STATUS OF OAK SEEDLINGS AND SAPLINGS IN THE NORTHERN UNITED STATES: IMPLICATIONS FOR SUSTAINABILITY OF OAK FORESTS

Chris W. Woodall, Randall S. Morin, Jim R. Steinman, and Charles H. Perry[1]

Abstract.—Oak species are a substantial component of forest ecosystems in a 24-state region spanning the northern U.S. During recent decades, it has been documented that the health of oak forests has been experiencing large-scale decline. To further evaluate the sustainability of oak forests in nearly half the states of the U.S., the current status of oak seedlings and saplings was analyzed using a variety of large-scale data sources, such as forest inventories and climate summaries. Study results indicated that oak seedlings and saplings tremendously lag other oak forest components (e.g., large trees) in terms of their stand occupancy relative to non-oak tree species. An indicator of future oak sustainability was developed and correlated with climatic variables indicating that climatic stresses may be an additional contributing factor to regional oak sustainability. Overall, the future of oak forests in the northern U.S. is at risk unless disturbances occur that increase oak regeneration and reduce oak mortality, especially among seedlings/saplings.

INTRODUCTION

It has been proposed that North America's oak forests may be entering an extended period of poor health (Kessler 1992), a situation that has been occurring at a national scale for the past century (Thomas and Boza 1984). The deterioration of oak forest health, evidenced by numerous symptoms and precipitated by various causal factors, is collectively termed "oak decline" (Thomas and Boza 1984, Starkey and Oak 1989, Lawrence and others 2002). Oak decline results from the interaction of predisposing (e.g., low site productivity, advance tree ages), inciting (e.g., insect defoliation, droughts), and contributing factors (e.g., poor forest management practices) (Starkey and Oak 1989, Manion, 1991, Lawrence and others 2002). This multitude of stresses eventually weakens oak trees, resulting in sparse foliage, thin crowns, crown dieback, reduced radial growth, and eventually death (Lawrence and others 2002). Silvicultural efforts to reduce tree mortality have included stand density reductions, increasing species diversity, and removal of senescing oaks (Clatterbuck and Kauffman 2006). Because oak decline is a phenomenon with a complex etiology (Manion 1991, Oak and others 1996), there is need for baseline data, long-term studies, and new analytical procedures (Kessler 1989, Nebeker and others 1992, Oak and others 1996).

The decline and mortality of oaks have been noted across large scales since the late 1970s. Researchers often consider oak decline in conjuction with the broader issue of oak sustainability (for examples, see Dwyer and others 1995, Lawrence and others 2002, Moser and others 2006, Shifley and Woodall 2007, Widmann and Williams 2007, Woodall and others 2005a). These studies observe that by volume, oak forests currently dominate many northern forests. Across the northern United States, the growing stock volume of oak tree species on timberland has increased more than 77 percent since 1963 to a present-day

[1]Research Forester (CWW), USDA Forest Service, Northern Research Station, 1992 Folwell Avenue, St. Paul, MN 55108; Research Forester (RSM), USDA Forest Service, Northern Research Station, 11 Campus Blvd., Suite 200, Newtown Square, PA; Forest Health Monitoring Coordinator (JRS), USDA Forest Service, State and Private Forestry, 11 Campus Blvd., Suite 200, Newtown Square, PA; Soil Scientist (CHP), USDA Forest Service, Northern Research Station, 1992 Folwell Avenue, St. Paul, MN 55108; CWW is the corresponding author: to contact, call (651)649-4151, or email cwoodall@fs.fed.us

total of greater than 1.4 billion cubic meters (Smith and others 2004, In press). During the same period, however, volumes of other tree species commonly associated with oak forest types, have risen at even more dramatic rates. Ash (*Fraxinus* spp.), maple (*Acer* spp.), and yellow-poplar (*Liriodendron tulipifera*) had their net growing stock volumes increase by 251, 134, and 132 percent since 1963, respectively. Current total volume of ash, maple, and yellow-poplar are approximately 1.4, 0.4, and 0.3 billion cubic meters, respectively. Despite oak's prevalence in terms of volume across the northern U.S., evidence from recent studies (Moser and others 2006, Shifley and Woodall 2007, Widmann and Williams, 2007) suggests that both oak sapling mortality and a lack of seedlings portend a doubtful future for oak forests. Given that oak seedlings and saplings may indicate the sustainability of future oak resources, their further examination is warranted.

The goal of this study was to conduct an assessment of oak seedlings and saplings as an indicator of oak forest sustainability in the 24-state region of the northern United States. Specific objectives were: 1) to determine the current status (e.g., trees per ha and mortality) of oak seedlings/saplings in contrast to non-oak species seedlings/saplings; 2) to suggest an indicator of oak sustainability building upon results from the previous objective; and 3) to correlate the indicator of oak sustainability with both stand-level parameters, such as oak mortality, and climatic factors, such as average annual precipitation.

METHODS

Forest Inventory Data

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service, the only congressionally mandated national inventory of U.S. forests, conducts a 3-phase inventory of forest attributes of the country (Bechtold and Patterson 2005). The FIA sampling design is based on a tessellation of the United States into hexagons approximately 2,428 ha in size with at least one permanent plot established in each hexagon. In phase 1, the population of interest is stratified and plots are assigned to strata to increase the precision of estimates. In phase 2, tree and site attributes are measured for forested plots established in each hexagon. Phase 2 plots consist of four 7.32-m fixed-radius subplots on which standing trees are inventoried. For assessment of current oak forest attributes, inventory data from 1999 onwards were utilized; 17,421 inventory plots were included in the analysis. This study's 24-state study region includes: Connecticut, Delaware, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Dakota, Vermont, West Virginia, and Wisconsin (Fig. 1). Plots were included in the analysis if at least one oak tree greater than 2.54 cm diameter at breast height (d.b.h.) was measured. Because growth/removals/mortality were not observed on all inventory plots, lower sample sizes occurred when these variables were utilized and are noted in results.

Climate Data

Three climatic variables were used in this study: average annual maximum temperature (TMAX), average annual minimum temperature (TMIN), and average annual precipitation (PRECIP). Data for these variables were obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset utilizing a 4-km grid cell size (PRISM Group 2004). Each of these three variables is represented by a 30-year climate normal. As such, PRECIP is the mean annual total precipitation from 1971 to 2000. TMAX and TMIN are the mean daily temperature extremes for that period.

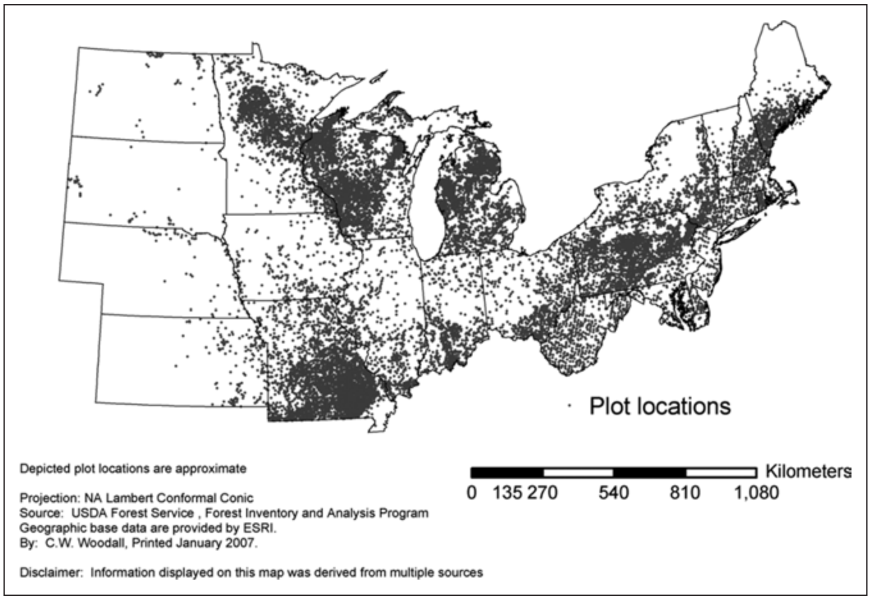

Figure 1.—Distribution of study plots with at least one oak tree present (d.b.h > 2.54 cm) (Note: plot locations are approximate due to privacy laws)

Analysis

For the purposes of this study, seedlings were defined as live trees with a d.b.h. less than 2.54 cm and at least 30.48 cm in height. Saplings were defined as live trees with a d.b.h. less than 15 cm. All study plots were assigned to classes according to ratios of oak biomass to total stand biomass. These classes represented a continuum of oak prevalence in forest stands. Next, the mean ratios of oak species attributes to non-oak species attributes were determined by each class of oak biomass ratio. Examined oak species attributes were: 1) trees per hectare (TPH) with a d.b.h >15 cm; 2) trees per hectare with a d.b.h. <15 cm; 3) average annual growth (gross); 4) average annual removals; 5) average annual mortality; 6) seedlings per hectare; 7) average annual growth (gross) for trees with a d.b.h. <15 cm; 8) average annual removals for trees with a d.b.h. <15 cm; and 9) average annual mortality for trees with a d.b.h. <15 cm).

Based on the initial results of the preceding analyses, an indicator of oak sustainability was developed that incorporates attributes of tree seedlings and saplings:

$$Indicator = Seed_R + Sap_R - SapMort_R \qquad [1]$$

Where $Seed_R$ is the ratio of oak seedlings to non-oak seedlings per plot, Sap_R is the ratio of oak saplings to non-oak saplings per plot, and $SapMort_R$ is the ratio of oak sapling mortality to non-oak sapling mortality per plot.

When we use the formulation as an indicator of oak forest sustainability, the highest value of 2 indicates that all seedlings and saplings in an oak forest were oak species with no mortality of oak saplings. A value of 0 indicates either that no oak species constituted seedlings/saplings or sapling mortality outweighed seedlings/saplings. Finally, the indicator was then correlated (Pearson's correlation coefficients) with ancillary data including climatic variables and stand variables not included in the indicator formulation.

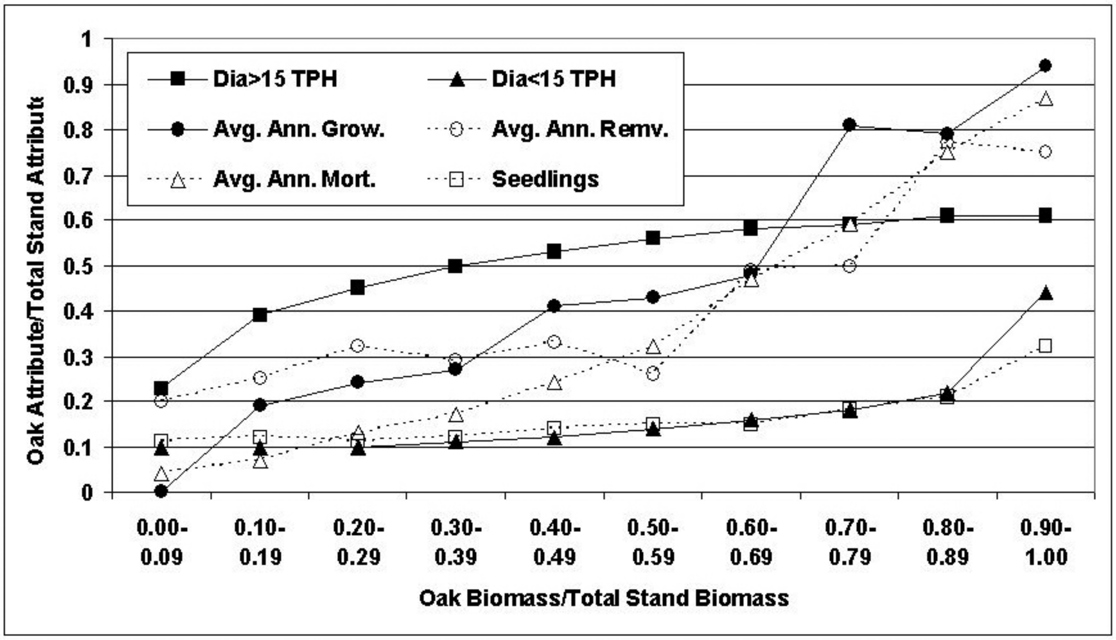

Figure 2.—Mean ratios of oak forest attributes by classes of oak biomass ratio (ratio of oak species biomass to non-oak biomass) for all inventory plots containing at least one oak tree.

RESULTS

Status of Oak Seedling and Saplings

Study results indicate that the average annual growth, mortality, and removals of oak tree species are commensurate with the amount of total stand biomass occupied by oak species (Fig. 2). For example, in a stand that had between 80 and 90 percent of its biomass in oak species, oak species themselves constituted between 75 and 80 percent of the stand's average annual growth, removals, and mortality. In contrast, seedlings/saplings accounted for only roughly 21 percent of the total seedlings/saplings in the same stand. Even in stands with more than 90 percent of their tree biomass in oak species, seedlings/saplings represented only a minority of the tree species in the stand. The very low amount of seedlings/saplings was common across all oak biomass ratio classes. As found in this and earlier studies (Woodall and others 2005b, Moser et al. 2006, Shifley and Woodall 2007, Widmann and Williams 2007), the oak resource across large scales is typified by mature oak forests that constitute a sizable portion of forest volume growth but have very few seedlings and/or sapling-sized trees to maintain oak forest types in the future.

The mean ratios of oak sapling average annual growth, removals, and mortality to those of non-oak species by classes of oak biomass ratios indicated that oak trees have less average annual growth compared to non-oak saplings in oak forests (Fig. 3). The mortality and removals of oak saplings was roughly commensurate with what may be expected in oak forests. For example, in a stand that had between 80 and 90 percent of its biomass in oak species, oak species themselves constituted between 55 and 65 percent of the stands' average annual removals and mortality but only 41 percent of the average annual growth. Even in stands with more than 90 percent of their biomass in oak trees, oak sapling growth was only 61 percent of all the sapling growth in the stand. Overall, oak saplings are conspicuously absent in large numbers in forest stands dominated by oak biomass. Although oak sapling mortality is not excessively high, oak sapling growth is poor relative to non-oak species, indicating a higher hazard of future mortality.

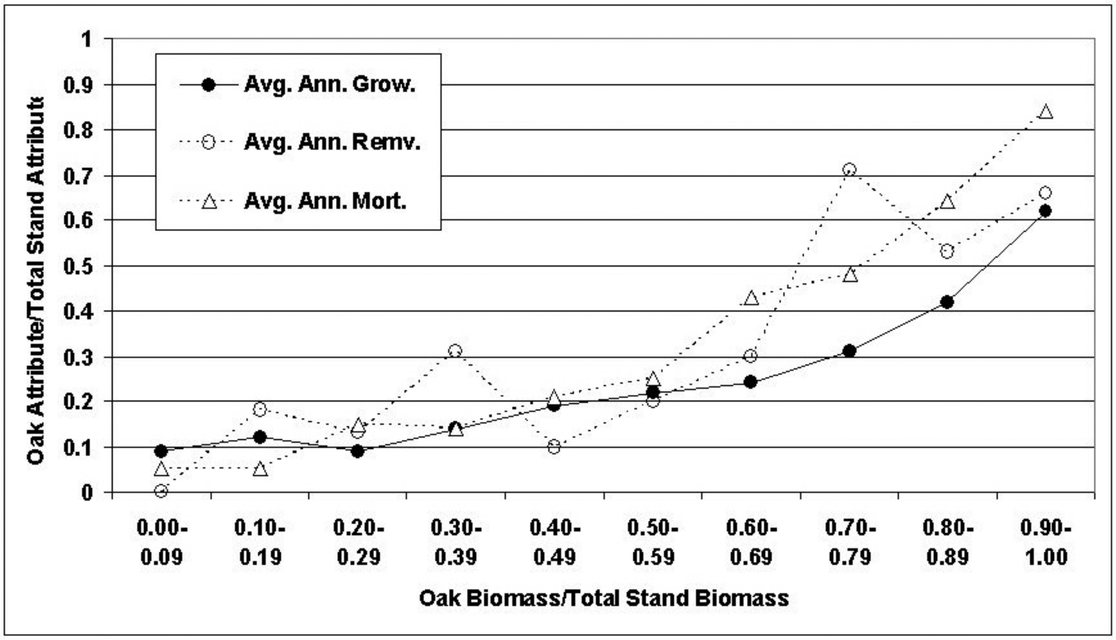

Figure 3.—Mean ratios of oak sapling attributes (d.b.h. <15 cm) by classes of oak biomass ratio (ratio of oak species biomass to non-oak biomass) for all inventory plots containing at least one oak tree.

A Proposed Indicator of Oak Sustainability

The proposed oak sustainability indicator simply incorporates the status of oak seedlings and saplings relative to non-oak species into one indicator. The order statistics of the oak sustainability indicator displayed a stark and dismal assessment of the future of oak forests in the northern states (Table 1). The median oak forest in the multi-state region had seedlings and saplings (minus average annual sapling mortality) that constituted only 20 percent of the stand's total seedling/saplings counts (minus sapling mortality). The distribution of this study's oak sustainability indicator was heavily skewed to the left where the mode was 0 and the first quartile was only 0.02. Unless oak species are a superior survivor of smaller-tree mortality compared to other non-oak tree species, the extent and condition of current oak forests will likely decline in the future. In numerous species mixtures, oak species definitely out-compete non-oak seedlings to perpetuate oak forests (Johnson and others 2002). The critical question is whether the disparity between oak and non-oak seedlings can be ameliorated by oak's superior survival traits. Therefore, monitoring the survival of oak regeneration relative to non-oak species may be critical to the forecasting of the nation's oak resources.

Table 1.—Order statistics for this study's oak sustainability indicator for oak forest types in the northern U.S. (n=5,729) (Note: mean=0.39, mode=0.00)

Percentiles	Oak Sustainability Indicator
100 Maximum	2.00
99	1.89
95	1.40
90	1.09
75 Quartile 3	0.60
50 Median	0.20
25 Quartile 1	0.02
10	0.00
5	0.00
1	0.00
0 Minimum	0.00

Oak Sustainability Indicator and Ancillary Information

We correlated the oak sustainability indicator with other oak forest attributes (e.g., average annual oak growth) and climatic variables (e.g., TMAX) (Table 2). The variables showed only weak correlations ; some correlation coefficients were near 0 (p-value > 0.05). The oak sustainability indicator was negatively

Table 2.—Pearson's correlation coefficients and significance for this study's oak decline indicator, additional oak forest attributes, and ancillary information in oak forest types, North Central and Northeastern U.S.

	Oak sustainability indicator		
Variables	Corr. Coeff.	p-value	n
Mean annual max. temp.	-0.20	<0.001	1732
Mean annual min. temp.	-0.01	0.605	1732
Mean annual precipitation	-0.16	<0.001	1732
Mean annual oak growth	0.02	0.413	1543
Mean annual oak mortality	0.01	0.605	1543
Oak trees per hectare (d.b.h >15 cm)	0.22	<0.001	5729

correlated with all climatic variables and achieved its highest correlation (-0.20) with TMAX. These results lend further credence to the hypothesis that higher temperatures and the sometimes associated periods of drought may be leading to the decrease in oaks (for examples see Starkey and others, 1989, Moser and others 2005, Clatterbuck and Kaufmann 2006), in particular the rate of establishment and survival of oak seedlings/saplings. On the other hand, the negative correlation (-0.16) of the oak sustainability index with precipitation is a surprising result; it may be more reflective of the coarse spatial and temporal scale of the climatic data rather than of site-specific response to one summer's drought.

CONCLUSIONS

This study highlights the continued progression of oak decline in forests of the northern U.S. This decline, although first evidenced by the mortality of large red oaks, may actually be better foretold by the current status of oak seedlings and saplings across large-regions. The inclusion of oak regenerative capacities in regional oak resource assessments may serve as an indicator of the negative impacts of possible climate change and large-sized oak mortality (e.g., reduced oak seed banks). Future oak sustainability explorations should include more explicit spatial analyses, refined assessment of oak versus non-oak tree species dynamics, and further incorporation of both climatic and individual tree health indices (including pest damage).

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