Allegheny National Forest Health

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Abstract.—Since 1985 72 percent of the forest land on the Allegheny National Forest has been subject to at least one moderate to severe defoliation from any of three native or three exotic agents. In addition, droughts affected the forest in 1972, 1988 and 1991. As a result, at least 20 percent of the forest shows tree mortality in from 10 to 80 percent of the overstory trees. Sugar maple is the most seriously affected species. The impacts of this mortality are compounded by the impacts of up to 70 years of overbrowsing by white-tailed deer.

Long-term silvicultural research studies were reexamined and showed that most of the sugar maple mortality is occurring in sapling and pole–size stems, mortality is worse on dry than on wet sites, and even–age silvicultural treatments, especially thinning, are associated with reduced amounts of mortality and reduced rates of mortality.

INTRODUCTION

The Allegheny National Forest (ANF), a half-million acre tract of largely forest land on the unglaciated portion of the Allegheny Plateau in northwestern Pennsylvania, was established in 1923. Early surveyor's records suggest that the original forest consisted primarily of American beech, *Fagus grandifolia* Ehrh., (44 percent) and eastern hemlock, *Tsuga canadensis* (L.) Carr (20 percent). Sugar maple, *Acer saccharum* Marsh., red maple, *A. rubrum* L., and white pine, *Pinus strobus* , each represented 5 percent, and black cherry, *Prunus serotina* Ehrh., represented only 0.8 percent of the trees recorded in these early surveys (Whitney 1994). Wind, including tornadoes, was the primary natural disturbance, along with drought and ice (Bjorkbom and Larson 1977). Fire, both natural and anthropogenic, was also a force, especially near river drainages (see, for example, Lutz 1930). Browsing by deer and hare, defoliation by insects, and forest diseases were also undoubtedly part of the natural disturbance regime of these forests.

The forests of the Allegheny Plateau region were harvested lightly for selected species and products throughout most of the 19th century. With the onset of the Industrial Revolution near the close of the 19th century, however, harvesting practices changed, and final removal cuts with very complete utilization took place across the region from about 1890 to 1930, creating a significant regional age-class imbalance (Marquis 1975). In 1993, 75 percent of the forest land base on the ANF contained stands between 60 and 110 years of age (U.S. Department of Agriculture Allegheny National Forest 1993).

These even-aged second growth forests contain a diverse mix of species, often stratified vertically and by diameter. The Allegheny hardwood, or cherry-maple type, for example, is dominated by the shade-intolerant black cherry, which survives only in the largest diameter classes and codominant or dominant crown classes. Red maple, the birches, *Betula lenta* L. and *B. alleghaniensis* Britton, white ash, *Fraxinus americana* L., and other species of low to intermediate tolerance are most frequently found in the mid- to largest diameter

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classes and codominant crown positions, while the shade tolerant sugar maple and American beech, of the same age as the other species, persist as saplings and small poles in intermediate and suppressed crown positions. When species from the most shade-tolerant group are found in the main crown canopy and largest diameter classes, they are often holdovers from the previous stand, regenerated after mid–19th century partial cuts.

The turn-of-the-century cutting brought about dramatic changes in the species composition of this forest. Black cherry, only 0.8 percent of the presettlement witness trees, represents 28 percent of the trees in today's forest. Red maple has increased from 5 to 25 percent, and sugar maple from 5 to 13 percent (Lois DeMarco, personal communication).

Another important change occurred as the second-growth forest developed. White-tailed deer, *Odocoileus virginianus*, which had been nearly extirpated from Pennsylvania during the turn-of-the-century harvest period, were protected by the Pennsylvania Game Commission beginning in 1907, and the herd made a remarkable recovery. By 1929, scientists were noting losses in the shrub layer of the forest (Pennsylvania Game Commission 1991). Since that time, deer herds have been above the target level established by state game managers for the region, with the exception of two brief periods in the 40's and 70's associated with severe winters (Redding 1995).

Deer browsing has had a major impact on forest understories, regeneration development and wildlife habitat (Tilghman 1989, Jones and others 1993, deCalesta 1994). Regeneration of species dependent upon advance regeneration, as many of the second-growth species are, is frequently absent. Other species that interfere with the establishment and survival of natural regeneration by casting dense shade at the forest floor level (Horsley 1991, 1993) fill the growing space vacated by browsed seedlings. These plants include hay-scented and New York fern, *Dennstaedtia punctilobula* and *Thelypteris noveboracensis*, grasses and sedges, beech root suckers, and striped maple, *A. pennsylvanicum* L., seedlings. These effects occur in both managed and unmanaged forests, and have severely impacted natural regeneration processes in the two major old-growth blocks within the ANF (Hough 1965, Bjorkbom and Larson 1977, Whitney 1984, Walters and Nowak 1993).

FOREST HEALTH CONCERNS SINCE 1985

Since 1985 management challenges on the ANF have been increased by the activities of a series of natural and exotic agents. Native defoliators (elm spanworm, *Ennomus subsignarius*, cherry scallop shell moth, *Hydria prunivorata*, and forest tent caterpillar, *Malacosoma disstria*) have defoliated 385,000 acres moderately to severely since 1991. Exotic defoliators (gypsy moth, *Lymantria dispar*, and pear thrips, *Taeniothrips inconsequens*) and an exotic insect/disease complex (beech bark disease, *Cryptococcus fagisuga* and *Nectria* spp.) have affected 317,000 acres since 1985. Figure 1 shows portions of the ANF that have been moderately to severely defoliated from one to four times between 1985–95. Only 28 percent of the ANF has not received at least one moderate to severe defoliation. The last 10 years included two droughts, 1988 and 1991, a killing frost on Memorial Day 1992, and both unusually snowfree and unusually snowy winters. And finally, although effects have not been documented, the atmospheric deposition on the ANF's unglaciated and often base-cation poor soils is quite acidic. Collectively, these agents—insects and diseases, droughts and other climatic extremes, and soil-site conditions—have led to the decline of many tree species.

During the 1985–95 decade, personnel of the USDA Forest Service, Northeastern Area State and Private Forestry, Forest Health Protection group working with personnel of the Allegheny National Forest have sprayed more than 248,000 acres with insecticides to reduce defoliation by gypsy moth, elm spanworm, and forest tent caterpillar.

MORTALITY AND MANAGEMENT RESPONSES

Despite these significant efforts to protect the forest from defoliation stresses, the forest has experienced both sudden and gradual tree mortality. During the droughty summer of 1988, for example, tree mortality in the oak type occurred almost overnight in mid- to late-August, especially

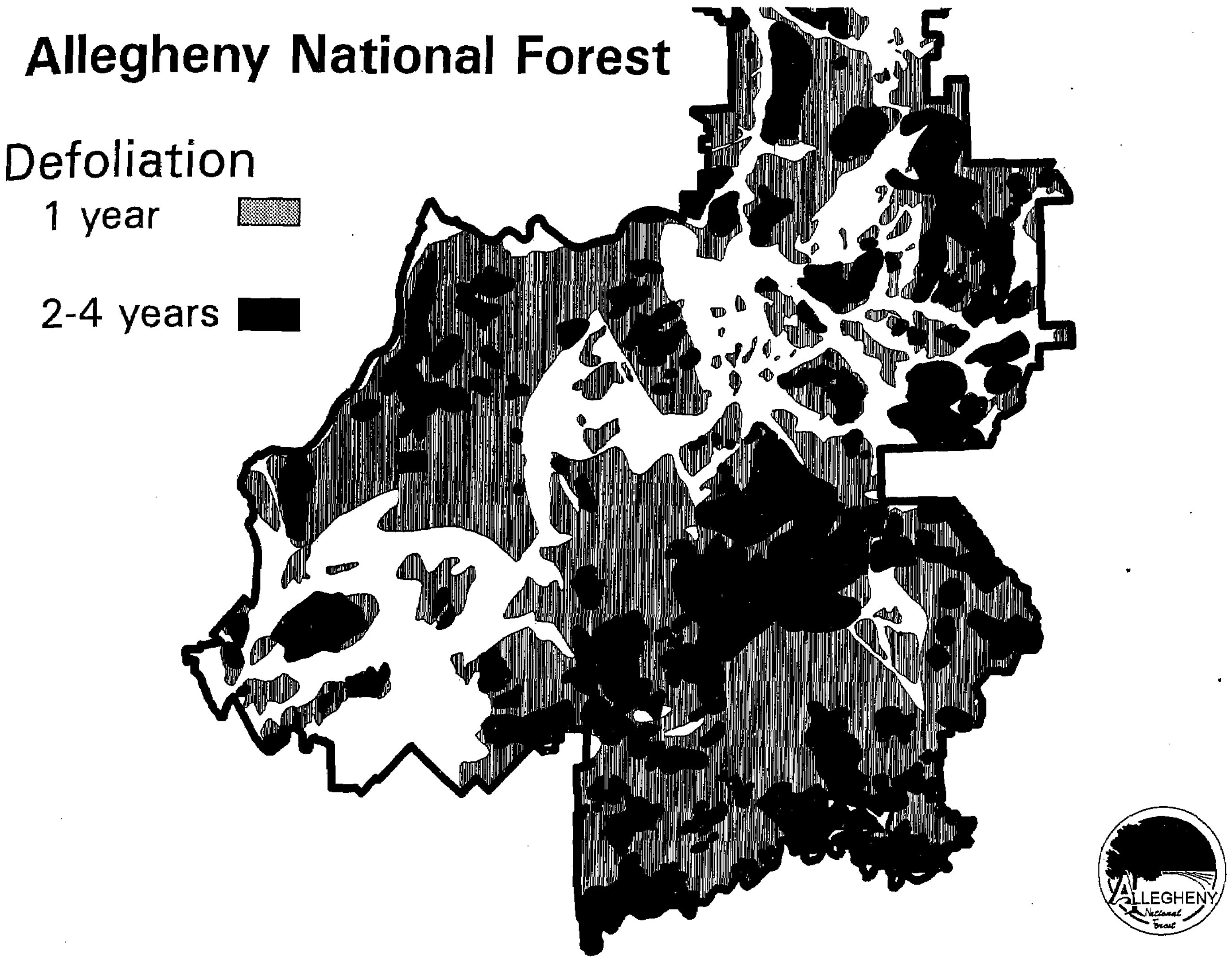

Figure 1.—Map of the Allegheny National Forest showing areas that experienced moderate to severe defoliation from 1 to 4 times during the decade 1985–94.

in areas defoliated by gypsy moth in previous years. Approximately 108,000 acres have suffered from 10 to 80 percent tree mortality since 1985.

During 1994, color infrared photography was used to identify the sites of current decline. Results indicated that approximately 90,000 acres are currently affected. We have used inventory data collected on 12,000 of these acres during the summer of 1994 to characterize the current decline.[4] Within the acres surveyed, 12 percent of the basal area was already dead, and another 16 percent was judged to be at risk with less than 50 percent crown remaining. Sugar maple was the most heavily

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[4] *McWilliams, William H.; Arner, Stanford; Nowak, Christopher A.; White, Robert; Stout, Susan L. in preparation. Characterizing impacts in declining stands of the Allegheny National Forest. Res. Note. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station.*

impacted species, 28 percent dead and 31 percent at risk. White ash (27 percent dead and 20 percent at risk), beech (12 percent dead and 17 percent at risk), birch (14 percent dead and 4 percent at risk), and red maple (8 percent dead and 13 percent at risk) were other important species with mortality. Within the sugar maple group, mortality averaged about 14 ft^2 per acre, of which 12 ft^2 per acre was in trees of less than 15" diameter at breast height. Rates of mortality were actually highest in the largest size classes, but these represent less than 1 percent of the sugar maple in the sample.

Managers are particularly concerned about the implications of these declines for forest regeneration. In some places, the increased light reaching the forest floor as a result of the recent defoliations and crown dieback has resulted in increased establishment and growth of tree seedlings. Only 8 percent of the stands in the 12,000-acre sample had adequate tree regeneration, including shade-tolerant saplings of sufficient health to leave as part of a new stand. But in many places, the beneficiaries of increased light have been ferns, grasses, and sedges, and as mortality removes trees that could provide seed for natural tree regeneration, the management challenges increase. More than 70 percent of the stands in the 12,000-acre sample had fern understory stocking in excess of 30 percent, the level associated with interference with regeneration establishment (Marquis and others 1992). Allegheny National Forest managers commonly use intensive silvicultural practices—including herbicides, fencing, aerial fertilization of established seedlings, and individual tree seedling protectors—to overcome the barriers to natural regeneration. In addition, managers are working with scientists to identify appropriate management strategies for declining stands that do not require regeneration treatments.

As of spring 1995, environmental assessments to identify regeneration and, where appropriate, timber salvage responses to the mortality had been completed for 58,000 acres. Work is under way on environmental assessments for the remaining 51,000 acres known to be affected, and new photography and field reconnaissance will be used during the 1995 growing season to identify new or increased mortality.

RESEARCH RESPONSES

As the decline and mortality on the ANF accelerated, scientists looked for explanations and patterns. We used two long-term studies on the Kane Experimental Forest (KEF), a 1700-acre tract within the boundaries of the ANF on which research into forest management has been conducted since 1929, to examine the effects of silviculture on decline and mortality. We focused these analyses on sugar maple because it is the most significantly impacted species in the Allegheny and northern hardwood types, and because mortality first occurred in this species.

One study was designed to assess the impacts of even-age thinning to different residual relative densities on stand development. A series of two-acre treatment plots were installed on the KEF in 1973–75. Treatments were thinnings predominantly from below, and the original stand was an even-age, 55-year-old Allegheny hardwood stand. Treatments were accomplished through a combination of commercial and non-commercial removals. A complete description of the study can be found in Marquis and Ernst (1992) and Nowak.[5] During 1987, the vigor of individual sugar maple trees on these plots was assessed.[6] We reanalyzed the data from those plots that received thinnings to residual relative stand densities from 50 to 70 percent (Roach 1977, Stout and Nyland 1986) and control plots, to assess the impacts of thinning on sugar maple mortality. We used data from the inventories taken after treatment in the early 1970's, and measurements taken 15 years later, around 1990. These plots occurred across two toposequences typical of the ANF landscape. Comprehensive soil analyses were completed on all these plots during the mid–1980's (Auchmoody, L. unpublished data on file at the Forestry Sciences Laboratory, Warren, PA). We used these soil analyses to assign a soil drainage class to each of the study plots, enabling us to assess the impacts of soil drainage on sugar maple decline symptoms and mortality. Figure 2 shows decline

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[5] *Nowak, Christopher A. in review. Wood volume increment in thinned, 50– to 55–year–old, mixed species Allegheny hardwoods. Canadian Journal of Forest Research.*

[6] *Redding, James. 1987. Study 76 Progress Report for Blocks II and III: Maple decline survey. Unpublished report on file at the Forestry Sciences Laboratory, Warren, PA.*

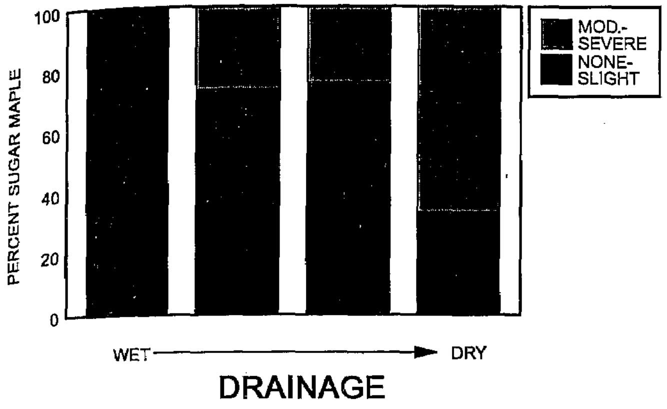

Figure 2.—Proportion of sugar maple trees showing decline symptoms in control plots from the Kane Experimental Forest thinning study, as a function of soil drainage. Each bar represents a 2-acre treatment plot.

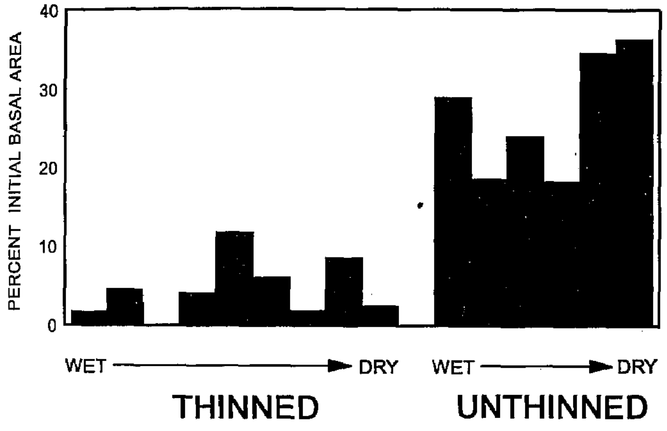

Figure 3.—Relative mortality (proportion of post-treatment sugar maple basal area that died during the 15 years after treatment, 1973–75 to 1988–90) in thinned and control plots from the Kane Experimental Forest thinning study, as a function of soil drainage and treatment. Each bar represents a 2-acre treatment plot.

Table 1.—Absolute and relative mortality of sugar maple in thinned and unthinned, 50-year-old Allegheny hardwoods, 15 years after treatment.

	Treatment				
	Unthinned		Thinned		
Variable	n	mean	n	mean	p-value[a]
Number of stems					
Absolute (stems per acre)	6	286 (40)[b]	9	24 (19)	<0.01
Relative (percent of initial)	6	69 (19)	9	15 (11)	<0.01
Basal area					
Absolute (ft^2 per acre)	6	11.9 (6.3)	9	1.3 (1.4)	<0.01
Relative (percent of initial)	6	26.8 (7.8)	9	4.6 (3.7)	<0.01

[a] *p-values from t-tests between unthinned and thinned.*

[b] *Values in parentheses below each mean are standard deviations.*

symptoms of sugar maple as a function of soil drainage in four uncut, control plots. Decline symptoms were higher on the drier soils. Wet soils had virtually no decline.

Figure 3 shows relative mortality, or the proportion of posttreatment sugar maple basal area that was dead after 15 years, in thinned vs. unthinned plots, across the toposequences. This figure shows that the soil drainage effect was much stronger in unthinned plots. Table 1 shows both absolute and relative sugar maple mortality. In basal area, mean relative sugar maple mortality was six times less than the mortality in the unthinned plots (p<0.01). Relative mortality corrects for the fact that thinned plots had fewer trees at the beginning of the period.

Another study on the KEF was installed to test the effects of different silvicultural systems on stand development, growth, and yield. Three variants of uneven-age silviculture, two-age silviculture, and even-age silviculture were investigated. Treatments were applied to 4.9-acre plots during the winter of 1979–80 in four blocks of five treatments each. This study was installed in a multi-age stand resulting from a heavy partial cut during 1900. The study is completely described in Stout (1994). The analysis reported here is based on final measurements taken during the winter of 1995.

For this investigation, we pooled the plots that had received even-age or two-age treatments, and contrasted them with the plots that had received uneven-age treatments. Figure 4 shows the relative mortality (proportion of sugar maple trees left after treatment) in these two groups. Table 2 shows the values displayed in this chart, as well as the wide variation around the means. Differences are not significant but indicate a strong trend. As shown in Table 2, the differences are more nearly significant when expressed as proportions of basal area. The large relative mortality when expressed as stems per acre reflects the fact that the mortality was most severe in small trees, which is consistent with the observations from the analysis of ANF mortality plots and with observations from the thinning study. Even-age and two-age treatments discriminate against smaller trees, while uneven-age treatments leave trees in all size classes, and smaller sugar maple trees have been more vulnerable to the stresses of the last decade.

Note that in this older stand, the rates of mortality are much greater than those in the younger, thinned stands. There are several possible explanations for this. Potentially the most important is the measurement period: data analyzed for the thinned stand were collected in 1990, before the worst mortality, and data for the silvicultural systems study were collected in 1995. Based on observations in both stands during 1995, however, we believe that mortality in the older stand is indeed higher than that in the younger stand. In addition to age, this may be because 17 of the 20 plots in the silvicultural systems study were on moderately to well-drained, or dry, soils.

Table 2.—Absolute and relative mortality of sugar maple in 90-year-old and older multi-age Allegheny hardwood stands treated with uneven and even-age silviculture, 15 years after treatment.

	Treatment				
	Unthinned		Thinned		
Variable	n	mean	n	mean	p-value[a]
Number of stems					
Absolute (stems per acre)	12	28 (14.9)[b]	7	22 (13.8)	<0.44
Relative (percent of initial)	12	66 (11)	5[c]	59 (11)	<0.26
Basal area					
Absolute (ft^2 per acre)	12	9 (7.4)	7	8 (4.3)	<0.74
Relative (percent of initial)	12	62 (16.9)	5	53 (13.8)	<0.31

[a] *p-values from t-tests between stands receiving uneven- and even-age treatments*

[b] *Values in parentheses below each mean are standard deviations.*

[c] *Two of the even-age stands received intermediate treatments. We have calculated absolute mortality by summing mortality for the two time periods, but there is not a comparable way to calculate relative mortality.*

LONG-TERM RESPONSES

The scale and severity of the decline and mortality in Allegheny hardwood forests has, frankly, surprised managers and researchers alike. We have focused on the dimensions of the problems on the ANF in this paper, but industrial, non-industrial private, and state agencies are experiencing similar problems. Although we have known that the species composition of our second-growth forests is quite different from the original forests of our region, they appeared to be healthy and vigorous until the last decade. The most serious challenge to their sustainability was posed by white-tailed deer browsing on regeneration. Understanding the ecosystem implications of the current decline, and designing a response that offers the best hope of sustaining these forests, will require a comprehensive program of research and adaptive management. Such a program is already beginning.

During the first week of June 1995, a team of scientists and managers from across the northeastern United States met to study the problem and design a comprehensive response. The team included pathologists, physiologists, silviculturists, entomologists, geologists, hydrologists, and managers from state, federal, and industrial landown-

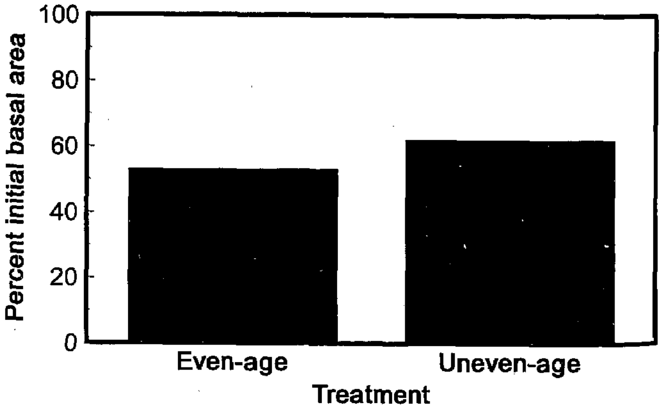

Figure 4.—Relative mortality (proportion of post–treatment sugar maple basal area that died during the 15 years after treatment, 1980–1995) in plots managed by even–age and uneven–age silvicultural systems from the Kane Experimental Forest silvicultural systems study.

ers. Insects, diseases, climate effects, nutrient depletion and soil effects, and anthropogenic stressors were all considered as contributing agents. Participants will design a series of studies that will assess both the patterns and processes associated with this decline. In particular, a coalition including all three branches of the Forest Service (National Forest Systems, Research, and State and Private Forestry), forest industry, and Pennsylvania state agencies is cosponsoring a spatial assessment. Information about soils, landform, recent and long-term management history, tree species composition, and defoliation history will be entered in a geographic information system to assess the scope of the problem across the northern tier of Pennsylvania and to detect correlations among these layers and current mortality. At the same time, other scientists will be working on a series of mechanistic studies to identify both causal factors and remedial strategies. Managers will remain heavily involved in this research, using early outcomes as adaptive management strategies.

Already this research has stimulated new understanding of the Allegheny hardwood ecosystem. Patterns of decline and mortality appear to have some association with patterns of glaciation in the region, in addition to the associations with soil drainage identified above. Calcium depletion, not previously studied in this region, has become an important hypothesis. Stand history, particularly shifts in the relative abundance of tree species, may have predisposed some tree species to their current declines. While the challenge of sustaining forests in the face of these declines is indeed a serious one, we anticipate learning a great deal about our ecosystem in the process of meeting this challenge.

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LITERATURE CITED

Bjorkbom, John C.; Larson, Rodney G. 1977. The Tionesta Scenic and Research Natural Areas. Gen. Tech. Rep. NE-31. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 24 p.

deCalesta, David S. 1994. Effect of white-tailed deer on songbirds within managed forests in Pennsylvania. Journal of Wildlife Management. 58(4):711–718.

Horsley, Stephen B. 1991. Using RoundUp and Oust to control interfering understories in Allegheny hardwood stands. *In:* McCormick, Larry H.; Gottschalk, eds. Proceedings: 8th Central Hardwoods Conference, 1991, March 4–6: University Park, PA. Gen. Tech. Rep. NE–148. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 281–290.

Horsley, Stephen B. 1993. Mechanisms of interference between hay-scented fern and black cherry. Canadian Journal of Forest Research. 23:2059–2069.

Hough, Ashbel F. 1965. A twenty-year record of understory vegetation change in a virgin Pennsylvania forest. Ecology. 46:370–373.

Jones, Stephen B.; deCalesta, David; Chunko, Shelby E. 1993. Whitetails are changing our woodlands. American Forests. November/December: 20–25,53–54.

Lutz, H.J. 1930. The vegetation of Heart's Content, a virgin forest in northwestern Pennsylvania. Ecology. 11:1–29.

Marquis, David A. 1975. The Allegheny hardwood forests of Pennsylvania. Gen. Tech. Rep. NE-15. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 32 p.

Marquis, David A. ; Ernst, Richard L. 1992. The effects of stand structure after thinning on the growth of an Allegheny hardwood stand. Forest Science. 37(4): 1182–1200.

Marquis, David A.; Ernst, Richard L.; Stout, Susan L. 1992. Prescribing silvicultural treatments in hardwood stands of the Alleghenies (revised). Gen. Tech. Rep. NE-96. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 101 p.

Pennsylvania Game Commission. [1991]. Pennsylvania Deer Management. Harrisburg, PA: Pennsylvania Game Commission. 4 p.

Redding, Jim. 1995. History of deer population trends and forest cutting on the Allegheny National Forest. *In:* Gottschalk, Kurt W.; Fosbroke, Sandra L., eds. Proceedings 10th Central Hardwood Forest Conference, Morgantown, WV, March 5–8, 1995. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. p. 214–224.

Roach, Benjamin A. 1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. Res. Pap. NE-373. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 30 p.

Stout, Susan L.; Nyland, Ralph D. 1986. Role of species composition in relative density measurement in Allegheny hardwoods. Canadian Journal of Forest Research. 16: 574–579.

Stout, Susan L. 1994. Silvicultural systems and stand dynamics in Allegheny hardwoods. New Haven, CT: Yale University. 168 p. D.F. dissertation.

Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. Journal of Wildlife Management. 53(3):524–532.

U.S. Department of Agriculture Allegheny National Forest. 1993. Monitoring and evaluation report for 1993. Warren, PA: U.S. Department of Agriculture, Forest Service, Allegheny National Forest.

Walters, Russell S.; Nowak, Christopher A. 1993. Understory vegetation changes on the Tionesta scenic and natural areas: 1942–1992. *In:* Conservation in working landscapes: 20th annual Natural Areas Conference; 1993. June 22–26: Orono, Maine. Orono, ME: University of Maine. not paginated.

Whitney, Gordon G. 1984. Fifty years of change in the arboreal vegetation of Heart's Content, an old- growth hemlock-white pine-northern hardwood stand. Ecology. 65(2):403–408.

Whitney, Gordon G. 1994. From coastal wilderness to fruited plain: a history of environmental change in temperate North America, 1500-present. New York: Cambridge University Press. 400 p.