FOREST COMPOSITION CHANGE IN THE EASTERN UNITED STATES

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Abstract.—Forest ecosystems in the eastern United States are believed to be experiencing a species composition change, but most evidence is anecdotal or localized. We used U.S. Forest Service Forest Inventory and Analysis data to quantify the annual changes of three common genera: *Acer* (maple), *Carya* (hickory), and *Quercus* (oak) with survey periods between 8 and 20 years across the eastern United States. The majority of the region had an increase in maple abundance. At the same time, hickories and oaks had a near universal decrease in the Central Hardwood region.

INTRODUCTION

Forest ecosystems in the eastern United States are believed to be experiencing a species composition change, where shade-tolerant species are becoming more abundant largely in response to forest maturity and change of disturbance regime (Nowacki and Abrams 2008). Many studies have pointed to significant declines in disturbance-dependent species such as oaks (Abrams and Nowacki 1992, Johnson 1976), with significant increase in shade-tolerant species such as red maple (Fei and Steiner 2007). However, most evidence is anecdotal or localized, and often lacking of quantitative information. To quantify the change at regional scales, we used U.S. Forest Service Forest Inventory and Analysis (FIA) data (USDA FS 2008) to describe the average changes in relative abundance of three common genera: *Acer* (maple), *Carya* (hickory), and *Quercus* (oak) during the period of 1980-2008 across the eastern United States.

METHODS

Data from FIA program were used in this study (USDA FS 2008). All states were inventoried periodically, but at irregular and asynchronous intervals before 2000. Most states have been inventoried annually, but partially, since 2000. For this study, we used FIA Mapmaker 3.0 (Miles 2008) to capture county-level information on the total number and volume of all live trees for all species in the eastern 37 states of the United States, defined here as North Dakota south to Texas and all states to the eastward. For most states we obtained data from two or more completed inventories, beginning with the first available measurement after 1980. The first inventory for each state (T_1) was a periodic survey conducted between 1980 and 1995 depending on the state. The second inventory (T_2) was defined as the latest available periodic survey or full-cycle, annual survey (all plots) as of June 2008. The interval between the two inventories ranged from eight to 20 years with an average of 16.4 years. Because a full-cycle, annual survey takes 5 to 7 years to complete, the median year was used to calculate the interval. In total, we used data from all 2,625 counties in 37 eastern states in the United States.

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Importance value (IV) was used to describe relative abundance of each species group for each inventory. In this study, we define IV as the mean of 1) relative density (*total number of oaks / total number of all live trees* x 100) of trees with a diameter of at least 1.0 inch; and 2) relative volume or dominance (*total volume of a species group / total volume of all live trees* x 100). To understand the general trend of current abundance for each genus, a trend surface was developed. Species group abundance from the most recent inventory within each county was first assigned to the county centroid, and extrapolated to the entire region using the Ordinary Kriging (12 point search radius) method in ArcGIS (ESRI Inc., Redlands, CA). To eliminate the distraction from nonforested areas, only forested areas (based on the 2001 National Land Cover Dataset, USGS 2008) were extracted. Changes in IV were further compared between T_1 and T_2 for counties that had data for both inventories. Because the intervals between T_1 and T_2 are different for each state, annual change rate was calculated by using the overall difference between T_1 and T_2 divided by interval length to eliminate the difference caused by different sampling intervals. Forest area constrained trend surfaces were also developed for changes of the above measures.

These developed trend surfaces were then superimposed by map of the ecoregions in four major regions in the eastern United States: Northern Hardwood Region, Central Hardwood Region, Southern Pine-Hardwood Region, and Forest-Prairie Transition Region (Bailey 1997) (Figs. 1-3). Percentages of areas within each ecoregion and across the eastern United States that experienced an increase or decrease in species group abundance were then tabulated in ArcGIS.

RESULTS

MAPLE

Spatial Distribution of Maple Abundance

Among the four major regions in the eastern United States, the Northern Hardwood Region had the highest maple abundance, followed by the Central Hardwood Region (Fig. 1a). The majority of the Northern Hardwood Region contained maple, and over 97 percent of the areas had maple IV > 5 percent. New York, northern Pennsylvania, and upper Michigan had the highest maple abundance (> 25 percent in IV). About 90 percent of the Central Hardwood Region had maple IV > 5 percent. However, maple is more concentrated in the eastern portion of the Central Hardwood Region, especially in the Allegheny Mountains in western Pennsylvania and West Virginia and the Cumberland Plateau regions. Maples in the remaining two regions were also widely distributed. The overall trend is that maples, as a group, are more abundant in the Appalachian Mountains and Southern Superior Uplands.

Changes in Maple Abundance through Time

More than 69 percent of the eastern forest has experienced some increase in maple abundance (Fig. 1b, Table 1). The Central Hardwood Region had the highest percentage of forested areas that experienced maple IV increase (>81 percent), followed by the Southern Pine-Hardwood Region (69 percent), and the Northern Hardwood Region (62 percent). In the Forest-Prairie Transition Region, more areas experienced a decrease (54 percent) in maple IV than areas increased. The majority of the Central Hardwood Region had an average annual maple IV increase > 0.1 percent, while areas in the southern unglaciated Allegheny Plateau in southeastern Ohio and western West Virginia had an average annual maple IV increase > 0.3 percent.

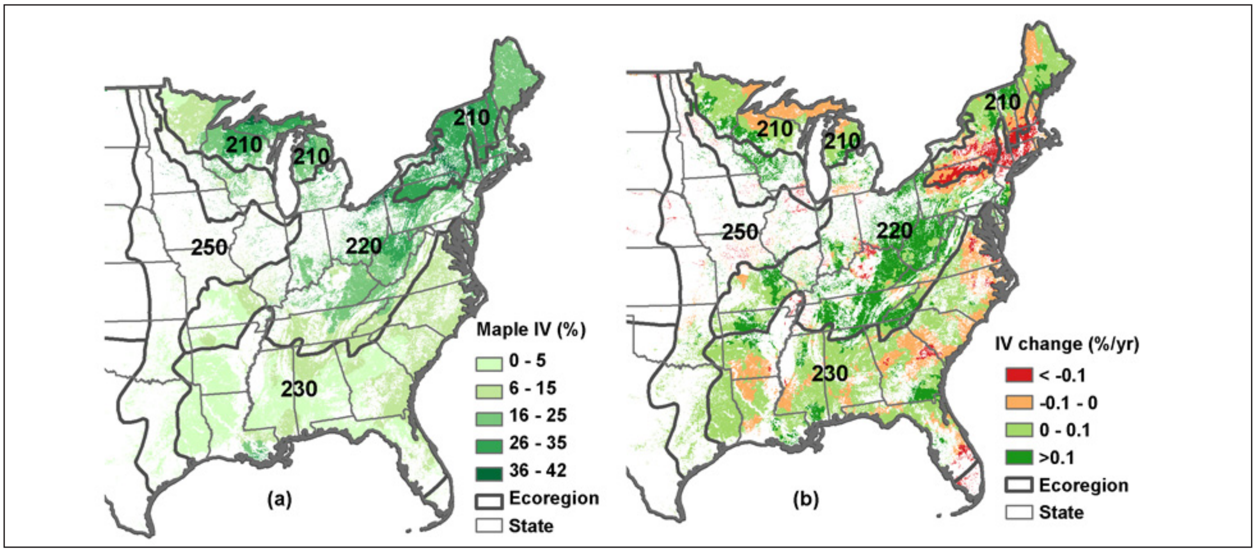

Figure 1.—(a) Current abundance, as measured by importance value ([relative density + relative volume] / 2), for all maple species in the eastern U.S. forested areas; and (b) mean annual change of importance value for all *Acer* species during the last two decades. Numbers correspond to Ecoregion Divisions (Bailey 1997): 210 – Northern Hardwood Region, 220 – Central Hardwood Region, 230 – Southern Pine-Hardwood Region, and 250 – Forest-Prairie Transition Region.

Table 1.—Percentage and acreage of forested area and decrease of the abundance for maple, hickory, and oak in percent of forested areas by ecoregion.

Ecoregion[a]	Total area (Million acres)	Forested (%)	Forested area (Million acres)	Areas decreased in abundance (%) Maple	Hickory	Oak
210	122	78.5	96	38.1	43.6	27.9
220	287	42.8	123	18.7	68.8	81.0
230	270	58.9	159	31.2	80.5	53.0
250	191	8.5	16	53.6	59.1	76.5

[a] Ecoregion: 210 – Northern Hardwood Region, 220 – Central Hardwood Region, 230 – Southern Pine-Hardwood Region, and 250 – Forest-Prairie Transition Region

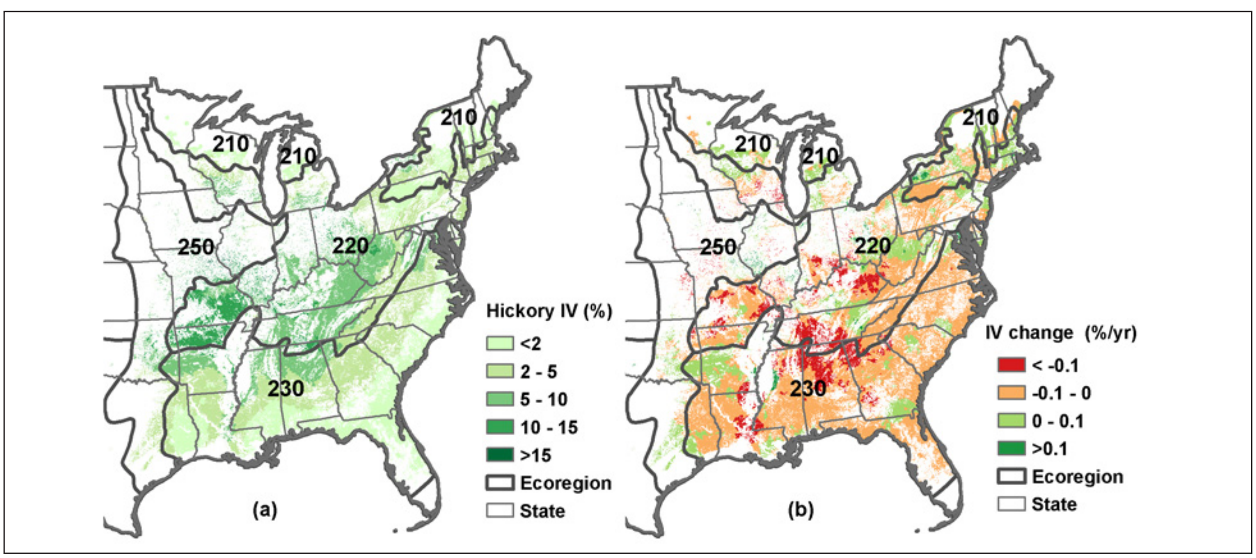

Figure 2.—(a) Current abundance for all hickory species in the eastern U.S. forested areas; and (b) mean annual change of importance value for all *Carya* species during the last two decades.

HICKORY

Spatial Distribution of Hickory Abundance

Hickory species are mainly distributed in the Central Hardwood Region and the Southern Pine-Hardwood Region (Fig. 2a). They also have a limited distribution in the southern portion of the Northern Hardwood Region and the Forest-Prairie Transition Region. The Central Hardwood Region had about 60 percent of its forested areas with > 5 percent of IV for hickory species. The highest hickory abundance was observed in the Ozarks in the Central Hardwood Region, followed by southern portion of the southern unglaciated Allegheny Plateau and the Northern Cumberland Plateau regions. Hickory in the Southern Pine-Hardwood Region is more concentrated in the northern boarder adjacent to the Central Hardwood Region.

Changes in Hickory Abundance through Time

More than 72 percent of the eastern forest has experienced some decrease in hickory abundance (Fig. 2b, Table 1). The Southern Pine-Hardwood Region had the highest percentage of forested areas that have experienced IV decrease (>80 percent), followed by the Central Hardwood Region (69 percent). A sharp hickory abundance decline was observed in the area of central Tennessee, northern Alabama, and northeastern Georgia. The Ozarks in Missouri and the Cumberland Plateaus in eastern Kentucky also experienced a prominent decline in hickory abundance. On the other hand, hickories increased in abundance in the northern portion of their distribution in Wisconsin, Michigan, New York, and other states in northern New England.

OAK

Spatial Distribution of Oak Abundance

Among the four regions in the eastern United States, the Central Hardwood Region had the highest oak abundance, followed by the Southern Pine-Hardwood Region, the Northern Hardwood Region, and the Forest-Prairie Transition Region (Fig. 3a). Within the Central Hardwood Region, the Ozarks had the highest oak abundance (> 40 percent in IV), and portions of the Appalachians from Pennsylvania southward and the adjacent Cumberland Plateau have significant concentrations of oak (IV > 20 percent). Within the Southern Pine-Hardwood Region, oak was most dominant in northern Georgia and Alabama and, eastern Texas and adjacent parts of Louisiana and Arkansas. Oak was rather sparsely but widely distributed across most of the Northern Hardwood Region, and the greatest concentrations occurred along the southern edge of the region where it borders the Central Hardwood Region. For the Forest-Prairie Transition Region, only limited area had notable oak distribution.

Changes in Oak Abundance through Time

The majority of the eastern forest has experienced a decrease in oak abundance (Fig. 3b, Table 1). In the Central Hardwood Region, oak abundance has decreased in over 81 percent of the forested areas that had decreases, with the sharpest declines occurring in the Ozarks, the Highland Rim in Tennessee, the Allegheny Plateaus in southwestern Pennsylvania and eastern Ohio, and the Driftless section in Wisconsin and Minnesota. The only area with prominent increase in oak abundance in this region was eastern Tennessee and Northern Georgia. In contrast, oak abundance increased in over 72 percent of the Northern Hardwood Region. Increases and decreases in oak abundance in the Southern Pine-Hardwood Region were about evenly split by area. The majority of the area in the Costal Plains in eastern Texas, Louisiana, Alabama, and Florida had considerable increases in oak abundance.

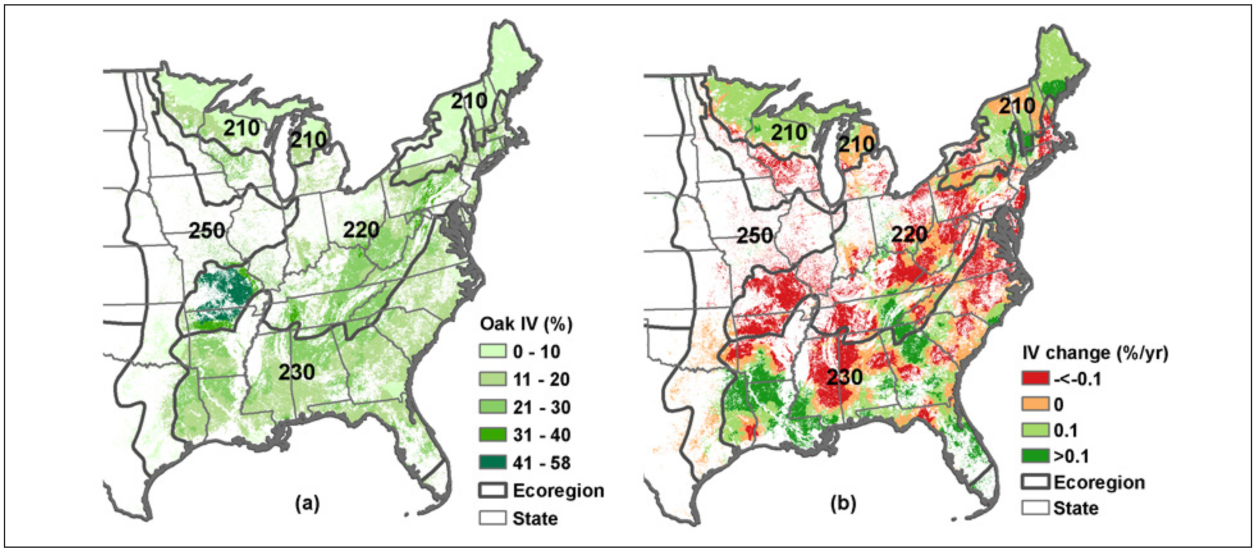

Figure 3.—(a) Current abundance for all oak species in the eastern U.S. forested areas; and (b) mean annual change of importance value for all *Quercus* species during the last two decades.

DISCUSSION

In general, maple species have registered an increase in most of the eastern forest, while oaks and hickories have registered a decrease in relative abundance, especially the Central Hardwood Region during the last two decades. However, the change is not universal. Maple species have sharply decreased in the southern portion of the New England area, while oaks have experienced an increase in majority of the Northern Hardwood Region. The reasons for these changes are unclear and probably complex, but several exogenous factors have been implicated because they are known to affect the growth and survival of these species groups, and they have changed markedly during the twentieth century. Fire suppression may be a major factor for the species composition change (Brose and others 1999, McCune and Cottam 1985). Modern forest harvest practices may be another major factor that favors shade-tolerant species (Fei and Steiner 2009). Invasions of exotic pests and pathogens such as gypsy moth (*Lymantria dispar*) and chestnut blight (*Cryphonectria parasitica*) may also result in altered species abundance (Fajvan and Woods 1996, Vandermast and others 2002). At the same time, the dramatic increase in white-tailed deer (*Odocoileus virginianus*) populations during the 20th century may also have contributed to declines in preferred food species including oak and hickory (Kittredge and Ashton 1995). Other factors such as climate change and modern land-use may also have contributed to the change in species composition. Overall, further study of species level abundance change is needed to better understand this problem.

LITERATURE CITED

Abrams, M.D.; Nowacki, G.J. 1992. **Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania.** Bulletin of the Torrey Botanical Club. 119: 19-28.

Bailey, R.G. 1997. **Ecoregions of North America, 1:15,000,000 scale map (rev.).** Washington, DC: U.S. Department of Agriculture, Forest Service.

Brose P.; Van Lear, D.; Cooper, R. 1999. **Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites.** Forest Ecology Management. 113: 125-141.

Fajvan, M.A.; Wood, J.M. 1996. **Stand structure and development after gypsy moth defoliation in the Appalachian Plateau.** Forest Ecology and Management. 89: 79-88.

Fei, S.; Steiner, K.C. 2007. **Evidence for the increasing abundance of red maple across the U.S.** Forest Science. 53: 473-477.

Fei, S.; Steiner, K.C. 2009. **Rapid capture of growing space by red maple.** Canadian Journal of Forest Research. 39: 1444-1452.

Johnson, P.S. 1976. **Model development of regeneration in clearcut red oak stands in the Driftless area.** In: Fralish, S.S.; Weaver, G.T.; Schlesinger, R.C., eds. Proceedings of the central hardwood forest conference. Carbondale, IL: Southern Illinois University: 455-475.

Kittredge, D.B.; Ashton, P.M.S. 1995. **Impacts of deer browse on regeneration in mixed-species stands in southern New England.** Northern Journal of Applied Forestry. 12: 115-120.

McCune, B.; Cottam, G. 1985. **The successional status of a southern Wisconsin oak wood.** Ecology. 66: 1270-1278.

Miles, P.D. 2008. **Forest inventory mapmaker web-application version 3.0.** Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. Available: http://www.fia.fs.fed.us/tools-data/

Nowacki, G.J.; Abrams, M.D. 2008. **The demise of fire and "mesophication" of forests in the eastern United States.** BioScience. 58(2): 123-138.

USDA Forest Service. 2008. **Forest inventory and analysis national program.** Washington, DC: U.S. Department of Agriculture, Forest Service. Available: http://www.fia.fs.fed.us/.

USGS. 2008. **National land cover dataset 2001 (NLCD 2001).** Washington, DC: U.S. Department of Interior, Geological Survey. Available: http://seamless.usgs.gov/.

Vandermast, D.B.; van Lear, D.H.; Clinton, B.D. 2002. **American chestnut as an allelopath in the southern Appalachians.** Forest Ecology and Management. 165: 173-181.