf pine, loblolly pine, eastern white pine, and pitch pine. Only 7 percent of the trees in this type were of species tolerant of competition.

2. Rate of Tree Mortality

This section of the study ascertained whether trees were dying at an accelerated rate.

Data show that percentages of dead trees in the oak-hickory and northern hardwood types were similar at 6 and 7 percent, respectively. About 6 percent of the trees in the northern hardwood types were removed as compared to 3 percent in the oak-hickory types.

Records of dead trees and removed trees in the FIA database represent cumulative amounts of mortality and cutting that occurred during the 10- to 15-year period between measurements of sampled plots. Analyses of data from the mixed mesophytic forest show that 6 percent of trees with at least 10 inches dbh were still standing or fallen dead and 4 percent have been removed (see Appendix Table C-1).

Mortality Rate of Different Species

Percentages of dead trees varied greatly among species, which indicate different rates of mortality and consequent changes in species composition. In the oak-hickory forest type, 7 percent of trees intolerant of competition were dead compared to 4 percent of tolerant species and 5 percent of species that were moderately tolerant (Figure 6). Species in the northern hardwood type that were tolerant of competition also had lower proportions of dead trees than species that were intolerant or moderately tolerant (Figure 7 on next page). These differences suggest that most of the recent mortality is related to the dynamics of forest succession.

In the oak-hickory forest type, species with the greatest proportions of dead trees were elm, black locust, pitch pine, Virginia pine, and scarlet oak. Species with the greatest percentages of dead trees in the northern hardwood type were black locust, birch, cucumbertree, elm, hemlock, and chestnut oak. Most of these species were intolerant of competition and representative of early stages of forest succession. Although elm is moderately tolerant of competition, high percentages of dead elm were most likely due to Dutch elm disease (DED) and elm yellows. DED is caused by a fungus [*Ophiostoma ulmi* (Buism.) Nannf.] and elm yellows is caused by a phytoplasm (Hicks and Mudrick 1993).

Tree cutting also accounts for recent mortality. In the oak-hickory type forest, loblolly pine, shortleaf pine, and Virginia pine showed the highest percentages of removed trees (9 to 25 percent) (see Figure 6 and Appendix Table A-3). Black oak, northern red oak, black cherry, black walnut, and sweetgum were also being removed faster than average from the oak-hickory forest. Within the northern hardwood

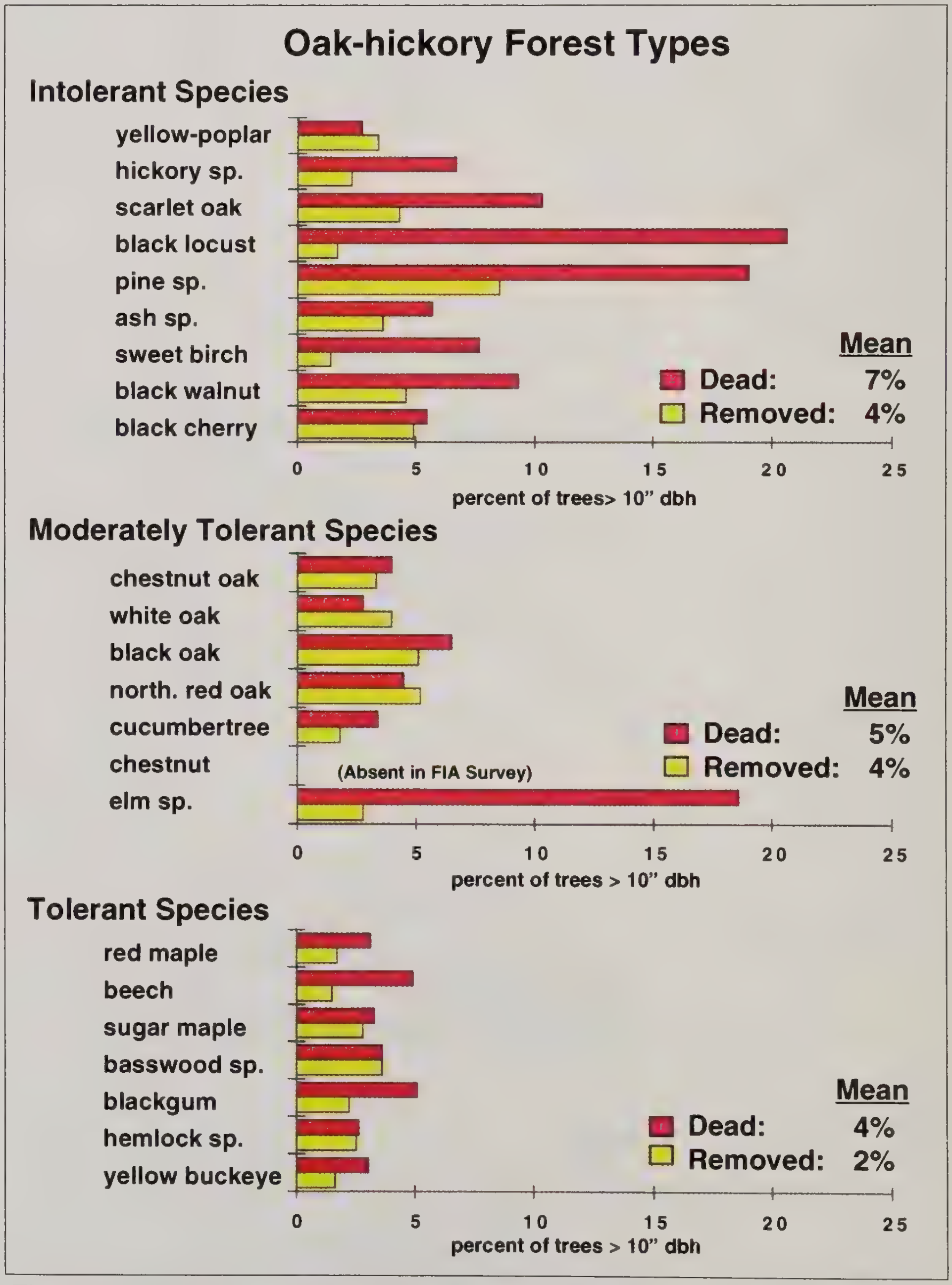


Figure 6. Percentages of dead trees and removed trees in oak-hickory forest types by tolerance to competition (FIA data).

forest, species moderately tolerant of competition were removed more frequently than the tolerant and intolerant species (see Figure 7 and Appendix Table C-1). For example, black oak, chestnut oak, northern red oak, and white oak accounted for most of the 13 percent of removed trees. Another 10 percent each of moderately tolerant (cucumbertree and elm) and intolerant species (black walnut and yellow-poplar) were also removed.

Rate of Mortality in Large Trees

Species in this study were represented by two sizes of trees: (1) those that were 10 to 15 inches dbh, and (2) trees larger than 15 inches dbh (see Appendix Table C-2). Proportions of dead trees were significantly greater among larger trees of hickory, scarlet oak, shortleaf pine, Virginia pine, elm, magnolia, and beech. However, for all combined species intolerant of competition (Figure 8), there were more dead trees in the 10 to 15 inch class.

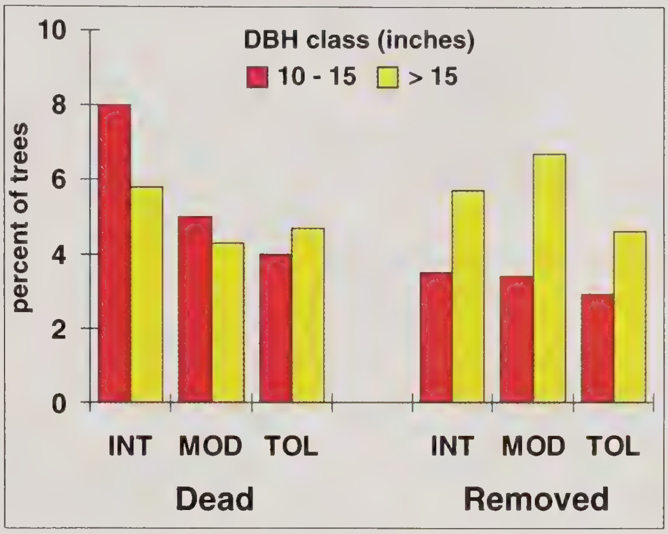


Figure 8. Percentages of dead trees and removed trees by dbh class and tolerance to competition: Intolerant (INT), moderately tolerant (MOD), and tolerant (TOL) (FIA data).

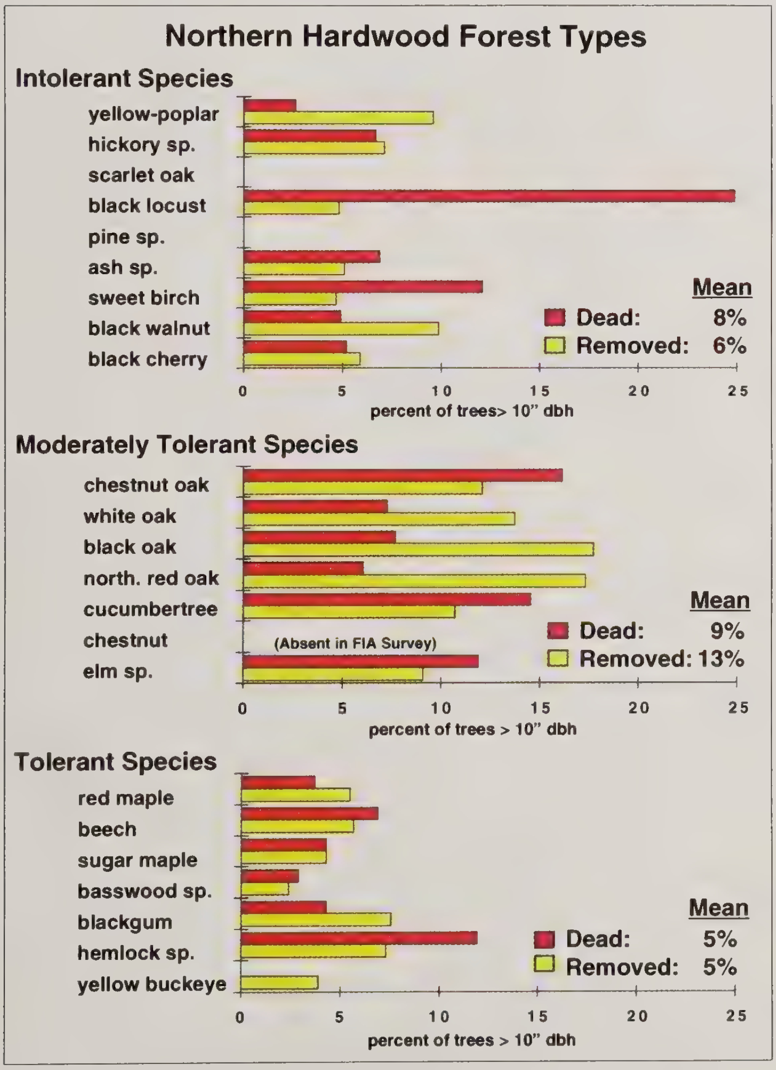


Figure 7. Percentages of dead trees and removed trees in northern hardwood forest types by tolerance to competition (FIA data).

In general, more of the larger trees (>15 inches dbh) were removed than trees that were 10 to 15 inches dbh for most species. These results indicate selective logging of timber species and support previous studies showing that changes in forest composition and structure are partly due to a disproportionate removal of large trees of marketable species (Birch and others 1992).

Mortality by Geographic Locations

Significantly greater percentages of dead trees belonged to intolerant species within oak-hickory forests (Figure 9) at the Appalachian plateau (ecological subregions 212G, 221E and 221H) than in mountainous areas (subregions M221A, M221B, and M221C). Specifically, at least 10 percent of the aspen, birch, black locust, sassafras, scarlet oak, and Virginia pine were dead when they occurred in the plateau subregions (Appendix Tables C-3 through C-10). Percentages of dead trees of moderately tolerant species (mostly oak) were also greater in the northern hardwood forests of the Appalachian plateau than in other subregions (Figure 10).

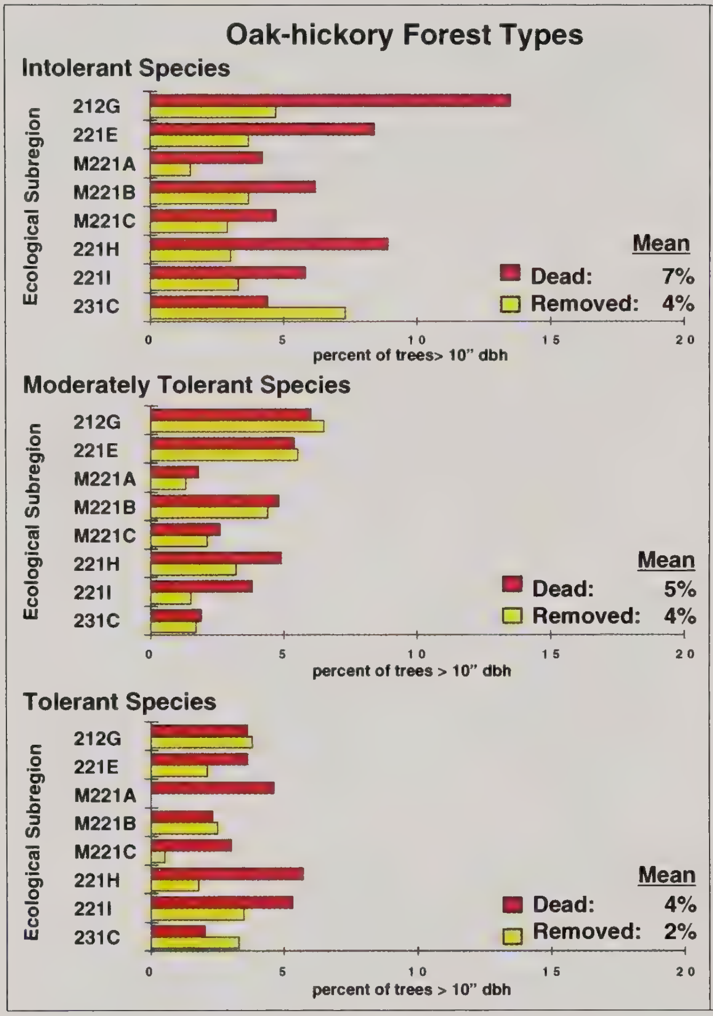


Figure 9. Percentages of dead trees and removed trees in oak-hickory forest types by tolerance to competition and ecological subregion (FIA data).

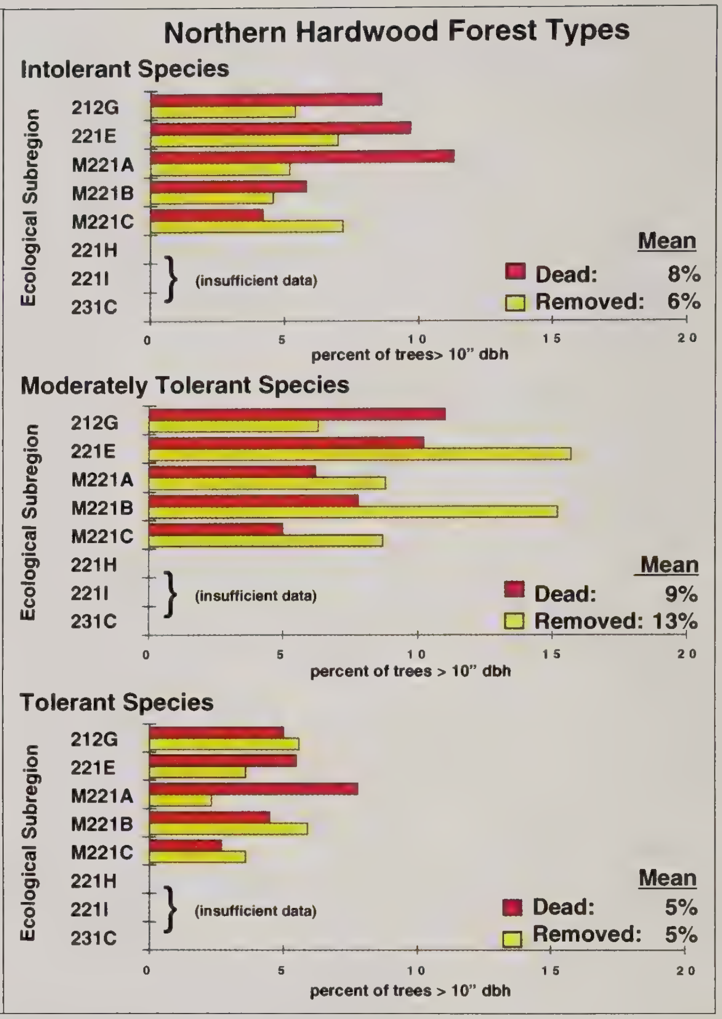
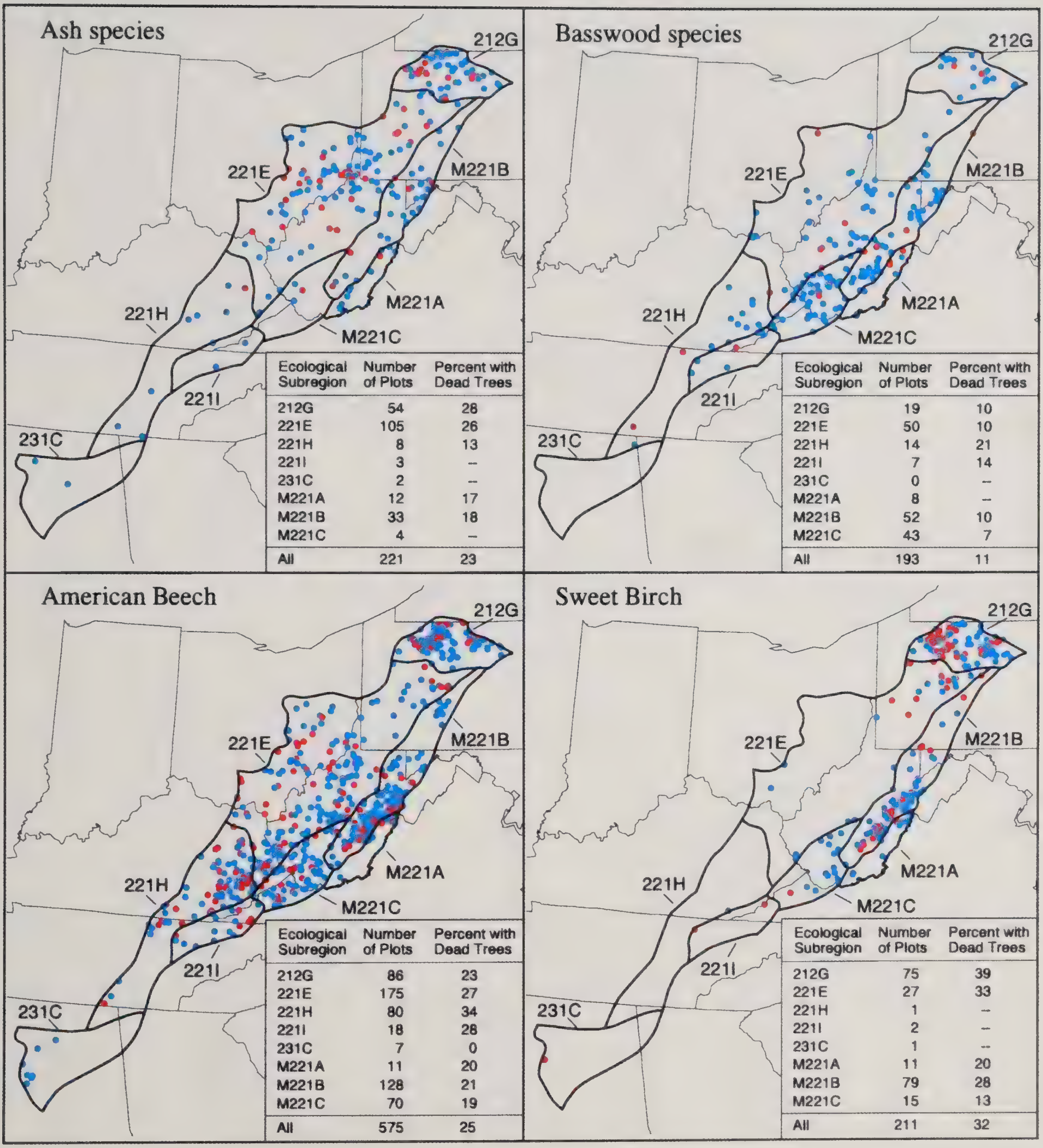


Figure 10. Percentages of dead trees and removed trees in northern hardwood forest types by tolerance to competition and ecological subregion (FIA data).

Percentages of removed trees were also greater in the northern hardwood forest types of subregions 212G, 221E, M221B, and M221C (see Figure 10). Species with the greatest proportions of removed trees in the mountainous subregions of M221B and M221C were cucumbertree, red maple, oak, and yellow-poplar. Black walnut, elm, oak, and yellow-poplar were removed more than other species in subregion 221E, while hemlock, beech, and oak were more frequently removed in subregion 212G. In the oak-hickory forest, subregions 212G and M221B also had greater percentages of removed trees than other subregions.

Figures 11-15 on the following pages show the locations of plots with dead trees and illustrate the differences in mortality among ecological subregions. Throughout the region, an average of 20 percent of the plots contained dead trees. However, significantly more plots in subregions 212G, 221E, and 221H contained dead trees of several species (see Appendix Table D-1). Subregion 212G contained plots with the highest number of dead trees, where dead birch, hemlock, sugar maple, and chestnut oak were found on at least 30 percent of the plots containing these species. Red maple was the only species with dead trees on less than 20 percent of the sampled plots. Subregions 221E and 221H also contained many species with dead trees on more than 20 percent of the plots (see Appendix Table D-1). In 221E, significantly more than 20 percent of the plots contained dead black locust, elm, scarlet oak, Virginia pine, hickory, black cherry, and beech. Significantly greater percentages of plots in subregion 221H contained dead beech, hickory, black oak, and scarlet oak.



Ash species

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	54	28
221E	105	26
221H	8	13
221I	3	--
231C	2	--
M221A	12	17
M221B	33	18
M221C	4	--
All	221	23

Basswood species

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	19	10
221E	50	10
221H	14	21
221I	7	14
231C	0	--
M221A	8	--
M221B	52	10
M221C	43	7
All	193	11

American Beech

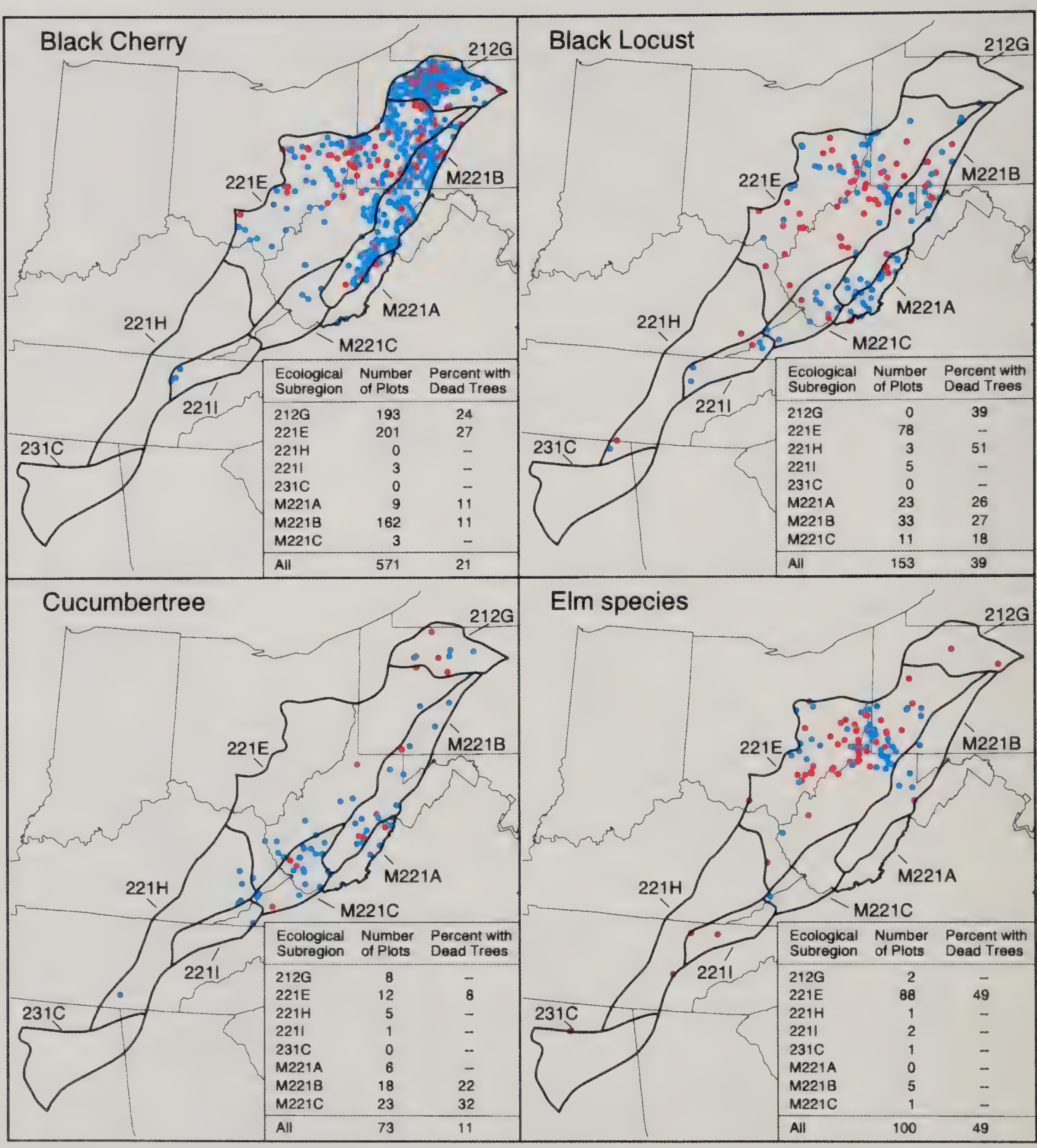
Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	86	23
221E	175	27
221H	80	34
221I	18	28
231C	7	0
M221A	11	20
M221B	128	21
M221C	70	19
All	575	25

Sweet Birch

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	75	39
221E	27	33
221H	1	--
221I	2	--
231C	1	--
M221A	11	20
M221B	79	28
M221C	15	13
All	211	32

Dead Trees greater than 10 inches DBH:
● Present ● Absent

Figure 11. FIA plots containing at least three trees greater than 10 inches dbh.



Black Cherry

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	193	24
221E	201	27
221H	0	--
221I	3	--
231C	0	--
M221A	9	11
M221B	162	11
M221C	3	--
All	571	21

Black Locust

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	0	39
221E	78	--
221H	3	51
221I	5	--
231C	0	--
M221A	23	26
M221B	33	27
M221C	11	18
All	153	39

Cucumbertree

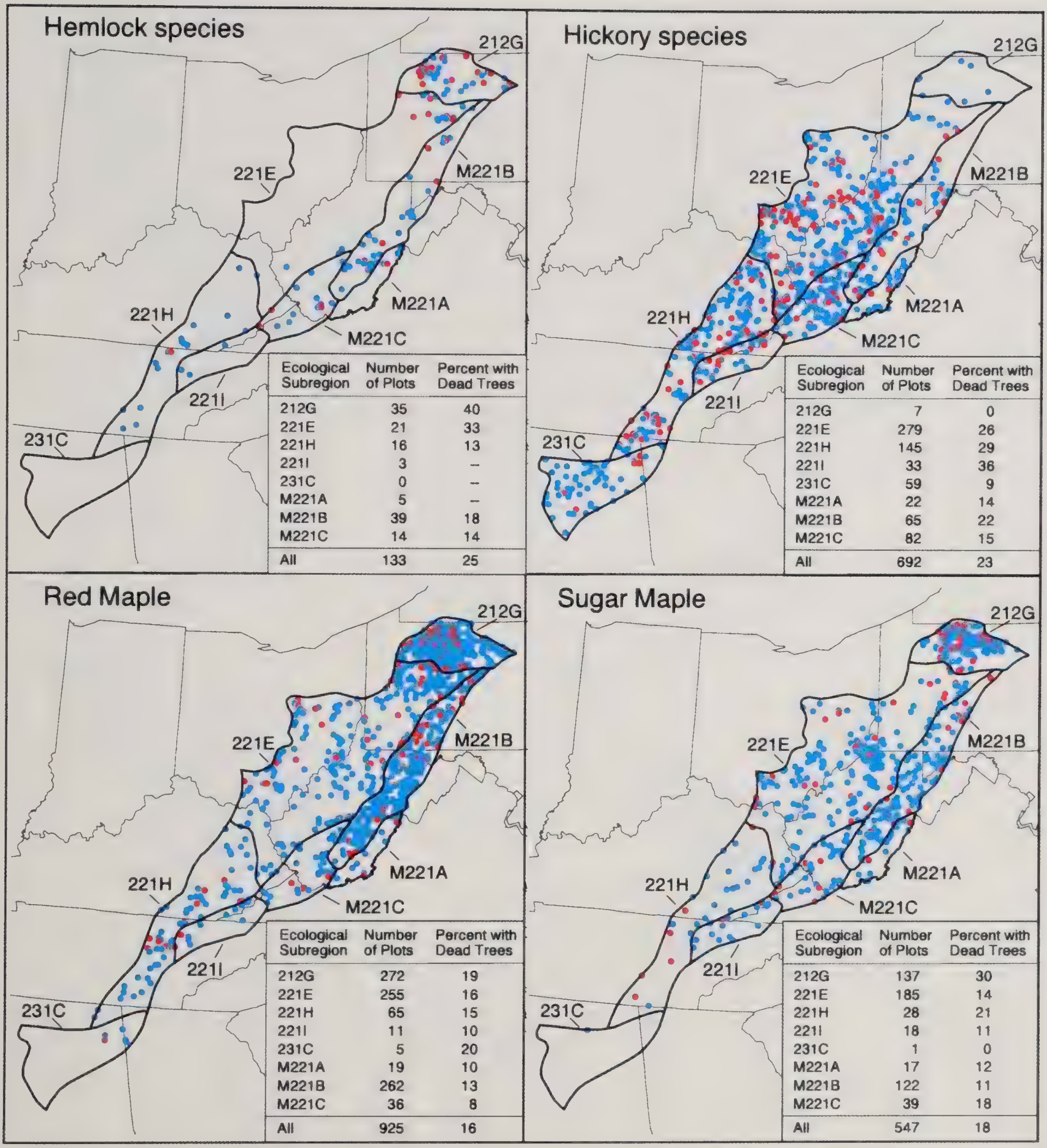
Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	8	--
221E	12	8
221H	5	--
221I	1	--
231C	0	--
M221A	6	--
M221B	18	22
M221C	23	32
All	73	11

Elm species

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	2	--
221E	88	49
221H	1	--
221I	2	--
231C	1	--
M221A	0	--
M221B	5	--
M221C	1	--
All	100	49

Dead Trees greater than 10 inches DBH:
Present Absent

Figure 12. FIA plots containing at least three trees greater than 10 inches dbh.



Hemlock species

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	35	40
221E	21	33
221H	16	13
221I	3	--
231C	0	--
M221A	5	--
M221B	39	18
M221C	14	14
All	133	25

Hickory species

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	7	0
221E	279	26
221H	145	29
221I	33	36
231C	59	9
M221A	22	14
M221B	65	22
M221C	82	15
All	692	23

Red Maple

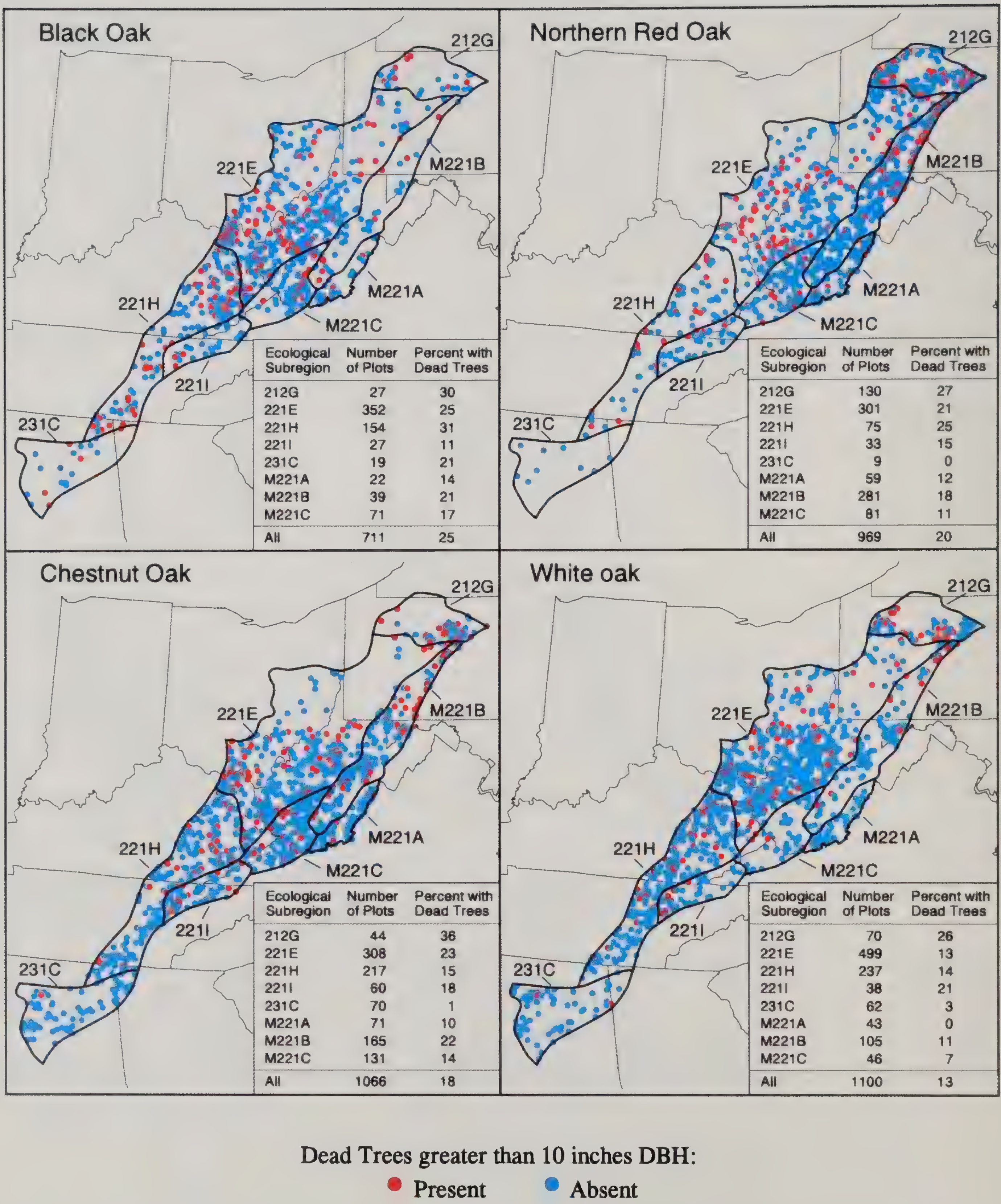
Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	272	19
221E	255	16
221H	65	15
221I	11	10
231C	5	20
M221A	19	10
M221B	262	13
M221C	36	8
All	925	16

Sugar Maple

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	137	30
221E	185	14
221H	28	21
221I	18	11
231C	1	0
M221A	17	12
M221B	122	11
M221C	39	18
All	547	18

Dead Trees greater than 10 inches DBH:
● Present ● Absent

Figure 13. FIA plots containing at least three trees greater than 10 inches dbh.



Black Oak

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	27	30
221E	352	25
221H	154	31
221I	27	11
231C	19	21
M221A	22	14
M221B	39	21
M221C	71	17
All	711	25

Northern Red Oak

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	130	27
221E	301	21
221H	75	25
221I	33	15
231C	9	0
M221A	59	12
M221B	281	18
M221C	81	11
All	969	20

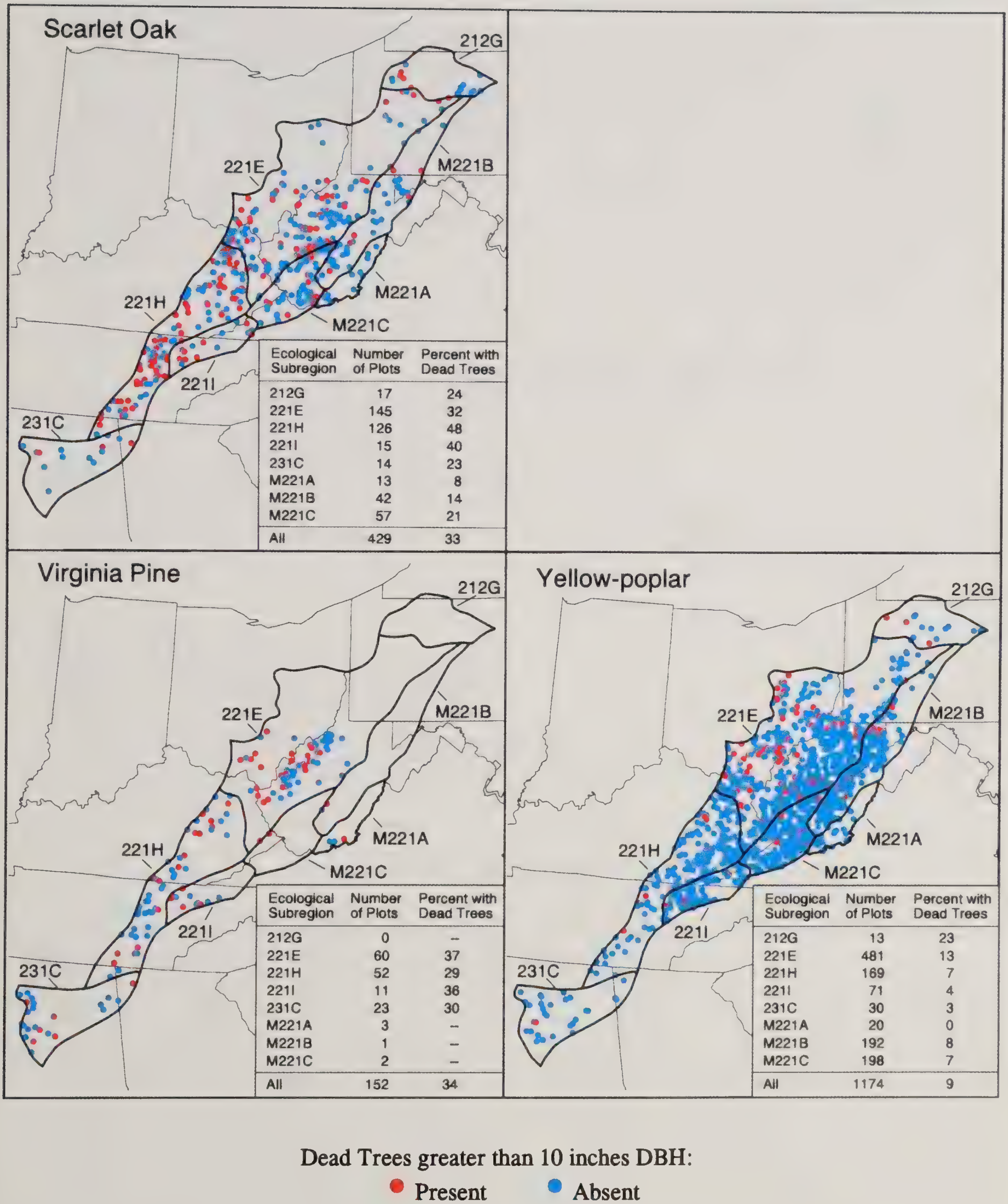
Chestnut Oak

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	44	36
221E	308	23
221H	217	15
221I	60	18
231C	70	1
M221A	71	10
M221B	165	22
M221C	131	14
All	1066	18

White oak

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	70	26
221E	499	13
221H	237	14
221I	38	21
231C	62	3
M221A	43	0
M221B	105	11
M221C	46	7
All	1100	13

Figure 14. FIA plots containing at least three trees greater than 10 inches dbh.



Scarlet Oak

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	17	24
221E	145	32
221H	126	48
221I	15	40
231C	14	23
M221A	13	8
M221B	42	14
M221C	57	21
All	429	33

Virginia Pine

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	0	--
221E	60	37
221H	52	29
221I	11	36
231C	23	30
M221A	3	--
M221B	1	--
M221C	2	--
All	152	34

Yellow-poplar

Ecological Subregion	Number of Plots	Percent with Dead Trees
212G	13	23
221E	481	13
221H	169	7
221I	71	4
231C	30	3
M221A	20	0
M221B	192	8
M221C	198	7
All	1174	9

Figure 15. FIA plots containing at least three trees greater than 10 inches dbh.

The maps also show that plots containing dead trees were often in proximity to plots with no dead trees. The interspersion of plots with and without dead trees and lack of well-defined spatial patterning suggests that tree mortality is not associated with any widespread disturbance. Exceptions occur within subregion 221E, which had more plots with dead hickory and yellow-poplar; a similar situation was observed in southeastern Ohio. Additionally, the northern section of subregion M221B has a greater frequency of plots with dead red maple, chestnut oak, northern red oak, and white oak than the southern section.

3. Causes of Recent Tree Mortality

Forest Succession

Most dead trees in the mixed mesophytic forest were probably the result of competition among species during forest succession. FIA data showed that species with the greatest percentage of dead trees were mostly trees that occupied forests at early stages of succession, were intolerant of competition, and which were not among the list of species deemed characteristic of the forest 50 years ago (Braun 1950). These species include aspen, sweet birch, black locust, scarlet oak, sassafras, and Virginia pine. Conversely, species with lower than average percentages of dead trees were moderately tolerant or tolerant of competition and were characteristic of the mixed mesophytic forest in a mid- to late-successional stage. The greater proportion of dead trees of early-successional species suggests that the composition of the forest tends to change to one that more closely resembles the historical forest.

Rates of forest succession may vary among geographic locations as a function of inherent differences in climate, physiography, and soils that affect competitive interactions among tree species. These influences are somewhat evident from differential percentages of dead trees of some species among ecological subregions. The co-occurrence of northern hardwood forest types and oak-hickory types may also indicate that some forest stands have progressed to late-successional stages sooner than others. However, some of these stands will not progress to a cover of late-successional species because of restrictive site conditions (Spurr and Barnes, 1992). Oak-hickory forest types represent the climax stage of succession in these cases.

Logging and Land Clearing

Cutting of trees is a disturbance that has occurred mostly on private non-industrial land where larger trees of more marketable species are selectively harvested (Birch and others 1992). FIA data showed that 4 percent of all overstory trees (consisting mostly of oak, sugar maple, black cherry, and yellow-poplar) in the region have been cut. These data indicate that species with the greatest proportion of removed trees are not the same as those with the greatest percentages of dead trees. Removal of trees therefore represents a selective disturbance with a distinct influence on changes in species composition. The tendency to cut early- and mid-successional species may be accelerating forest succession processes. This hypothesis could not be tested with data used in this study, but results from other studies have demonstrated recent increases in species tolerant and moderately tolerant of competition (Abrams and Downs 1990).

Some of the mortality in the forest may also be a consequence of poorly planned logging operations which wound and weaken remaining trees (Nichols and others 1994). At least one-third of the FIA plots containing dead black cherry, chestnut oak, or hickory species also had stumps of removed trees (Figure 16; see also Appendix Table D-2). In contrast, less than 20 percent of the plots that contained dead trees of these species had no evidence of tree cutting. Dead trees of ash, red maple, sugar maple, northern red oak, scarlet oak, and yellow-poplar were also more frequently associated with stumps of removed trees. Additional analyses indicated that dead trees of several species were more frequently associated with removed trees in 221E and M221B than in other subregions (see Appendix Tables D-3 and D-4). Species associated with evidence of logging included black cherry, sugar maple, red maple, chestnut oak, white pine, and yellow-poplar. These results indicate that a portion of tree mortality in the mixed mesophytic forest is related to logging injury. Even so, analyses in this study do not offer definitive evidence because trees on some of the FIA plots were probably cut *after* neighboring trees died.

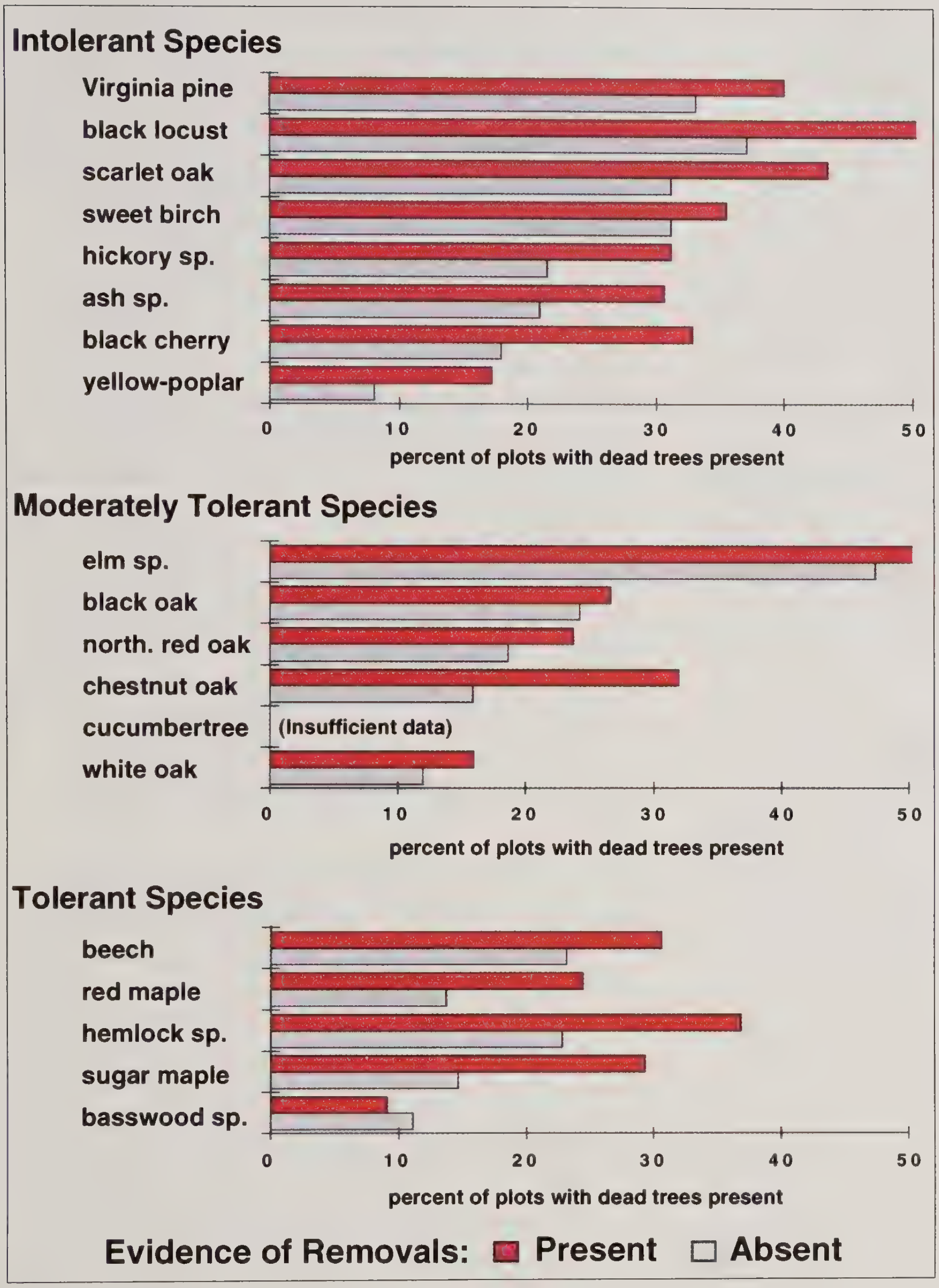


Figure 16. Percentages of FIA plots containing dead trees of selected species for plots with and without evidence of any removed trees.

Insects, Diseases, Weather, and Fire

Forest insects, diseases, weather events, and fire regularly occur within the mixed mesophytic forest and are likely explanations for some of the recent tree mortality. Although exact locations of past disturbances were not available, the percentages and locations of dead trees of some species are indicative of several documented disturbances (Hicks and Mudrick 1993; Twardus and Mielke 1995).

In addition to preventing American chestnut from regaining status in the overstory, chestnut blight also infects scarlet oak (Torsello and others 1994). This disease may explain why more than 10 percent of the scarlet oak analyzed in this study were dead (see Appendix Table C-1). The particularly high percentage of dead scarlet oak in subregion 221I implies that this species will become a smaller component of the overstory here than in some other areas.

In the last two decades, gypsy moth [*Lymantria dispar* L.] defoliation and beech bark disease have caused the deaths of the oak and beech components of the forests in western Pennsylvania, Maryland, and northern counties of West Virginia. High percentages of dead elm in the forest may be attributed to Dutch elm disease and elm yellows. Other insects, diseases, weather events, and fires have also caused tree mortality of other species and have played a role in shaping the composition of the forest (Hicks and Mudrick 1993).

Disturbances caused by changes in land use to non-forested conditions are also evident. Population growth and urban encroachment have reduced some of the forested acreage; however, the effects of land use have been partially offset by the reversion of abandoned farms to forest. Although the effects caused by logging and land clearing are conspicuous, it was beyond the scope of this study to assess how much forestland has recently changed use.

Air Pollution

Tree species of the mixed mesophytic forest that are sensitive to sulfur, nitrogen and/or ozone air pollutants are: ash, white oak, yellow-poplar, black cherry, loblolly pine, Virginia pine, eastern white pine, birch, and aspen (Shriner and others 1990). While this study did not attempt to quantify the relationships between tree mortality and air pollution, FIA data show that several species sensitive to pollutants had percentages of dead trees equal to or less than species insensitive to pollutants. For example, yellow-poplar, a species sensitive to air pollutants, has significantly less dead trees than black locust, which is said to be tolerant of pollutants. In addition, dead trees of pollutant-sensitive species did not occur along well-defined spatial gradients. Fewer dead trees were found in mountainous ecological subregions, which is naturally subjected to greater amounts of pollutants.

4. The Future Forest

Forest succession is a dynamic natural process that will continue to cause changes in species composition of the mixed mesophytic forest as it matures. Different disturbances to the forest are likely to recur in the future, and just like any weather phenomenon, their locations, timing, and magnitude are not predictable. The effects of air pollutants on forest trees are also still uncertain and can only be determined by continual monitoring of the forest.

Continual monitoring of the forests comes from two sources: FIA and Forest Health Monitoring (FHM) programs at each of the eight research stations of the USDA Forest Service. Each Forest Service research station is required by law to conduct FIA programs. Northeastern Area, State and Private Forestry, conducts the FHM program in cooperation with the National Association of State Foresters (NASF).

FIA measures sampled plots to estimate a variety of resource attributes. All states containing mixed mesophytic forests are remeasured every 1 to 5 years. Analyses in this study pertaining to the overstory of the mixed mesophytic forest could easily be applied to new FIA data as these become available. Historical comparisons of species composition and percentages of dead trees and removed trees as estimated in this study can be made to quantify changes in forest composition.

The FHM program includes measurements from sampled plots that are similar in design to those implemented by the FIA program (USDA Forest Service 1997). In the mixed mesophytic forest, FHM plots are currently measured at randomly selected locations in Maryland, Ohio, Pennsylvania, Virginia, and West Virginia at the time this publication was written (1998). The FHM plots are less numerous than FIA plots, but include more measurements of forest health including conditions of tree crowns and evidence of tree damage. The abundance and diversity of pollutant-sensitive lichens and ozone-sensitive plants are also quantified on or near the FHM plots. Analyses of data from these surveys will provide more detail about the conditional status of the mixed mesophytic forest at the turn of the century.

Conclusions

This study showed the interplay between various factors involved in forest succession and the disturbances associated with temporal and spatial changes in the mixed mesophytic forest. Analyses of data published by Braun (1950) and FIA data collected by the Northeastern Research Station showed the following:

- ❑ Two-thirds of all analyzed FIA plots were in the oak-hickory type. This suggests that most of the forest in the 1980s was in an earlier stage of succession than that observed by Braun in the 1940s.
- ❑ Six percent of all trees at least 10 inches in diameter on FIA plots were observed as standing or have fallen (dead), and 4 percent had been removed.
- ❑ Differential proportions of dead trees among species correspond to expected mortality from competition during forest succession; species intolerant of competition had the greatest proportions of dead trees.

- For most species intolerant of competition, percentages of dead trees that were 10 to 15 inches in diameter were significantly greater than of dead trees larger than 15 inches.

- A greater proportion of dead trees belonged to early successional species, which suggests that forest composition is changing to one that more closely resembles the historical forest as described by Braun.

- Differences in dead trees among locations were most evident in ecological subregion 212G covering north central Pennsylvania, where dead sweet birch, hemlock, sugar maple, and chestnut oak were found on at least 30 percent of the sampled plots containing these species.

- Dead trees of species sensitive to pollutants did not occur along well-defined spatial gradients; fewer dead trees were found in mountainous ecological subregions where trees were exposed to higher amounts of pollution.

*****

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Appendices

List of Appendices

Table A-1
Common and Scientific Names of Trees in the Overstory of the Mixed Mesophytic Forest

Common Name	Scientific Name
Ash, Green	*Fraxinus pennsylvanica* Marsh.
Ash, White	*Fraxinus americana* L.
Aspen, Bigtooth	*Populus gandidetata* Michx.
Aspen, Quaking	*Populus tremuloides* Michx.
Basswood, American	*Tilia americana* L
Basswood, American	*Tilia heterophylla* Vent.
Beech, American	*Fagus grandiflora* Ehrh
Birch, Sweet	*Betula lenta* L.
Birch, Yellow	*Betula allehaniensis* Britton
Blackgum	*Nyssa sylvatica* Marsh.
Buckeye, Ohio	*Aesculus glabra* Wild
Buckeye, Yellow	*Aesculus octandra* Marsh.
Cherry, Black	*Prunus serotina* Ehrh.
Chestnut, American	*Castanea dentata* (Marsh.) Borkh.
Cucumbertree	*Magnolia acuminata* L.
Elm, American	*Ulmus americana* L.
Elm, Slippery	*Ulmus rubra* Muhl.
Hemlock, Carolina	*Tsuga caroliniana* Englem.
Hemlock, Southern	*Tsuga canadensis* (L.) Carr.
Hickory, Bitternut	*Carya cordiformis* (Wangenh.) K. Koch
Hickory, Mockernut	*Carya tomentosa* (Poir.) Nutt.
Hickory, Pignut	*Carya glabra* (Mill.) Sweet
Hickory, Shagbark	*Carya ovata* (Mill.) K. Koch.
Hickory, Shellbark	*Carya laciniosa* (Michx. f.) Loud.
Locust, Black	*Robinia psuedoacacia* L.
Magnolia, Fraser	*Magnolia fraseri* Walt.
Maple, Red	*Acer rubrum* L.
Maple, Sugar	*Acer saccharum* Marsh.
Oak, Black	*Quercus velutina* Lam.
Oak, Chestnut	*Quercus prinus* L.
Oak, Northern Red	*Quercus rubra* L.
Oak, Scarlet	*Quercus coccinea* Muenchh.
Oak, Shumard	*Quercus shumardii* Buckl.
Oak, Southern Red	*Quercus falcata* Michx.
Oak, White	*Quercus alba* L.
Persimmon	*Diospyros virginiana* L.
Pine, Eastern White	*Pinus strobus* L.
Pine, Loblolly	*Pinus taeda* L.
Pine, Pitch	*Pinus rigida* Mill.
Pine, Shortleaf	*Pinus echinata* Mill.
Pine, Virginia	*Pinus virginiana* Mill.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Sweetgum	*Liquidambar styraciflua* L.
Walnut, Black	*Juglans nigra* L.
Yellow-Poplar	*Liriodendron tulipifera* L.

Table B-1
Species Composition of Different Geographic Areas as Summarized from Data by Braun (1950)

Species	Cumberland Mountains (n=7027)	Appalachian Plateau (n=2250)	Allegheny Mountains (n=863)	All Areas (n=10140)
	--------------------	percent of all trees	--------------------	
Ash sp.	1.3	2.6	5.6	1.9
Birch sp.	1.4	1.0	11.5	2.2
Black cherry	0.1	0.0	2.1	0.2
Black locust	0.2	0.0	0.1	0.2
Hickory sp.	3.4	6.7	0.9	3.9
Oak scarlet	0.7	0.0		0.5
Pine sp.	1.4	0.1		1.0
Sassafras	0.1	0.0		0.0
Yellow-poplar	9.6	12.5		9.4
Walnut black	0.5	0.9		0.6
All Intolerants	18.5	23.7	20.3	19.8
Chestnut	9.5	1.5	13.4	8.1
Elm sp.	0.1	1.0		0.3
Magnolia sp.	1.4	2.1	5.5	1.9
Oak, black	0.4	1.3		0.5
Oak, chestnut	5.9	2.7	0.9	4.8
Oak, n. red	3.0	3.1	6.7	3.3
Oak, white	7.1	13.0	1.1	7.9
All Moderates	27.5	24.8	27.7	26.9
Basswood sp.	6.3	4.0	8.5	6.0
Beech	16.9	20.4	17.7	17.7
Blackgum	1.9	2.8		1.9
Buckeye sp.	4.8	1.5		3.7
Hemlock sp.	7.6	15.5		8.7
Maple, red	2.5	2.6	10.7	3.2
Maple, sugar	12.2	3.9	15.0	10.6
All Tolerants	52.2	50.6	51.9	51.8
Other species	1.8	0.9	0.1	1.5
Total	100.0	100.0	100.0	100.0

Table C-1
Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for all combined ecological subregions.

Species	Oak-Hickory				Northern Hardwood				Oak-Pine			
	n =	% C	% D	% R	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	1030	1.7	5.7	3.6	1098	**5.6**	6.9	5.1	29	0.7	---	---
Aspen sp.	308	0.6	**14.0**	1.2	280	1.7	**24.2**	2.9	6	0.2	---	---
Birch sp.	625	1.2	**7.7**	1.4	1156	**6.5**	**12.1**	4.7	10	0.3	---	---
Black cherry	1174	2.0	5.5	4.9	4031	**19.7**	5.2	5.9	35	0.9	5.1	0.0
Black locust	1054	1.9	**20.6**	1.7	293	1.7	**24.9**	4.8	3	0.1	---	---
Black walnut	502	0.9	**9.3**	4.6	104	0.6	4.7	**9.9**	11	0.4	---	---
Hickory sp.	4684	**8.4**	**6.7**	2.3	345	1.8	6.7	7.1	179	5.5	3.5	0.7
Oak, scarlet	3103	**4.8**	**10.3**	4.3	19	0.1	---	---	155	3.7	**9.9**	0.9
Pine, loblolly	145	0.2	0.4	**24.9**	0				323	**7.7**	1.1	6.1
Pine, pitch	207	0.4	**21.7**	4.2	2	0.0	---	---	72	2.0	**11.7**	2.3
Pine, shortleaf	274	0.6	**12.4**	**10.1**	0				324	**9.9**	**10.1**	4.5
Pine, Virginia	500	1.0	**20.1**	9.4	16	0.1	---	---	655	**19.6**	**7.9**	2.6
Sassafras	422	0.8	**18.9**	0.6	40	0.3	**17.2**	0.0	1	0.0	---	---
Sweetgum	213	0.4	4.5	8.9	2	0.0	---	---	48	1.4	5.3	0.0
Yellow-poplar	8378	**13.4**	2.7	3.4	613	3.0	2.6	**9.6**	289	**7.0**	2.7	2.0
All Intolerant	**22619**	**38.4**	**7.3**	**3.6**	**7999**	**41.0**	**8.1**	**5.7**	**2140**	**59.4**	**6.4**	**2.9**
Cucumbertree	580	0.9	3.4	1.8	183	0.9	**14.5**	**10.7**	3	0.1	---	---
Elm sp.	549	1.0	**18.6**	2.8	308	1.7	**11.9**	9.1	12	0.4	---	---
Magnolia sp.	122	0.2	0.8	2.5	32	0.2	4.2	0.0	2	0.1	---	---
Oak, black	4966	**7.2**	**6.5**	5.1	114	0.5	7.7	**17.7**	156	3.6	6.8	2.9
Oak, chestnut	7800	**12.1**	4.0	3.3	111	0.6	**16.1**	**12.1**	203	**4.9**	0.1	1.8
Oak, northern red	6782	**9.5**	4.5	5.2	730	3.2	6.1	**17.3**	114	2.9	1.7	0.0
Oak, other red	402	0.7	3.0	2.2	9	0.0	---	---	144	3.6	5.4	0.8
Oak, other white	315	0.5	**10.9**	2.3	7	0.0	---	---	107	2.8	**12.3**	2.4
Oak, white	7451	**11.7**	2.8	4.0	213	1.1	7.3	**13.7**	405	**9.2**	1.5	1.5
Pine, white	163	0.2	6.9	4.0	69	0.3	8.0	6.8	201	4.0	5.9	0.0
All Intermediate	**29130**	**44.1**	**4.6**	**4.1**	**1776**	**8.5**	**9.1**	**13.4**	**1347**	**31.7**	**4.0**	**1.5**
Basswood sp.	759	1.2	3.6	3.6	695	3.5	2.9	2.4	3	0.1	---	---
Beech	2529	3.1	4.9	1.5	1888	**8.6**	**6.9**	5.7	29	0.7	---	---
Blackgum	712	1.1	5.1	2.2	51	0.2	4.3	7.6	28	0.7	---	---
Buckeye sp.	231	0.4	3.0	1.6	46	0.2	0.0	3.9	3	0.1	---	---
Hemlock sp.	341	0.5	2.6	2.5	522	2.3	**11.9**	7.3	60	1.3	2.7	0.0
Maple, red	4245	**7.4**	3.1	1.7	3648	**18.5**	3.7	5.5	154	3.9	4.2	0.9
Maple, sugar	1614	2.6	3.3	2.8	2984	**15.4**	4.3	4.3	26	0.7	---	---
All Tolerant	**10431**	**16.3**	**3.6**	**2.0**	**9834**	**48.8**	**4.8**	**5.0**	**303**	**7.4**	**4.1**	**2.9**
Other Species	**707**	**1.2**	**19.0**	**1.3**	**314**	**1.6**	**12.3**	**7.0**	**54**	**1.4**	**9.7**	**0.0**
All Species	**62887**	**100**	**5.6**	**3.5**	**19923**	**100**	**6.6**	**6.1**	**3844**	**100**	**5.5**	**2.4**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-2
Percentages of dead trees and removed trees on FIA sample plots by diameter class.

Species	Number of sampled trees		Percent Dead		Percent Removed	
	10-15"	>15"	10-15"	>15"	10-15"	>15"
Ash sp.	1231	926	**6.9**	4.8	3.8	**5.6**
Aspen sp.	499	95	18.5	18.0	**2.2**	0.0
Birch sp.	1392	399	**11.1**	6.9	3.5	3.0
Black cherry	2963	2277	**6.1**	3.2	5.0	**7.0**
Black locust	933	417	**22.5**	17.1	2.3	2.9
Black walnut	406	211	7.8	10.0	4.0	**10.1**
Hickory sp.	3451	1757	6.1	**8.2**	2.1	**4.1**
Oak, scarlet	1632	1645	9.2	**12.1**	3.0	**6.3**
Pine, loblolly	246	222	0.9	1.0	**13.4**	8.0
Pine, pitch	231	50	**20.5**	7.0	3.2	**7.2**
Pine, shortleaf	502	96	10.7	**15.8**	6.6	**11.2**
Pine, Virginia	1006	165	13.5	**15.5**	5.3	7.0
Sassafras	379	84	**19.6**	11.6	0.6	0.0
Sweetgum	168	95	4.7	5.7	**9.0**	0.0
Yellow-poplar	4838	4442	**3.0**	2.0	2.7	**5.8**
All Intolerant	**19877**	**12881**	**8.0**	**5.8**	**3.5**	**5.7**
Cucumbertree	423	343	**6.6**	4.4	4.2	3.1
Elm sp.	572	297	15.2	**19.8**	4.8	6.4
Magnolia sp.	113	43	0.9	**3.8**	2.0	2.0
Oak, black	2296	2940	**6.9**	6.1	3.7	**7.6**
Oak, chestnut	4231	3883	**4.4**	3.5	2.7	**4.8**
Oak, northern red	3218	4408	4.8	4.3	5.0	**8.2**
Oak, other red	298	257	3.9	3.1	1.8	2.4
Oak, other white	263	166	11.7	9.1	2.3	2.1
Oak, white	4357	3712	2.9	2.5	2.8	**7.2**
Pine, white	181	252	**8.3**	4.4	0.5	**5.5**
All Intermediate	**15952**	**16301**	**5.0**	**4.3**	**3.4**	**6.7**
Basswood sp.	788	669	3.2	3.5	1.9	**5.4**
Beech	1636	2810	5.0	**6.8**	3.6	3.4
Blackgum	387	404	4.7	6.0	2.0	**3.6**
Buckeye sp.	149	131	2.7	1.9	0.5	**4.9**
Hemlock sp.	386	537	**8.8**	6.5	3.4	**7.3**
Maple red	5215	2832	3.4	3.4	2.9	**4.8**
Maple sugar	2771	1853	4.0	3.8	3.2	**5.2**
All Tolerant	**11332**	**9236**	**4.0**	**4.7**	**2.9**	**4.6**
Other Species	**675**	**400**	**16.2**	**18.0**	**2.7**	**3.1**
All Species	**47836**	**38818**	**6.2**	**5.1**	**3.3**	**5.8**

Highlighted values for a given diameter class are significantly greater ($p < 0.05$) than percentages for the other class.

Table C-3

Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion 212G.

Species	Oak-Hickory				Northern Hardwood			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	45	1.2	11.9	0.0	401	**5.1**	7.6	5.2
Aspen sp.	56	2.1	**24.0**	2.9	210	3.1	**28.4**	3.9
Birch sp.	70	2.6	2.7	0.0	556	**8.0**	**13.8**	5.6
Black cherry	98	3.2	3.7	0.3	1972	**22.9**	4.5	5.7
Black locust								
Black walnut	9	0.2	---	---				
Hickory sp.	26	0.8	---	---	29	0.4	---	---
Oak, scarlet	125	4.0	8.1	**12.1**	4	0.0	---	---
Pine, loblolly								
Pine, pitch	22	0.7	---	---	1	0.0	---	---
Pine, shortleaf								
Pine, Virginia								
Sassafras					1	0.0	---	---
Sweetgum								
Yellow-poplar	77	2.2	**37.2**	1.5	55	0.6	5.9	0.0
All Intolerant	**528**	**17.1**	**13.5**	**4.7**	**3229**	**40.2**	**8.6**	**5.4**
Cucumbertree	40	1.3	10.5	0.0	53	0.6	**13.7**	7.6
Elm sp.	10	0.3	---	---	5	0.1	---	---
Magnolia sp.								
Oak, black	174	**5.1**	8.7	8.3	13	0.1	---	---
Oak, chestnut	324	**10.9**	9.3	3.8	21	0.3	---	---
Oak, northern red	1100	**29.5**	4.4	7.8	157	1.7	8.8	8.5
Oak, other red	3	0.1	---	---	2	0.0	---	---
Oak, other white								
Oak, white	449	**14.3**	5.2	6.0	40	0.5	**13.0**	3.7
Pine, white	15	0.4	---	---	36	0.4	3.4	3.6
All Intermediate	**2115**	**61.8**	**6.0**	**6.5**	**327**	**3.7**	**11.0**	**6.3**
Basswood sp.	7	0.3	---	---	121	1.6	6.5	6.1
Beech	43	1.5	9.8	**9.9**	604	**7.4**	5.5	5.7
Blackgum	2	0.1	---	---	4	0.1	---	---
Buckeye sp.								
Hemlock sp.	23	0.7	---	---	206	2.3	**14.4**	**13.1**
Maple, red	505	**17.3**	2.8	2.7	2209	**28.3**	3.7	5.2
Maple, sugar	33	1.1	12.6	7.2	1187	**16.0**	5.4	5.2
All Tolerant	**613**	**20.9**	**3.6**	**3.8**	**4331**	**55.6**	**5.0**	**5.6**
Other Species	**8**	**0.2**	---	---	**34**	**0.5**	**4.0**	**0.0**
All Species	**3264**	**100**	**6.9**	**5.6**	**7921**	**100**	**6.6**	**5.5**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-4
Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion 221E.

Species	Forest Type							
	Oak-Hickory				Northern Hardwood			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	589	2.6	7.3	4.2	400	**8.1**	7.7	5.5
Aspen sp.	226	1.2	**10.6**	1.0	56	1.4	11.5	0.0
Birch sp.	103	0.5	6.8	2.5	95	1.9	**15.9**	0.0
Black cherry	605	2.7	7.0	5.4	1056	**21.7**	8.3	7.9
Black locust	460	2.2	**27.4**	2.7	145	3.2	**34.2**	6.3
Black walnut	314	1.5	**8.9**	4.1	87	2.0	3.6	**10.1**
Hickory sp.	1880	**9.1**	6.7	2.7	134	2.8	4.5	8.6
Oak, scarlet	1152	4.4	**9.7**	4.8	8	0.2	---	---
Pine, loblolly								
Pine, pitch	79	0.4	**27.7**	5.5	1	0.0	---	---
Pine, shortleaf	22	0.1	---	---				
Pine, Virginia	221	1.2	**23.7**	5.5	13	0.3	---	---
Sassafras	247	1.3	**22.4**	1.1	32	0.8	**18.4**	0.0
Sweetgum	15	0.1	---	---				
Yellow-poplar	3256	**13.6**	3.0	4.1	276	**5.1**	2.4	**10.6**
All Intolerant	**9169**	**40.9**	**8.4**	**3.7**	**2303**	**47.6**	**9.7**	**7.0**
Cucumbertree	110	0.4	7.6	1.8	21	0.3	---	---
Elm sp.	443	2.1	**20.2**	2.6	264	**5.6**	**11.4**	**10.6**
Magnolia sp.	1	0.0	---	---	1	0.0	---	---
Oak, black	2410	**9.1**	6.7	6.3	67	1.0	9.8	**19.3**
Oak, chestnut	2299	**9.4**	5.0	4.8	29	0.6	---	---
Oak, northern red	1896	**6.6**	4.8	7.0	210	3.6	9.3	**20.5**
Oak, other red	24	0.1	---	---	7	0.1	---	---
Oak, other white	45	0.2	**22.3**	0.0	4	0.1	---	---
Oak, white	3575	**14.6**	2.6	5.5	101	1.9	**10.8**	**19.6**
Pine, white	37	0.2	11.3	0.0	33	0.5	13.1	10.4
All Intermediate	**10840**	**42.8**	**5.4**	**5.5**	**737**	**13.7**	**10.2**	**15.7**
Basswood sp.	203	0.8	5.9	1.9	127	2.5	5.0	2.3
Beech	949	3.2	5.4	1.3	350	**5.0**	7.5	5.3
Blackgum	179	0.7	0.8	3.5	19	0.4	---	---
Buckeye sp.	125	0.5	3.4	0.0	21	0.5	---	---
Hemlock sp.	44	0.2	0.0	0.0	101	1.7	**24.4**	0.0
Maple, red	1371	**6.2**	3.3	2.3	599	**12.1**	4.0	3.7
Maple, sugar	696	3.0	2.4	2.8	727	**14.6**	3.0	3.5
All Tolerant	**3567**	**14.7**	**3.6**	**2.1**	**1944**	**36.9**	**5.5**	**3.6**
Other Species	**360**	**1.7**	**13.1**	**1.6**	**93**	**1.8**	**19.6**	**2.4**
All Species	**23936**	**100**	**6.5**	**4.2**	**5077**	**100**	**8.2**	**6.8**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-5

Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion M221A.

Species	Oak-Hickory				Northern Hardwood			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	37	1.7	0.0	6.6	63	**12.0**	1.4	3.0
Aspen sp.	1	0.0	---	---				
Birch sp.	62	2.7	2.5	0.0	37	**7.4**	**13.9**	0.0
Black cherry	37	1.3	0.0	0.0	29	**5.6**	5.3	5.3
Black locust	166	**6.8**	8.6	0.0	34	**7.0**	**17.3**	8.5
Black walnut	21	1.0	0.0	0.0	6	1.1	---	---
Hickory sp.	149	**6.2**	4.9	3.3	19	3.8	---	---
Oak, scarlet	95	4.1	7.6	4.0				
Pine, loblolly								
Pine, pitch	28	1.1	8.2	1.7				
Pine, shortleaf								
Pine, Virginia	13	0.6	---	---	1	0.4	---	---
Sassafras	8	0.4	---	---				
Sweetgum								
Yellow-poplar	171	**7.1**	0.0	0.0	9	1.6	---	---
All Intolerant	**788**	**33.1**	**4.2**	**1.5**	**198**	**38.9**	**11.3**	**5.2**
Cucumbertree	45	1.7	3.4	0.0	5	0.8	---	---
Elm sp.	2	0.1	---	---	2	0.5	---	---
Magnolia sp.	7	0.2	---	---				
Oak, black	143	**5.4**	1.4	4.1	2	0.3	---	---
Oak, chestnut	528	**19.9**	1.8	1.5	1	0.2	---	---
Oak, northern red	408	**14.7**	1.9	0.7	31	4.4	6.8	**13.1**
Oak, other red	1	0.0	---	---				
Oak, other white	2	0.1	---	---				
Oak, white	249	**9.3**	1.1	0.9	2	0.3	---	---
Pine, white	39	1.3	1.2	0.0				
All Intermediate	**1424**	**52.8**	**1.8**	**1.3**	**43**	**6.6**	**6.2**	**8.8**
Basswood sp.	45	1.6	3.4	0.0	26	4.2	---	---
Beech	43	1.7	6.6	0.0	59	**12.6**	1.5	0.0
Blackgum	14	0.6	---	---	1	0.1	---	---
Buckeye sp.	12	0.4	---	---	1	0.2	---	---
Hemlock sp.	18	0.6	---	---	16	2.7	---	---
Maple, red	131	**5.9**	2.1	0.0	43	**9.3**	**25.5**	0.0
Maple, sugar	63	2.5	0.0	0.0	109	**20.6**	4.6	4.2
All Tolerant	**326**	**13.3**	**4.6**	**0.0**	**255**	**49.7**	**7.8**	**2.3**
Other Species	**19**	**0.8**	---	---	**23**	**4.8**	**6.1**	**0.0**
All Species	**2557**	**100**	**3.0**	**1.2**	**519**	**100**	**9.0**	**3.8**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-6
Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion M221B.

Species	Forest Type							
	Oak-Hickory				Northern Hardwood			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	101	1.0	4.9	5.8	182	3.5	5.8	5.4
Aspen sp.	20	0.3	---	---	14	0.3	---	---
Birch sp.	233	2.7	**11.7**	2.6	436	**9.5**	**9.7**	5.1
Black cherry	360	3.7	4.5	6.1	958	**18.1**	2.5	3.9
Black locust	196	2.3	**16.9**	2.4	98	2.2	**16.9**	2.2
Black walnut	32	0.3	8.6	**21.9**	7	0.1	---	---
Hickory sp.	452	**4.9**	6.7	0.5	103	2.0	7.9	6.3
Oak, scarlet	293	2.8	5.1	4.6	2	0.0	---	---
Pine, loblolly								
Pine, pitch	14	0.1	---	---				
Pine, shortleaf								
Pine, Virginia	8	0.1	---	---				
Sassafras	72	0.9	**17.0**	0.0	4	0.1	---	---
Sweetgum	1	0.0	---	---				
Yellow-poplar	1504	**14.1**	2.3	4.3	173	3.2	2.6	7.5
All Intolerant	**3286**	**33.4**	**6.2**	**3.7**	**1977**	**39.0**	**5.8**	**4.6**
Cucumbertree	130	1.3	2.3	4.9	81	1.7	**19.4**	**15.4**
Elm sp.	14	0.1	---	---	33	0.7	5.1	0.0
Magnolia sp.	58	0.6	0.0	0.0	27	0.5	---	---
Oak, black	297	2.8	7.2	4.1	22	0.3	---	---
Oak, chestnut	1308	**13.0**	6.0	4.2	40	0.8	**26.2**	**14.4**
Oak, northern red	1996	**18.5**	4.4	5.5	284	**5.0**	2.8	**19.7**
Oak, other red	13	0.1	---	---				
Oak, other white	1	0.0	---	---	1	0.0	---	---
Oak, white	718	**7.0**	2.6	2.2	51	1.0	0.0	**10.7**
Pine, white	14	0.1	---	---				
All Intermediate	**4549**	**43.6**	**4.6**	**4.4**	**539**	**10.0**	**7.8**	**15.2**
Basswood sp.	138	1.4	3.9	**10.0**	263	**4.9**	0.9	0.2
Beech	346	2.9	3.4	2.4	631	**11.6**	**9.1**	6.8
Blackgum	97	0.8	2.8	3.8	17	0.3	---	---
Buckeye sp.	9	0.1	---	---	9	0.1	---	---
Hemlock sp.	84	0.7	1.2	4.3	175	2.9	4.0	6.4
Maple, red	1238	**13.2**	2.4	1.3	752	**14.5**	1.8	8.4
Maple, sugar	296	3.0	0.7	3.5	727	**13.9**	4.9	4.1
All Tolerant	**2208**	**22.1**	**2.3**	**2.5**	**2574**	**48.2**	**4.5**	**5.9**
Other Species	**81**	**0.9**	**9.7**	**0.0**	**149**	**2.8**	**9.1**	**14.0**
All Species	**10124**	**100**	**4.7**	**3.7**	**5239**	**100**	**5.5**	**6.5**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-7

Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion M221C.

Species	Forest Type							
	Oak-Hickory				Northern Hardwood			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	73	1.1	1.3	1.1	30	3.5	6.5	0.0
Aspen sp.	1	0.0	---	---				
Birch sp.	107	1.7	6.2	0.0	16	2.9	---	---
Black cherry	25	0.4	---	---	9	1.1	---	---
Black locust	132	2.1	**11.7**	0.0	11	1.7	0.0	0.0
Black walnut	39	0.6	**20.1**	8.2	3	0.5	---	---
Hickory sp.	558	**8.5**	6.0	1.6	37	**5.9**	9.2	0.0
Oak, scarlet	367	**5.5**	7.5	4.1	2	0.4	---	---
Pine, loblolly								
Pine, pitch	18	0.3	---	---				
Pine, shortleaf	6	0.1	---	---				
Pine, Virginia	15	0.3						
Sassafras	58	0.9	**14.6**	0.0	3	0.6	---	---
Sweetgum	17	0.4	---	---				
Yellow-poplar	1446	**21.9**	1.8	3.1	56	**8.5**	3.2	**16.7**
All Intolerant	**2862**	**43.9**	**4.7**	**2.9**	**167**	**25.1**	**4.2**	**7.2**
Cucumbertree	169	2.4	1.5	1.4	18	2.3	---	---
Elm sp.	16	0.2	---	---	1	0.3	---	---
Magnolia sp.	25	0.5	---	---	4	0.9	---	---
Oak, black	498	**6.4**	5.0	4.3	6	0.8	---	---
Oak, chestnut	965	**13.0**	1.6	1.7	12	2.0	---	---
Oak, northern red	562	**6.7**	3.0	1.3	25	3.3	---	---
Oak, other red	8	0.1	---	---				
Oak, other white	4	0.1	---	---	2	0.4	---	---
Oak, white	371	**5.6**	2.5	1.3	8	1.7	---	---
Pine, white								
All Intermediate	**2618**	**35.0**	**2.6**	**2.1**	**76**	**11.6**	**5.0**	**8.7**
Basswood sp.	220	3.2	0.3	0.2	117	**16.8**	1.4	2.5
Beech	440	**4.8**	2.2	0.1	122	**16.6**	2.9	6.4
Blackgum	103	1.4	2.2	1.1	7	0.8	---	---
Buckeye sp.	42	0.7	0.0	0.0	7	0.8	---	---
Hemlock sp.	65	0.9	6.7	1.0	17	2.5	---	---
Maple, red	355	**6.1**	2.6	0.6	25	3.7	---	---
Maple, sugar	207	3.1	7.7	1.1	137	**19.7**	0.7	3.5
All Tolerant	**1432**	**20.1**	**3.0**	**0.5**	**432**	**60.9**	**2.7**	**3.6**
Other Species	**55**	**1.0**	**18.4**	**0.0**	**8**	**2.4**	---	---
All Species	**6967**	**100**	**3.8**	**2.1**	**683**	**100**	**3.8**	**5.0**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-8

Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion 221H.

Species	Forest Type							
	Oak-Hickory				Oak-Pine			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	109	1.1	2.4	2.7	3	0.2	---	---
Aspen sp.	4	0.1	---	---				
Birch sp.	27	0.3	---	---				
Black cherry	17	0.1	---	---	3	0.2	---	---
Black locust	52	0.6	**45.2**	0.0	1	0.1	---	---
Black walnut	58	0.6	8.3	0.0	4	0.3	---	---
Hickory sp.	1057	**11.1**	**8.7**	2.2	58	**5.4**	8.5	0.0
Oak, scarlet	856	**7.8**	**13.7**	1.8	80	**5.0**	**15.4**	0.0
Pine, loblolly	4	0.0	---	---	45	3.6	2.2	**19.1**
Pine, pitch	45	0.4	**18.2**	4.2	25	2.0	---	---
Pine, shortleaf	167	2.0	**13.0**	**9.6**	227	**18.9**	**10.7**	3.1
Pine, Virginia	152	1.8	**19.2**	**9.8**	253	**20.1**	5.0	1.0
Sassafras	24	0.3	---	---				
Sweetgum	63	0.6	3.4	**15.7**	2	0.1	---	---
Yellow-poplar	1221	**11.6**	2.2	1.9	77	**4.9**	2.6	0.0
All Intolerant	**3856**	**38.5**	**8.9**	**3.0**	**778**	**60.7**	**7.5**	**2.6**
Cucumbertree	64	0.5	0.0	0.0	1	0.1	---	---
Elm sp.	31	0.3	**15.3**	8.8	4	0.4	---	---
Magnolia sp.	15	0.2	---	---	1	0.2	---	---
Oak, black	1119	**9.6**	**7.5**	3.4	59	4.0	9.0	0.0
Oak, chestnut	1527	**13.5**	3.5	3.3	70	4.2	0.3	3.0
Oak, northern red	534	4.2	**8.3**	3.0	28	2.1	---	---
Oak, other red	110	1.1	5.8	6.1	67	**4.8**	4.5	0.0
Oak, other white	153	1.5	**11.5**	3.1	55	4.2	**20.3**	3.0
Oak, white	1558	**15.1**	3.0	2.8	135	**8.6**	2.1	0.9
Pine, white	54	0.4	5.4	7.8	31	2.2	0.0	0.0
All Intermediate	**5165**	**46.3**	**4.9**	**3.2**	**451**	**30.8**	**5.6**	**1.1**
Basswood sp.	101	0.9	7.5	3.4				
Beech	557	3.5	7.1	1.4	4	0.1	---	---
Blackgum	211	1.9	7.7	0.7	17	1.2	---	---
Buckeye sp.	29	0.3	---	---				
Hemlock sp.	83	0.6	0.4	1.1	17	0.9	---	---
Maple, red	464	**4.8**	4.4	1.8	73	**4.9**	6.5	0.0
Maple, sugar	214	1.9	5.3	2.5	4	0.3	---	---
All Tolerant	**1659**	**13.8**	**5.7**	**1.8**	**115**	**7.4**	**6.8**	**0.0**
Other Species	**125**	**1.3**	**43.6**	**2.7**	**15**	**1.2**	---	---
All Species	**10805**	**100**	**7.1**	**2.9**	**1359**	**100**	**7.0**	**1.9**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-9
Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion 221L.

Species	Forest Type							
	Oak-Hickory				Oak-Pine			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	46	1.7	4.7	1.2	2	1.4	---	---
Aspen sp.								
Birch sp.	23	1.0	---	---				
Black cherry	25	1.1	---	---	2	0.9	---	---
Black locust	48	2.6	9.7	1.0				
Black walnut	25	0.9	---	---	1	0.6	---	---
Hickory sp.	235	**9.4**	7.9	0.9	10	**4.8**	---	---
Oak, scarlet	95	3.7	**16.1**	**11.3**	7	3.0	---	---
Pine, loblolly					8	4.0	---	---
Pine, pitch	1	0.0	---	---				
Pine, shortleaf	17	0.8	---	---	29	**17.3**	---	---
Pine, Virginia	38	1.6	**18.2**	2.8	61	**32.7**	10.4	0.0
Sassafras	13	1.0	---	---				
Sweetgum	10	0.4	---	---	1	0.4	---	---
Yellow-poplar	516	**19.4**	2.0	3.6	18	**6.0**	---	---
All Intolerant	**1092**	**43.7**	**5.8**	**3.3**	**139**	**71.1**	**8.3**	**2.3**
Cucumbertree	21	0.8	---	---				
Elm sp.	16	0.5	---	---				
Magnolia sp.	15	0.8	---	---				
Oak, black	192	**6.0**	4.2	2.0	12	**4.9**	---	---
Oak, chestnut	448	**13.9**	2.7	0.4	5	2.2	---	---
Oak, northern red	202	**6.6**	4.8	2.0	12	**4.5**	---	---
Oak, other red	36	1.1	2.3	1.8	3	1.4	---	---
Oak, other white	12	0.7	---	---	4	1.9	---	---
Oak, white	236	**8.2**	2.6	2.6	28	**8.9**	---	---
Pine, white	4	0.1	---	---	1	0.1	---	---
All Intermediate	**1182**	**38.9**	**3.8**	**1.5**	**65**	**23.9**	**8.7**	**0.0**
Basswood sp.	43	1.4	2.1	**15.9**				
Beech	104	2.8	6.3	0.0	2	0.6	---	---
Blackgum	63	1.9	**16.9**	3.3	1	0.2	---	---
Buckeye sp.	14	0.5	---	---				
Hemlock sp.	24	0.9	---	---				
Maple, red	138	**5.2**	4.8	0.0	4	1.9	---	---
Maple, sugar	98	3.4	2.3	5.1	1	0.5	---	---
All Tolerant	**484**	**16.1**	**5.3**	**3.5**	**8**	**3.2**	**---**	**---**
Other Species	**38**	**1.4**	**26.7**	**0.0**	**3**	**1.9**	---	---
All Species	**2796**	**100**	**5.2**	**2.6**	**215**	**100**	**8.0**	**1.6**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table C-10
Percentages of species composition (C), dead trees (D), and removed trees (R) by forest type and shade tolerance for ecological subregion 231C.

Species	Forest Type							
	Oak-Hickory				Oak-Pine			
	n =	% C	% D	% R	n =	% C	% D	% R
Ash sp.	30	1.2	1.9	0.0	7	0.7	---	---
Aspen sp.								
Birch sp.					5	0.6	---	---
Black cherry	7	0.4	---	---	3	0.3	---	---
Black locust								
Black walnut	4	0.1	---	---	1	0.2	---	---
Hickory sp.	327	**15.0**	1.9	2.5	78	**8.4**	1.4	1.8
Oak, scarlet	120	**5.3**	**12.6**	1.9	31	2.8	4.5	0.0
Pine, loblolly	141	**5.1**	0.0	**25.0**	270	**22.2**	0.9	3.6
Pine, pitch								
Pine, shortleaf	62	3.6	5.9	**15.9**	61	**7.2**	5.6	6.6
Pine, Virginia	53	2.7	**13.3**	**32.5**	104	**13.1**	8.7	5.9
Sassafras								
Sweetgum	107	**4.5**	6.1	1.3	45	**4.8**	5.6	0.0
Yellow-poplar	187	**6.5**	1.3	0.0	52	4.2	0.0	0.5
All Intolerant	**1038**	**44.3**	**4.4**	**7.3**	**657**	**64.6**	**3.8**	**3.4**
Cucumbertree	1	0.0	---	---				
Elm sp.	17	0.7	---	---	5	0.5	---	---
Magnolia sp.	1	0.0	---	---	1	0.1	---	---
Oak, black	133	**5.3**	5.5	4.3	30	2.7	3.3	3.4
Oak, chestnut	401	**17.1**	0.5	0.8	68	**6.9**	0.0	0.0
Oak, northern red	84	3.2	0.8	2.5	22	2.1	---	---
Oak, other red	207	**8.1**	1.6	0.6	71	**6.2**	7.0	1.8
Oak, other white	98	4.0	4.1	2.7	45	4.1	3.4	1.9
Oak, white	295	**11.2**	1.6	1.7	101	**8.9**	0.0	0.7
Pine, white								
All Intermediate	**1237**	**49.7**	**1.9**	**1.7**	**343**	**31.5**	**2.3**	**1.4**
Basswood sp.	2	0.1	---	---	1	0.1	---	---
Beech	47	1.1	0.0	7.4	5	0.4	---	---
Blackgum	43	2.0	0.7	3.2	7	0.8	---	---
Buckeye sp.								
Hemlock sp.					1	0.2	---	---
Maple, red	43	1.7	5.5	1.5	9	1.0	---	---
Maple, sugar	7	0.3	---	---				
All Tolerant	**142**	**5.2**	**2.0**	**3.3**	**23**	**2.4**	**---**	**---**
Other Species	**21**	**0.8**	---	---	**14**	**1.5**	---	---
All Species	**2438**	**100**	**3.1**	**4.3**	**1037**	**100**	**3.4**	**2.7**

Highlighted values represent species that comprise at least 5 percent of the composition or with percentages of dead or removed trees significantly greater ($p < 0.05$) than percentages for all species.

Values for dead trees or removed trees are not shown for species with less than 30 sampled trees.

Table D-1
Percentages of FIA plots with dead tree species by ecological subregion.

Species	All		212G		221E		221H		221I		231C		M221A		M221B		M221C	
	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%
ash sp.	221	23.1	54	27.8	105	25.7	8		3		2		12		33	18.2	4	
basswood sp.	193	10.9	19		50	10.0	14		7		0		8		52	9.6	43	7.0
beech	575	24.5	86	23.3	175	**26.9**	80	**33.8**	18		7		11		128	21.1	70	18.6
birch sp.	211	**31.8**	75	**38.7**	27	33.3	1		2		1		11		79	27.9	15	
black cherry	571	21.2	193	24.4	201	**27.4**	0		3		0		9		162	11.1	3	
black locust	153	**39.2**	0		78	**51.3**	3		5		0		23	26.1	33	27.3	11	
cucumbertree	73	19.2	8		12		5		1		0		6		18		23	31.5
elm sp.	100	**49.0**	2		88	**47.7**	1		2		1		0		5		1	
hemlock sp.	133	24.8	35	**40.0**	21	33.3	16		3		0		5		39	18.0	14	
hickory sp.	692	23.1	7		279	**25.8**	145	**29.0**	33	**36.4**	59	8.5	22	13.6	65	21.5	82	14.6
maple, red	925	15.7	272	18.8	255	15.7	65	15.4	11		5		19		262	13.4	36	8.3
maple, sugar	547	17.7	137	**29.9**	185	14.1	28	21.4	18		1		17		122	10.7	39	18.0
oak, black	711	**24.6**	27	29.6	352	25.0	154	**31.2**	27	11.1	19		22	13.6	39	20.5	71	16.9
oak, chestnut	###	17.9	44	**36.4**	308	22.7	217	14.8	60	18.3	70	1.4	71	9.9	165	21.8	131	13.7
oak, northern red	969	19.5	130	26.9	301	21.3	75	25.3	33	15.2	9		59	11.9	281	17.8	81	11.1
oak, scarlet	429	**32.6**	17		145	**31.7**	126	**48.4**	15		14		13		42	14.3	57	21.1
oak, white	###	12.6	70	25.7	499	12.8	237	13.9	38	21.1	62	3.2	43	0.0	105	10.5	46	6.5
pine, Virginia	152	**34.2**	0		60	**36.7**	52	28.9	11		23	30.4	3		1		2	
yellow-poplar	###	9.4	13		481	13.3	169	6.5	71	4.2	30	3.3	20	0.0	192	7.8	198	6.6
Average	**###**	**19.6**	**63**	**27.3**	**191**	**21.8**	**73**	**22.6**	**19**	**16.0**	**16**	**6.5**	**20**	**10.0**	**96**	**15.7**	**49**	**12.8**

Highlighted values represent species with dead trees found on a percentage of plots significantly greater ($p < 0.05$) than the overall average of 19.6 percent.
Percentages are only shown for species represented by at least 20 sample plots within a given forest type.

Table D-2

Percentages of FIA plots with dead tree species on plots with and without tree removals.

Species	All Types				Northern Hardwood				Oak-Hickory				Oak-Pine			
	With Removals		Without Removals		With Removals		Without Removals		With Removals		Without Removals		With Removals		Without Removals	
	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%
Ash sp.	49	30.6	172	20.9	29	**48.3**	107	**22.4**	20	5.0	64	18.8	0		1	
Basswood sp.	22	9.1	171	11.1	12		89	10.1	10		82	12.2	0		0	
Beech	111	30.6	464	23.1	56	30.4	189	23.8	54	29.6	273	22.7	1		2	
Birch sp.	31	35.5	180	31.1	26	30.8	125	35.2	5		54	20.4	0		1	
Black cherry	125	**32.8**	446	**17.9**	97	**37.1**	331	**19.0**	28	17.9	111	14.4	0		4	
Black locust	21	52.4	132	37.1	5		29	37.9	16		103	36.9	0		0	
Cucumbertree	11		62	19.4	3		14		8		48	14.6	0		0	
Elm sp.	26	53.9	74	47.3	12		25	36.0	14		48	52.1	0		1	
Hemlock	19	36.8	114	22.8	14		64	31.3	5		43	11.6	0		7	
Hickory sp.	119	**31.1**	573	**21.5**	8		24	16.7	109	30.3	531	22.0	2		18	
Maple, red	172	**24.4**	753	**13.7**	81	**25.9**	297	**16.5**	89	**23.6**	435	**12.0**	2		21	9.5
Maple, sugar	116	**29.3**	431	**14.6**	84	**32.1**	275	**17.1**	31	22.6	154	10.4	1		2	
Oak, black	128	26.6	583	24.2	6		8		119	27.7	558	24.2	3		17	
Oak, chestnut	141	**31.9**	925	**15.8**	2		8		138	**32.6**	884	**16.3**	1		33	3.0
Oak, northern red	169	23.7	800	18.6	31	12.9	60	21.7	138	**26.1**	728	**18.4**	0		12	
Oak, scarlet	53	43.4	376	31.1	0		0		49	**44.9**	363	**30.6**	4		13	
Oak, white	182	15.9	918	12.0	9		18		169	16.6	844	12.1	4		56	8.9
Pine, Virginia	25	40.0	127	33.1	0		1		11		43	44.2	14		83	26.5
Yellow-poplar	169	**17.2**	1005	**8.1**	19	21.1	64	10.9	143	**17.5**	910	**7.6**	7		31	16.1
Average	**89**	**27.2**	**437**	**18.0**	**26**	**31.0**	**91**	**20.5**	**61**	**25.0**	**330**	**17.3**	**2**		**16**	**17.3**

Highlighted values represent species with dead trees found on a percentage of plots significantly greater ($p < 0.05$) than the overall average of19.6 percent. Percentages are only shown for species represented by at least 20 sample plots within a given forest type.

Table D-3
Percentages of FIA plots with dead tree species on plots with and without tree removals.

Species	Ecological Subregion															
	212G				221E				221H				221I			
	With Removals		Without Removals		With Removals		Without Removals		With Removals		Without Removals		With Removals		Without Removals	
	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%
Ash sp.	12		42	23.8	24	29.2	81	24.7	3		5		0		3	
Basswood sp.	2		17		6		44	11.4	2		12		2		5	
Beech	28	28.6	58	20.7	34	29.4	141	26.2	11		69	33.3	3		15	
Birch sp.	19		56	39.3	3		24	29.2	0		1		0		2	
Black cherry	50	34.0	143	21.0	46	**43.5**	155	**22.6**	0		0		1		2	
Black locust	0		0		14		64	51.6	1		2		0		5	
Cucumbertree	3		5		1		11		1		4		0		1	
Elm sp.	0		2		26	53.9	62	45.2	0		1		0		2	
Hemlock	10		25	36.0	1		20	35.0	2		14		0		3	
Hickory sp.	3		4		62	25.8	217	25.8	21	42.9	124	26.6	7		26	26.9
Maple, red	65	26.2	207	16.4	50	**26.0**	205	**13.2**	10		55	16.4	2		9	
Maple, sugar	35	34.3	102	28.4	43	**32.6**	142	**8.5**	6		22	18.2	3		15	
Oak, black	6		21	28.6	74	27.0	278	24.5	22	40.9	132	29.6	4		23	13.0
Oak, chestnut	4		40	32.5	60	**33.3**	248	**20.2**	32	21.9	185	13.5	4		56	17.9
Oak, northern red	20	30.0	110	26.4	74	25.7	227	19.8	11		64	25.0	5		28	14.3
Oak, scarlet	3		14		23	39.1	122	30.3	12		114	45.6	1		14	
Oak, white	13		57	26.3	98	**19.4**	401	**11.2**	34	11.8	203	14.3	7		31	19.4
Pine, Virginia	0		0		9		51	37.3	7		45	28.9	3		8	
Yellow-poplar	4		9		77	**22.1**	404	**11.6**	22	13.6	147	5.4	12		59	5.1
Average	**15**	**30.3**	**48**	**24.3**	**38**	**28.7**	**152**	**20.0**	**10**	**24.4**	**63**	**21.6**	**3**		**16**	**14.8**

Highlighted table values denote a significantly greater percentage of plots ($p < 0.05$) with both dead and removed trees than adjacent values for plots with dead trees and no removed trees. Percentages are only shown for categories with at least 20 sample plots.

Table D-4

Percentages of FIA plots with dead tree species on plots with and without tree removals.

Species	Ecological Subregion															
	231C				M221A				M221B				M221C			
	With Removals		Without Removals		With Removals		Without Removals		With Removals		Without Removals		With Removals		Without Removals	
	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%	n =	%
Ash sp.	0		2		2		10		7		26	19.2	1		3	
Basswood sp.	0		0		1		7		7		45	11.1	2		41	4.9
Beech	3		4		0		11		24	29.2	104	19.2	8		62	16.1
Birch sp.	0		1		0		11		8		71	28.2	1		14	
Black cherry	0		0		1		8		27	11.1	135	11.1	0		3	
Black locust	0		0		1		22	22.7	4		29	24.1	1		10	
Cucumbertree	0		0		0		6		5		13		1		22	13.6
Elm sp.	0		1		0		0		0		5		0		1	
Hemlock	0		0		0		5		4		35	17.1	2		12	
Hickory sp.	11		48	8.3	2		20	10.0	7		58	19.0	6		76	13.2
Maple, red	1		4		0		19		41	**24.4**	221	**11.3**	3		33	9.1
Maple, sugar	0		1		4		13		23	17.4	99	9.1	2		37	16.2
Oak, black	4		15		2		20	15.0	7		32	18.8	9		62	19.4
Oak, chestnut	5		65	1.5	4		67	9.0	20	**40.0**	145	**19.3**	12		119	10.9
Oak, northern red	2		7		3		56	12.5	47	23.4	234	16.7	7		74	12.2
Oak, scarlet	1		13		1		12		5		37	13.5	7		50	20.0
Oak, white	10		52	3.9	2		41	0.0	13		92	10.9	5		41	7.3
Pine, Virginia	6		17		0		3		0		1		0		2	
Yellow-poplar	6		24	4.2	0		20	0.0	29	10.3	163	7.4	19		179	4.5
Average	**3**		**13**	**4.2**	**1**		**18**	**9.4**	**15**	**21.8**	**81**	**14.6**	**5**		**44**	**11.2**

Highlighted table values denote a significantly greater percentage of plots ($p < 0.05$) with both dead and removed trees than adjacent values for plots with dead trees and no removed trees. Percentages are only shown for categories with at least 20 sample plots.