ASSESSING FOREST MORTALITY PATTERNS USING CLIMATE AND FIA DATA AT MULTIPLE SCALES

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Abstract.—Forest Inventory and Analysis (FIA) and PRISM climate data from 1991-2000 were obtained for 10 states in the southeastern United States. Mortality was calculated for each plot, and annual values for precipitation and maximum and minimum temperature were extracted from the PRISM data. Data were then stratified by upland/bottomland for red oak species, and classification and regression tree (CART) analysis was used to determine the influence of climate variables on mortality at ecoregion province and section levels. The results presented here will provide a basis for future research on the causal factors related to red oak mortality.

INTRODUCTION

Increased mortality in red oak species (*Quercus*, section *Lobatae*) has been attributed to a variety of factors ranging from biotic (e.g., oak borers [Fan et al. 2008]) to abiotic (e.g., drought [Law and Gott 1987]). Such widespread loss of these species could lead to compositional changes in forests across the southeastern United States. While previous studies have sought to relate climatic factors to increased levels of mortality, few have considered the changes in mortality patterns at finer scales of analysis such as the ecoregion province level and section level. Analyzing the relationship between climatic factors and mortality at increasingly finer scales could allow for new insights into changing mortality trends for red oak species across the region. Thus, we assessed changes in mortality for upland and bottomland red oak species by: 1) determining the trends in mortality; and 2) using classification and regression tree (CART) to determine the relationships between mortality and climate variables at ecoregion provinces and sections for both upland and bottomland red oak species. The results of these analyses will help guide future research endeavors across the region as we seek to understand causal factors related to mortality for all species in the southeastern United States.

METHODS

Data including latitude, longitude, species codes, and basal areas of live and dead trees (red oaks) were extracted from the Forest Inventory and Analysis (FIA) database for 10 states in the southeastern United States for which inventory data were available between 1991-2000 (Oklahoma, Arkansas, Kentucky, Tennessee, Mississippi, Alabama, Georgia, Florida, South Carolina, and Virginia). Geographic information system (GIS) software was then used to extract total annual precipitation, maximum temperature, minimum temperature, and temperature range from PRISM (Oregon State University 2012) for 2 years preceding each inventory year as well as ecoregion province and section codes. Mortality was calculated as a percentage of dead basal area for each species type that occurred within each plot by dividing dead basal area by total basal area of the plot. The data were then divided based on sites upon which each species typically

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occurs (e.g., upland or bottomland [Table 1]) for red oak species. This was done in an effort to determine both the scale and degree of difference between the two groups. R statistical software was utilized to perform kernel smoothing using the ”stats” package (R Core Team 2012) to allow for the determination of a spatial trend in mortality, and CART analysis using the “rpart” package (Therneau et al. 2012) to determine the relationship between mortality and climate variables at the ecoregion province and section levels (Table 2).

Table 1.—List of upland and bottomland red oak species extracted from 1991-2000 Forest Inventory and Analysis (FIA) data for 10 southeastern states

	Common Name	Scientific Name
Upland	Scarlet oak	*Quercus coccinea*
	Southern red oak	*Quercus falcata*
	Blackjack oak	*Quercus marilandica*
	Northern red oak	*Quercus rubra*
	Black oak	*Quercus velutina*
	Bluejack oak	*Quercus incana*
Bottomland	Cherrybark oak	*Quercus pagoda*
	Water oak	*Quercus nigra*
	Nuttall oak	*Quercus texana*
	Willow oak	*Quercus phellos*
	Shumard oak	*Quercus shumardii*

Table 2.—Ecoregion sections used in analysis of mortality at the ecoregion province and section levels

Code	Section	Province
A	Arkansas Valley	Southeastern Mixed Forest
B	Atlantic Coastal Flatlands	Outer Coastal Plain Mixed Forest
C	Blue Ridge Mountains	Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow
D	Boston Mountains	Ozark Broadleaf Forest-Meadow
E	Central Ridge/Valley	Eastern Broadleaf Forest (Oceanic)
F	Coastal Plain/Flatwood, Lower	Outer Coastal Plain Mixed Forest
G	Coastal Plain, Middle	Southeastern Mixed Forest
H	Florida Coastal Lowlands, Eastern	Outer Coastal Plain Mixed Forest
I	Florida Coastal Lowlands, Western	Outer Coastal Plain Mixed Forest
J	Interior Low Plateau, Highland Rim	Eastern Broadleaf Forest (Continental)
K	Interior Low Plateau, Shawnee Hills	Eastern Broadleaf Forest (Continental)
L	Mid Coastal Plain, Western	Southeastern Mixed Forest
M	Mississippi Alluvial Basin	Lower Mississippi Riverine Forest
N	North Cumberland Mountains	Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow
O	North Cumberland Plateau	Eastern Broadleaf Forest (Oceanic)
P	Northern Ridge/Valley	Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow
Q	Ouachita Mountains	Ouachita Mixed Forest-Meadow
R	Ozark Highlands	Eastern Broadleaf Forest (Continental)
S	Southern Appalachian Piedmont	Southeastern Mixed Forest
T	Southern Cumberland Mountains	Eastern Broadleaf Forest (Oceanic)
U	Southern Cumberland Plateau	Southeastern Mixed Forest
V	Southern Ridge/Valley	Southeastern Mixed Forest
W	Southern Unglaciated Allegheny Plateau	Eastern Broadleaf Forest (Oceanic)
X	Upper Gulf Coastal Plain	Eastern Broadleaf Forest (Continental)

RESULTS

The highest level of mortality in upland red oak species occurred from coastal areas of southern Alabama northeastward through portions of the Appalachian Mountains. Portions of the Ozark Highlands showed 10-15 percent mortality while coastal areas of South Carolina ranged from 25-30 percent. At the ecoregion province level, CART results showed that the first split occurred at provinces, with the Eastern Broadleaf (Oceanic) province having the highest level of mortality (~25 percent). The second split was for current (inventory year) precipitation where 54 percent mortality levels were associated with precipitation less than 1053 mm, below the minimum value for average annual precipitation within the province. Analysis at the ecoregion section level was similar, with sections located in the eastern portion of the study area being associated with higher levels of mortality. A second split occurred with precipitation values less than 1051 mm (below minimum average values), with a third split indicating a few sections with mortality values approaching 60 percent (Fig. 1).

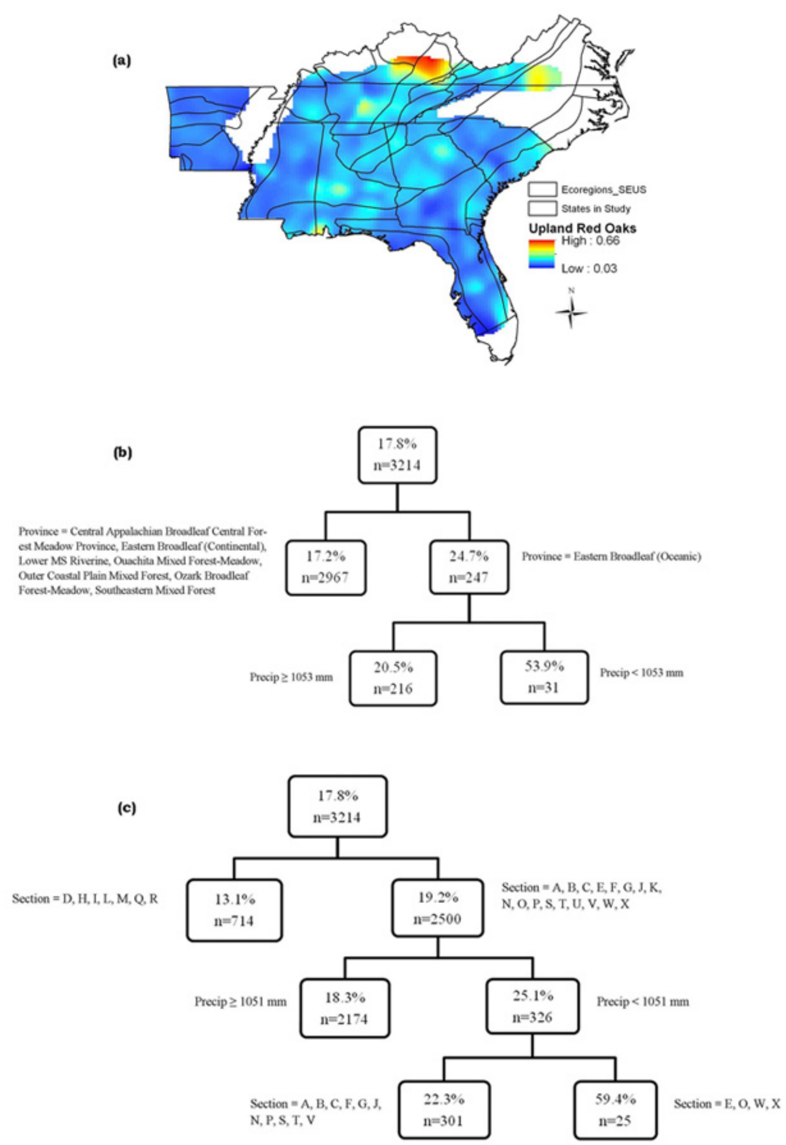

Figure 1.—Upland red oak species (a) spatial trend for mortality, (b) CART model at the ecoregion province level , and (c) CART model at the ecoregion section level.

The north to south spatial trend for bottomland red oak species was similar to the upland species, with the highest mortality values (ranging from 25 to 35 percent) occurring across northern portions of Alabama, across Tennessee and Kentucky, and in south-central portions of Virginia. The first split in the CART analysis at the province level occurred for the previous year's average annual temperature range with higher mortality associated with ranges exceeding 13.16 °C. A second split was associated with minimum average temperatures greater than 12.36 °C, although only 11 samples met this criterion. The CART model for the section level matches the province level but has a split for previous year's temperature range of less than 13.16 °C that shows mortality values near 19 percent for sections in the eastern part of the study area (Fig. 2)

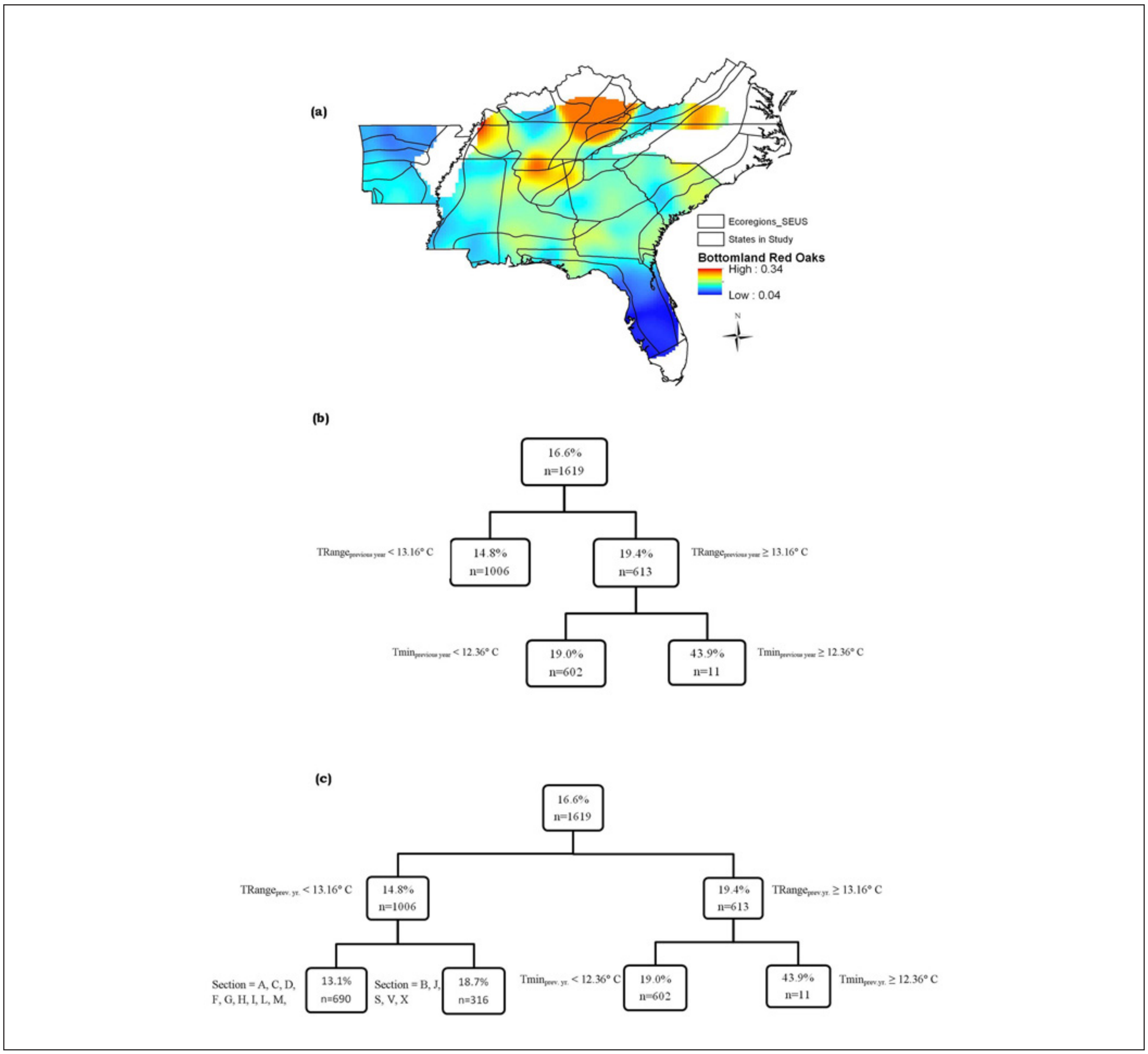

Figure 2.—Bottomland red oak species (a) spatial trend for mortality, (b) CART model at the ecoregion province level, and (c) CART model at the ecoregion section level.

DISCUSSION

The most notable findings are the changes in mortality between the two scales of analysis. The province level analysis for upland red oak species shows a split for which the highest mortality levels are associated with one province; however, when analysis occurs at the section level, many sections across the eastern portion of the study area show higher levels of mortality than those for sections in the west (e.g., Ozark Highlands). The number of sections that appear from within provinces not associated with increased levels of mortality in the province level analysis illustrates the importance of the increased level of detail that occurs at the section level. The sections are associated with detailed environmental and biological features (e.g., dominant forest cover) that provide a means of assessing differences across the region (McNab and Avers 1994). At finer scales, it is likely that micro-climatic influences are having a greater impact on mortality than at larger scales. Kabrick et al. (2007) found that ecological land types, determined at the stand scale, can be useful for determining areas where mortality is likely to be greatest by identifying areas that are less suitable for the support of healthy forests.

Also notable are the differences in mortality between upland and bottomland red oak species. The only climate variable of importance for upland species was average annual precipitation in the same year in which the inventory occurred while for bottomland species, the most influential variable was average annual temperature range. These findings point to the possible importance of extreme temperatures during some months of the year, which could act to stress trees in the impacted areas. The bottomland red oak ecoregion sections with increased mortality indicate some local or possibly regional influences such as associated forest or soil types, elevation, and/or aspect. Oak mortality events related to stand and site factors such as these can also vary across physiographic regions (Oak et al. 1996).

The different variables that influence the level of mortality for upland and bottomland red oaks vary at the scale of analysis but could also vary temporally. It has been established that drought can greatly influence red oak species mortality (Fan et al. 2012). Additional research could also assess variables such as tree age and growing season versus nongrowing season precipitation. The analysis performed here shows that there exists at least some fine scale interaction between mortality and climate variables. Future research will analyze the aforementioned variables as well as compare them to mortality trends in additional time periods.

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