

1997-03

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The Ohio Journal of Science. v97, n1 (March, 1997), 5-9
<http://hdl.handle.net/1811/23728>

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Forest Decline and Tree Mortality in a Southeastern Ohio Oak-Hickory Forest¹

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ABSTRACT. Many forests throughout the central Appalachians have been suspected, or observed, to be in declining health. Few studies have examined the vitality of southeastern Ohio's forests. The purpose of our study was to evaluate the health of a representative southeastern Ohio oak-hickory forest. Thirty-two 0.1 ha plots were sampled in August 1995 on the 550 ha Waterloo Wildlife Experiment Station (ODNR) in Athens County, OH. Data were collected for all living and dead stems with a DBH ≥ 10 cm (1,891 stems sampled). For living trees, a decline index (DI) was determined to evaluate the percentage of branch dieback, undersized leaves, and chlorosis. Dead trees were identified and categorized by mortality class (log vs. snag). *Quercus* spp. and *Carya* spp. accounted for 68% of all stems sampled (83% living). Among the live trees, only three species (*Juglans nigra*, *Sassafras albidum*, and *Cornus florida*) exhibited "non-healthy" DI values. All other species were observed to be healthy or exhibiting only trace symptoms of decline. In contrast to decline, high mortality was observed for *S. albidum* (29.1%), *Liriodendron tulipifera* (21.7%), and *Prunus serotina* (21.6%). *Quercus* spp. (17.0%), and *Carya* spp. (16.2%) exhibited moderate mortality. *Acer* spp. had the highest vitality among the dominant species. Most of the observed patterns can be explained by successional dynamics and known pathogenic processes. Various incongruities emphasize the need for long-term studies of forest dynamics and forest health monitoring.

OHIO J. SCI. 97 (1): 5-9, 1997

INTRODUCTION

Forest decline results from a reduction in growth and vigor and may be accompanied by widespread mortality of trees over a relatively large geographic area. There has been a considerable increase in the reporting of forest decline throughout the hardwood forest biome of eastern North America and thus possible cause for concern (Millers et al. 1989). The source of decline is often much more difficult to pinpoint and is frequently the result of multiple stresses including acidic deposition, ozone, atmospheric pollution, climatic extremes, and biotic pests.

The condition of eastern hardwood species and ecosystems of the United States has been summarized by Weiss and Rizzo (1987) and Millers et al. (1989). One of the more prominent examples of large scale species decline in northeastern North America is the sugar maple. Observed patterns of decline stimulated the creation of the North American Sugar Maple Decline Project, a joint endeavor between the United States and Canada, to monitor the changing crown conditions in sugar maples (Hertel and McKinney-McNeal 1991). Concurrently, the Forest Response Program was created in 1985 to examine the effects of acidic deposition and ozone on forest health and productivity. Since then, numerous studies have been completed and many regions are establishing long-term forest health surveys to better monitor changes occurring in the eastern deciduous forest (Loucks 1992). Compared to sugar maple however, many vegetation

types and individual species have received considerably less attention.

Throughout the eastern United States, large scale compositional changes have been observed in forests dominated by oak (*Quercus* spp.) and hickory (*Carya* spp.) (Christensen 1977, Lorimer 1984, McCarthy et al. 1987, Pallardy et al. 1988). Many of these changes are believed to be successional in nature and appear to be linked to regeneration problems (Lorimer 1993); i.e., oak and hickory may dominate the overstory while maple and beech dominate the understory, suggesting the potential for widespread forest type conversion. Failure of the oaks to regenerate has been tied to a variety of factors including competition (e.g., shade intolerance), altered disturbance regimes (e.g., fire), wildlife populations (e.g., insects, deer), and a variety of anthropogenic influences over the past century (Lorimer 1993). Failure to regenerate in the understory may or may not be tied to oak-hickory decline in the overstory. Certainly, increased stress or decline in the overstory would adversely affect tree reproduction (Marion 1991).

In Ohio, there have been few specific reports in the literature of oak and hickory decline (Millers et al. 1989). Regionally, *Quercus* mortality has been linked to a variety of causes including abiotic stresses (e.g., drought), insects (e.g., gypsy moth), and diseases (e.g., oak wilt). *Carya* mortality has usually been associated with insect outbreaks (e.g., hickory bark beetle and gypsy moth) (Millers et al. 1989, BCM pers. obs.). Hanson et al. (1976) noted oak mortality and decline associated with drought and insects throughout a multi-state region of the mid-west, including Ohio. McCarthy (1995) documented 50% hickory mortality, associated with insects, in a ten year study of forest dynamics in two hardwood stands in a southeastern Ohio forest. The lack of decline reports for

¹Manuscript received 25 June 1996 and in revised form 26 December 1996 (#96-15).

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oak-hickory vegetation in Ohio may simply be because the forest is essentially healthy. Alternatively, decline symptoms may be present but not reported due to a shortage of inventories explicitly designed to evaluate decline in certain forest types.

The purpose of this study was to conduct a preliminary forest health inventory of a representative oak-hickory forest of southeastern Ohio. A decline index was employed to categorize present symptoms and predict future dynamics while mortality was used as an indicator of past decline and its resultant effects on present forest dynamics.

METHODS

This study was conducted in August 1995 at the 550 ha Waterloo Wildlife Research Station (WWRS; Ohio Department of Natural Resources) located in Athens County, OH. The WWRS lies within the unglaciated portion of southeastern Ohio and as a result is composed of a heavily dissected topography. Braun (1950) included this area in the Mixed Mesophytic Forest Region, but acknowledged that most second-growth forests and those inhabiting upper slopes and ridges would be better described as oak-hickory (compare McCarthy et al. 1984). Timber stands at the station are even-aged and average 90-95 years (Nixon et al. 1975).

Thirty-two 0.1 ha plots (50 x 20 m) were established along pre-existing ridge-top hunting trails characterized by oak-hickory vegetation. The rationale for this approach was so that data might be re-sampled from known locations in subsequent years (although the plots were not established as "permanent plots" *sensu stricto*). These plots were widely dispersed throughout the 550 ha study area. Live stems greater than 10 cm diameter at breast height (DBH) were evaluated by the Decline Index (DI) method which evaluates four symptoms of decline (McLaughlin et al. 1992): branch dieback, undersized leaves, slight leaf chlorosis, and strong leaf chlorosis. All categories were evaluated on a percentage basis. Dieback was estimated with the aid of a 10% gradient defoliation template of tree crown silhouettes. For purposes of understanding the specifics of structural variation and stand dynamics, dead stems were separated and tallied as snags or logs.

Following the established system of McLaughlin et al. (1992), DI scores were assigned classes according to the severity of symptoms: healthy <11, trace 11-15.9, low 16-20.9, moderate 21-25, and severe >25. Calculations of the DI (McLaughlin et al. 1992) are as follows:

$$DI = DB + (A*UL) + (A*ST) + (A*SL/2)$$

where DB = dieback; A = weighting factor [(100 - DB)/400]; UL = undersized leaves; ST = strong chlorosis; and SL = slight chlorosis.

The distribution of mortality (used here as a percentage rather than a rate function) for the sample plots (N = 32) was evaluated using the moment statistics of D'Agostino et al. (1990) which evaluate significant departures from normality in the form of skewness and kurtosis. Because mature second-growth stands are expected to have a Gaussian diameter distribution of

living stems (Oliver and Larson 1990) and because mortality is a continuous trait, a normal distribution was used as the null hypothesis to test the patterns of mortality at the stand level. Significant departures in skewness would suggest unusually low or high mortality. Significant departures in kurtosis would indicate the evenness of mortality dispersion.

RESULTS

Based on the 32 sample plots, the mean density of live stems ≥ 10 cm DBH was determined to be 543.7 stem/ha. Living canopy species with the highest mean densities included *Quercus* spp. (250.9 stems/ha), *Carya* spp. (131.0 stems/ha) and *Acer* spp. (90.3 stems/ha) (Table 1). The midstory was dominated by *Sassafras albidum* (17.5 stems/ha) and *Cornus florida* (13.1 stems/ha). Twelve other minor species were present at low abundance (<10 stems/ha) throughout the study area (Table 1).

Sassafras albidum, a predominantly midstory, early successional species, exhibited the highest mortality (29.1%). Among potential canopy trees, mortality patterns were highest for *Liriodendron tulipifera* (21.7%) and *Prunus serotina* (21.6%). *Quercus* spp. and *Carya* spp. exhibited the next highest percentage of mortality with 17.0 and 16.2%, respectively. All other species had considerably lower mortality (<10%) and some were likely

TABLE 1

Density (stems/ha) of living and dead tree species encountered at the Waterloo Wildlife Research Station, Athens County, OH. Some species were combined at the generic level due to the difficulty of assigning species identity to decomposed stems.

Species	Living	Dead		Total
		Snag	Log	
<i>Quercus</i> spp. ¹	250.9	20.6	30.9	302.4
<i>Carya</i> spp. ²	131.0	7.5	17.8	156.3
<i>Acer</i> spp. ³	90.3	0.6	3.1	94.0
Unidentifiable ⁴		7.2	33.4	40.6
<i>Sassafras albidum</i>	17.5	4.1	3.1	24.7
<i>Cornus florida</i>	13.1	0.3	0.9	14.4
<i>Fagus grandifolia</i>	8.8			8.8
<i>Nyssa sylvatica</i>	7.2	0.3		7.5
<i>Liriodendron tulipifera</i>	5.6	0.6	0.9	7.2
<i>Populus grandidentata</i>	5.6	0.3	0.3	6.2
<i>Crataegus</i> sp.	4.1	0.3		4.4
<i>Prunus serotina</i>	3.4	0.3	0.6	4.3
<i>Juglans nigra</i>	3.4			3.4
<i>Oxydendron arboreum</i>	1.3			1.3
<i>Carpinus caroliniana</i>	0.6			0.6
<i>Aesculus octandra</i>	0.6			0.6
<i>Fraxinus</i> spp. ⁵	0.3			0.3

¹ Includes living stems of *Q. alba*, *Q. prinus*, *Q. rubra*, and *Q. velutina*.

² Includes living stems of *C. glabra*, *C. ovalis*, *C. ovata*, and *C. tomentosa*.

³ Includes living stems of *A. rubrum* and *A. saccharum*.

⁴ Highly decomposed material with generic identity uncertain.

⁵ Includes *F. americana* and *F. pennsylvanica*.

included in the "unidentifiable" category (due to advanced decomposition).

Based on average density data, 19.7% of all stems encountered were dead (i.e., downed logs or standing snags) forest-wide. Of the dead material, 68% (91.2 stems/ha) was in downed logs and 32% (42.2 stems/ha) in standing snags or leaners. *Quercus* spp., *Carya* spp., and unidentified stems accounted for >90% of all coarse woody debris yet represented only 70% of the living stems (Table 1). Part of the difference (ca. half) can be attributed to the absence of unidentifiable stems from the living component.

The frequency histogram of the $N = 32$ sample plots by percent mortality indicates that the data are statistically indistinguishable from a normal distribution (Fig. 1). The skewness coefficient was 0.42 ($P = 0.67$) and the kurtosis coefficient -1.31 ($P = 0.19$) resulting in an overall omnibus coefficient of 1.90 ($P = 0.39$).

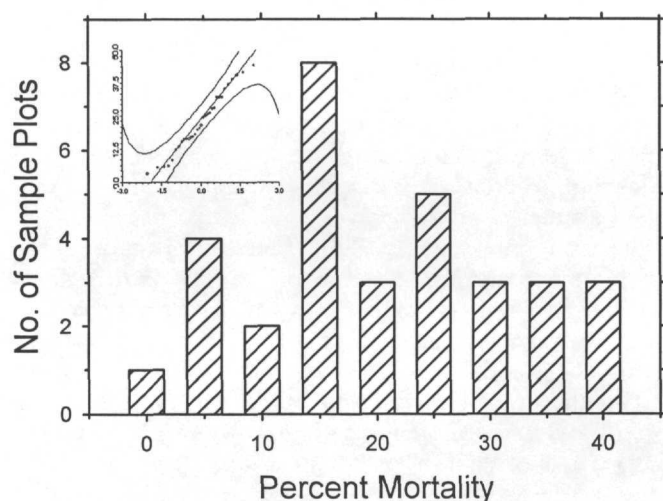


FIGURE 1. Frequency histogram displaying the patterns of mortality observed in $N = 32$ stands observed in the Waterloo Wildlife Research Station, Athens County, OH. Inset displays a normal probability plot of the data $\pm 95\%$ confidence interval.

An evaluation of the DIs indicates that several species are in moderate to severe decline: *Juglans nigra*, *Sassafras albidum*, and *Cornus florida* (Fig. 2). *Juglans* showed heavy signs of both leaf discoloration and dieback, however, the DI was quite variable. *Sassafras* and *Cornus* both showed more dieback than chlorosis of leaves. All other species evaluated were either healthy or only suspected of trace decline. The major canopy dominants, *Quercus* spp. and *Carya* spp., were generally considered healthy. *Fagus grandifolia* and *Acer* spp., the understory and midstory dominants, exhibited some of the highest vitalities (Fig. 2).

DISCUSSION

Decline surveys and mortality data provide two alternative forms of information about the health of a forest. Decline surveys are most useful for obtaining an assessment of the current condition of a forest and are useful for long-term studies monitoring forest health.

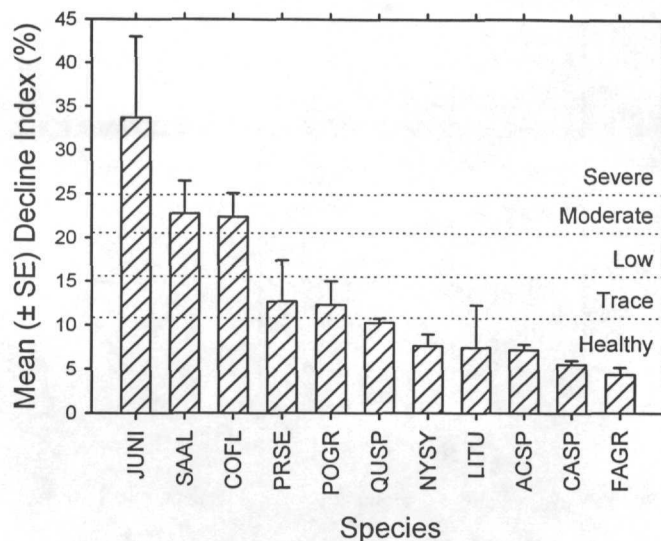


FIGURE 2. Mean (\pm SE) decline index (DI) for the major species of canopy trees present at Waterloo Wildlife Research Station, Athens County, OH. Species acronyms utilize the first two letters of the genus and specific epithet; sp is used for collective groups at the generic level (see Table 1 for species identities and complete binomials). Dotted lines separate species health categories (from healthy to severe decline) as defined by McLaughlin et al. (1992).

Mortality data provide a current assessment of the cumulative recent past forest conditions and may or may not be attributable to decline (e.g., local windthrow would not be considered decline). Thus, we are able to examine the current health of this representative oak-hickory forest and draw tentative conclusions about past conditions based on current structural data (McClenahan and McCarthy 1990).

Much of our data can be explained in the context of forest succession and known disease patterns. *Sassafras albidum* exhibited some of the greatest mortality and highest DI. This species is an early successional, shade intolerant species with a short life span and would be expected to be in this condition when found in mature even-aged stands of 90-100 years (Burns and Honkala 1990). *Cornus florida* is known to be currently experiencing a massive decline rangewide due to the dogwood anthracnose (*Discula destructiva* Redlin) which was first recorded in Ohio in 1990 (Daughtrey et al. 1996). The efficacy of our methodology is reinforced by a high DI and low mortality for this species (exactly what would be expected for a recent decline phenomenon). The high DI for *Juglans nigra* remains unclear, however, this species was in very low abundance and thus some of the patterns might be attributable to a sampling artifact.

Decline symptoms were not evident for the major canopy dominants. Living stems of both *Quercus* spp. and *Carya* spp. appeared healthy. However, these two groups had reasonably high mortality (16-17%). While *Carya* spp. mortality at WWES appears to be quite similar to that of regional data from southern Ohio (Griffith et al. 1993), *Quercus* spp. mortality at WWES is more than twice the regional average (Fig. 3). Whether these local and regional patterns of mortality are inordinately "high" or just "average" for mature, second-growth, oak-hickory vegetation is not particularly clear. Similar data collected

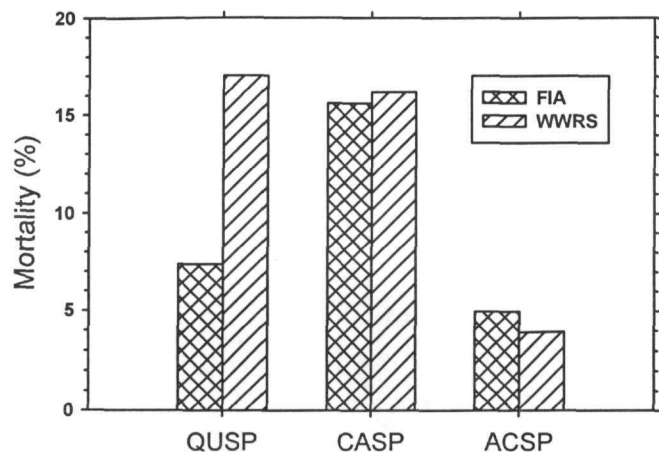


FIGURE 3. A comparison of the mortality (%) patterns for the three most abundant species groups at the Waterloo Wildlife Research Station (WWRS; this study) and regionally for south-central Ohio via Forest Inventory and Analysis data (FIA; Griffith et al. 1993).

from mature, second-growth, northern hardwood stands in western Maryland indicates that *in situ* mortality as high as 20% may not be uncommon (McCarthy and Bailey 1994). Runkle (1985) suggests that a reasonable rate of gap formation in temperate deciduous forests is $\approx 1\%$ per annum. If we assume that hardwoods require 15-20 years to decompose past recognition then we should expect about 15-20% of all stems in a stand to be dead and in various states of decomposition. Thus, by extension, the observed mortality of *Quercus* spp. and *Carya* spp. do not appear to be "unreasonably" high. Unfortunately, decomposition rates of eastern hardwoods have not been well studied.

Several studies have taken a populational or dendroecological approach to the examination of declining health of Ohio's forest species. McClenahan and McCarthy (1990) determined that a significant decrease in crown vigor of *Pinus rigida* could be due to air pollution in the Ohio Valley. Likewise, a similar study indicated a possible connection between pollution and altered dendrochronological patterns in white oak (McClenahan and Dochinger 1985). These and other studies indicate pollution as a possible factor in decline, but, as these authors acknowledge, absolute linkage (i.e., cause and effect) is often very difficult to prove. Nash et al. (1992) encountered a similar problem in examining the health of oak-hickory vegetation along a clear wet deposition gradient in nearby central Pennsylvania.

While the efficacy of the DI appeared reasonable, based on our expected results with sassafras and dogwood, other investigators have questioned the use of crown indices as a measure of forest health. For example, Hertel et al. (1993) found that while crown surveys indicated good health, their study area had actually experienced decreases in mean basal area, soil invertebrates, and two species of oak. While the DI system (McLaughlin et al. 1992) has been widely used with the monitoring of northern hardwoods and sugar maple in Canada, its efficacy with respect to other species or vegetation types is largely unknown. We found that crown dieback was the prominent feature discernible in

oak-hickory vegetation. The prominence of crown dieback (and its relation to decreased tree-ring growth) was also observed in a recent study of forest health in the oak-hickory vegetation of the Missouri Ozarks (Dwyer et al. 1995). The presence of chlorosis or undersized leaves was rarely noted in either our study or those of others. Either the oak and hickory observed in this study were in good health or these traits are not obviously discernible with these species. Unfortunately, the use of these traits is thought to make the DI system a stronger measure of decline since it does not combine measures of crown density and discoloration as do other indices (Innes and Boswell 1989, McLaughlin et al. 1992). Alternatively, the sensitivity of the DI might only be seen under low-level chronic stresses such as air or soil pollution (e.g., Nash et al. 1992). Stochastic climatic conditions and insect outbreaks are sporadic and temporally brief; thus, they might be adequately measured through mortality assessments. We also recognize that the DI is best suited as a monitoring tool for long-term studies where subtle trends may be detected against a backdrop of other more stochastic disturbances (Innes 1988, Manion 1991). The methods used to monitor decline are often so varied that comparing results across the board can be quite difficult (Blank et al. 1988, McLaughlin et al. 1992). More research is needed into the best measures of forest decline.

Overall, our study revealed a variety of patterns at the community and population levels, none of which seem to indicate obvious decline in southeastern Ohio's oak-hickory forests. Clearly, sporadic insect outbreaks, pathogens, and climatic events have caused excessive mortality of certain species in certain stands. Some stands exhibited mortality as high as 40%. However, an average of 20% dead stems in a stand appears to be reasonable without inferring excessive mortality or decline. Likewise, certain species were in an obvious state of decline, but these generally had a clear successional or pathogenic explanation. Changes occurring due to insects and pathogens may be a natural and necessary phenomenon (Castello et al. 1995). Direct observation suggests that *Acer* spp. in the canopy and midstory are quite healthy and likely to capture gap space as it becomes available. We did not describe understory vegetation (DBH <10 cm) in this study, however, this layer was dominated by *Acer* spp. which possessed a very high vitality. In the absence of changing disturbance regimes, this forest will likely be converted to a maple dominated forest. Evaluation of decline symptoms in smaller size classes might provide additional useful information to be used in understanding the oak regeneration problem.

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