NATURAL DISTURBANCE REGIMES IN OLD-GROWTH NORTHERN HARDWOODS

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Figure 1. Heavy partial blowdown in an old-growth forest in northern Wisconsin, caused by an intense thunderstorm in 1977.

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IN AN ESSAY ON THE MAINE Woods, Henry David Thoreau (1864, p. 198–99) remarked, "Humboldt has written an interesting chapter on the primitive forest, but no one has yet described for me the difference between that wild forest which once occupied our oldest townships, and the tame one which I find there today. It is a difference that would be worth attending to." For his part, Thoreau could only offer his general impressions about how the younger, second-growth forest had changed compared to the primary forest or old-growth. "It has lost its wild, damp, and shaggy look," Thoreau thought. "The countless fallen and decaying trees are gone, and consequently that thick coat of moss which lived on them is gone too. The earth is comparatively bare and smooth and dry."

Thoreau's inquiry is perhaps even more relevant today, given that nearly all of the eastern old-growth forest present in his day has since disappeared. Even the eastern national parks and wilderness areas are largely made up of second-growth forest cut over in the early 20th century. One motivation, in fact, for understanding how contemporary second-growth forest differs from the presettlement forest is that such knowledge could be useful in restoring some stands to a more "natural" state. The Ottawa National Forest in Michigan, for example, is interested in modifying traditional uneven-aged methods in managed second-growth stands to increase the amount of forest with old-growth characteristics. One long-term goal of the Apostle Islands National Lakeshore in Wisconsin is to restore disturbed ecosystems to a condition that would prevail today had humans not intervened in the past 100 years. The desire to restore old-growth characteristics in areas where they are rare or lacking makes the major issues concerning old-growth in the East somewhat different from those in the West, where the controversy centers to a greater extent on how much of the existing old-growth should be preserved.

Restoration efforts should avoid a single scheme that would guide all stands toward an equilibrium size structure.

The goal of restoring plant communities on some public lands to a more natural condition is worthy but presents a considerable challenge. A scientifically defensible approach to restoration requires not only that we know how the existing and "original" forests differ, but also that we understand the mosaic of stands on the landscape from a dynamic rather than a static perspective. Old-growth stands are periodically destroyed by natural disturbance (*fig. 1*); and if disturbance is frequent enough, old-growth may occupy only a small fraction of the landscape (Heinselman 1973). Periodic climatic change affects both species distributions and disturbance frequency (Sprugel 1991). Would a "natural landscape" at a particular time and place consist of a coarse mosaic of patches in various stages of succession, or would it be a more homogeneous, uneven-aged forest of shade-tolerant species? Would old-growth be rare or abundant? Do we really have any evidence that stand ages and the proportion of early successional forest types are substantially different now than in presettlement times? Public land managers wishing to restore natural conditions at either the stand or landscape level need some kind of blueprint, even if only a rough guide is possible.

Reconstructing the principal features of a natural age-class mosaic will be difficult in many parts of the East because detailed historical records are often lacking; few forest stands have escaped logging; and humans have probably altered the disturbance frequency, even in the existing old-growth remnants. A general description of stand dynamics and disturbance regimes is probably most feasible for the northern hardwood region and for similar mesophytic forests in the southern Appalachian region. The original township surveys of the 18th and 19th centuries provide valuable historical data for much of this region, and little or no timber cutting has been done on some large tracts of several thousand acres or more. Examples include parts of the Porcupine Mountains Wilderness State Park in Michigan, the Five Ponds Wilderness Area in New York, and the Great Smoky Mountains National Park and Kilmer-Slickrock Wilderness in North Carolina and Tennessee. Fortunately, the northern hardwood–mixed mesophytic region is also fairly extensive and contains many of the public forestlands in the East.

This paper summarizes what is known about natural disturbance, stand structure, and landscape age-class mosaics in northern hardwood and hemlock-hardwood forests as a basis for guiding possible restoration efforts. The geographic boundaries of the region under discussion, which correspond approximately to the natural range of eastern hemlock *(Tsuga canadensis)*, extend from northern Wisconsin to northern Maine, south to Pennsylvania and New York, and continue in a narrow belt along the Appalachian Mountains (Types 106, 108, and 103 of Küchler 1964, within regions 9 and 4a of Braun 1950). This discussion will largely focus on upland sites with loamy soils, on which successional trends are toward forests dominated by sugar maple *(Acer saccharum)*, beech *(Fagus grandifolia)*, hemlock, yellow birch *(Betula alleghaniensis)*, and basswood *(Tilia* spp.).

Early Perceptions

Northern hardwoods were traditionally viewed as an archetypal climax forest. Most of the dominant species (sugar maple, beech, and eastern hemlock) are shade-tolerant. There are no silvical reasons for supposing that these species require severe disturbance for their perpetuation. Intense fires are relatively uncommon in northern hardwoods, even during severe droughts (Hawley and Hawes 1912, Fahey and Reiners 1981). Nevertheless, hemlock and northern hardwoods are adaptable to many types of disturbance, and the majority of existing second-growth stands are actually even-aged, having developed after heavy logging in the early 20th century. Fires at times even enhance hemlock regeneration, and some old hemlock stands are clearly of fire origin (Hough and Forbes 1943). So the mere existence of northern hardwoods on a site cannot rule out severe disturbance as a factor in stand establishment. The wide range of tree sizes in hardwood stands can give a misleading impression of stand history too; many of the small, suppressed trees may be the same age as the large canopy trees (Oliver 1980).

Gates and Nichols (1930) were aware of these pitfalls during their small but pioneering study on the age structure of a recently cutover primary hemlock-hardwood stand in Michigan. Yet they concluded that "the forest comprises a goodly representation of trees of all ages" (p 398). Oosting and Bourdeau (1955) likewise found a broad range of ages in a southern Appalachian hemlock–mixed mesophytic stand, concluding that the forest was "unquestionably climax."

Observers in other areas came up with a much different interpretation of the northern hardwood forest. Maissurow (1941) stated that nearly all the northern hardwood forests in Wisconsin had burned over a 500-year period, and hemlock-hardwood mixtures are essentially even-aged "without a single exception " Graham (1941, p. 361–62), writing of the northern hardwood region of upper Michigan, called the climax forest "a phantom, always moving ahead in the future and becoming visible for only relatively brief periods on small areas," a conclusion echoed by Cline and Spurr (1942) in southern New Hampshire.

Occasional severe disturbance of the northern hardwood forest was probably never a serious point of dispute. Probably the main outcome of early discussions was recognition that massive disturbance is a more common force in shaping the regional landscape than formerly realized Indisputable evidence was provided when ecologists rediscovered the records of large blowdowns recorded by 19th-century land surveyors (Stearns 1949) and by contemporary events such as the remarkably destructive 1938 hurricane in New England (Foster 1988). However, early studies did not resolve the key issue of the frequency of such disturbances at a given point and their overall effect on the landscape age-class mosaic. Available evidence was of limited value for resolving whether heavy disturbance was common or rare—partly because most study sites were too few and too small to generalize to the regional landscape level, and partly because age structure evidence alone is not a good indicator of disturbance history.

More precise analytical procedures were needed, and these procedures needed to be applied systematically on a large scale. In recent years, a number of investigators using several independent lines of evidence have provided a more comprehensive overview of natural disturbance regimes across the northern hardwood region.

Evidence from Recent Studies

Land survey records. While not collected as scientific data, the original township surveys of the 18th and 19th centuries preserve a considerable amount of information about forest conditions before the logging era, systematically recorded over millions of acres in parts of the Northeast and Midwest. In most of the surveys, surveyors recorded the principal species of trees along each mile of township line in order of their abundance and noted the extent of windfalls, stands killed by fire, and other unusual features. Surveyors also marked and recorded one or more bearing or witness trees at each section corner.

Several important conclusions about the presettlement forest have been drawn from these early records. Where loamy soils predominate (such as northern New England, northern Pennsylvania, and Michigan's Upper Peninsula), forests of the 18th and 19th centuries were heavily dominated over extensive areas by shade-tolerant and midtolerant species such as hemlock, beech, yellow birch, and sugar maple. Early successional species (pine, aspen, paper birch) as a group typically made up less than 10% of the bearing trees, and these species were not frequently cited in surveyors' descriptive lists (Siccama 1971, Mladenoff and Howell 1980, Whitney 1990). On the other hand, pioneer species were often locally dominant on dry habitats such as sandy outwash plains. Species of pines, for example, made up more than 55% of bearing trees in parts of northern lower Michigan (Whitney 1986).

The land surveys contained many references to severe natural disturbances. In northern Wisconsin, for example, surveyors recorded 413 separate blowdowns, with an average size of 230 acres *(fig. 2)*. The largest blowdown covered approximately 9,300 acres (Canham and Loucks 1984). Burned lands were seldom recorded for upland sites with loamy soils, through fire sometimes followed blowdowns. Fire was more common on drier habitats. In a sandy pine-dominated area of lower Michigan, surveyor D.A. Pettibone wrote that "most of the township is . . . barrenly being burnt over so often" (Whitney 1986, p. 1556). In the region of Mount Katahdin in Maine, with relatively coarse granitic soil and a sizable mixture of spruce and fir, surveyors recorded three separate areas of burned land and birch-aspen forest with a combined area of more than 300,000 acres (Lorimer 1977).

Nevertheless, based on the rather low proportion of land area in windfalls and old burns at the time of the surveys, the intervals between severe disturbances on a given site must have been very long on many upland habitats with loamy soils. Estimates of the number of years required for severe winds to cause turnover of all stands on a large district of "hardwood lands" in the northern parts of Maine, New York, Pennsylvania, Michigan, and Wisconsin (that is, the disturbance cycle or inverse of average annual disturbance rate) were more than 1,000 years for all five locations (Lorimer 1977, Canham and Loucks 1984, Whitney 1986, Whitney 1990, Seischab and Orwig 1991). Estimates of the average cycle for intense, stand-replacement fires in late presettlement times were also long, ranging from 800 to 1,400 years. Although land survey records offer no direct evidence on stand age, these figures suggest that most northern hardwood stands were probably old-growth and many would have been uneven-aged.

Ancient charcoal deposits. The presence

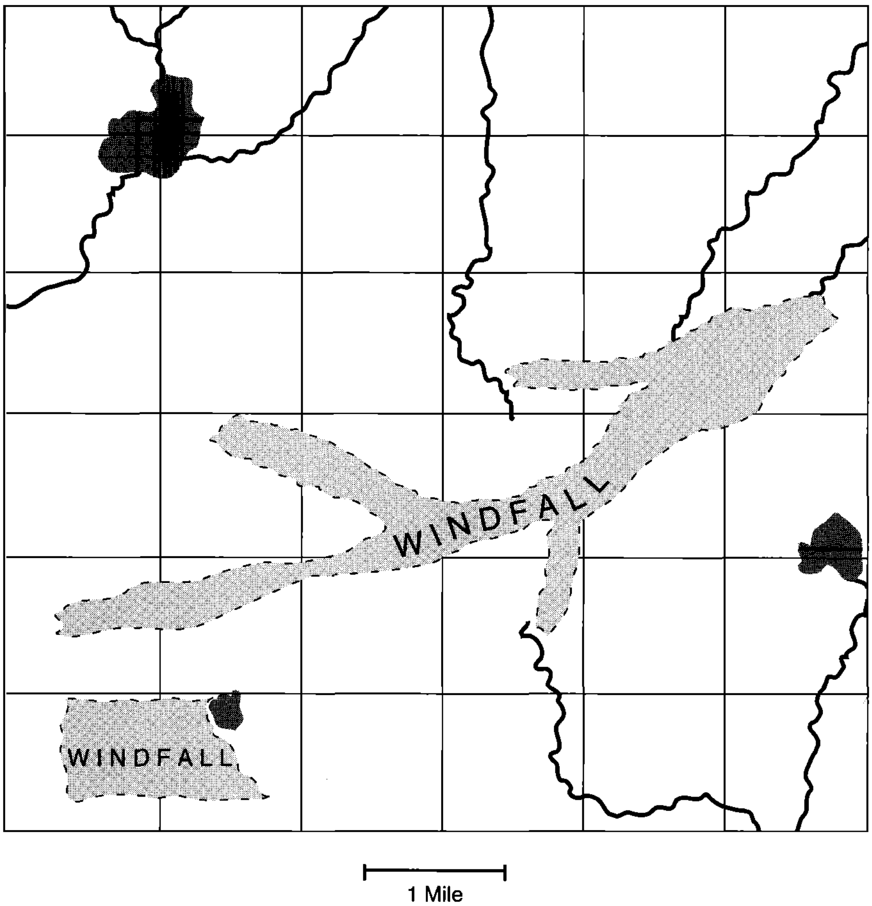

Figure 2. Land surveyors in the mid-19th century recorded 413 blowdowns in northern Wisconsin. The smaller shaded windfall area in the southwestern part of this township, at 410 acres, is about twice the average size. About 3% of the windfalls were as large or larger than the 1,500-acre shaded windfall swath shown in the center (adapted from Stearns 1949).

of charcoal in sediments of lakes, bogs, and small forest hollows provides important independent evidence on fire frequency in presettlement times. While sediments probably do not contain a complete record of surface fires, a major advantage is that a record of the more severe fires is possible over several thousand years. In areas such as northeastern Minnesota, where natural fire frequencies are known to be high, sediment cores have a consistently high ratio of charcoal fragments to pollen (Patterson and Backman 1988). Studies in the northern hardwood region suggest a much lower fire frequency in recent millenia. Major events are usually recorded at intervals of more than 1,000 years (Anderson et al. 1986, Patterson and Backman 1988, Davis et al. 1992), though Schoonmaker (1992) has estimated average intervals of 600 years in southern New Hampshire. A dramatic increase in charcoal concentration is often apparent at the time of European settlement.

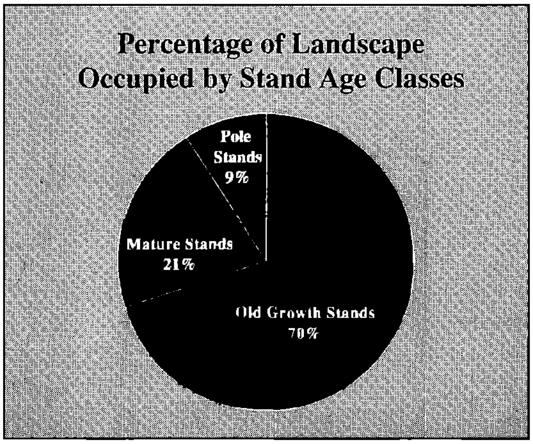

Figure 3. The proportion of stand age classes on 56,000 acres of remnant "pristine" landscapes in upper Michigan. Old-growth is defined by structural criteria (Frelich and Lorimer 1991a), but the canopies of old-growth stands are typically dominated by trees 130–300 years old.

Evidence from "pristine" landscapes. Three studies of relatively pristine northern hardwood landscapes have provided a rare opportunity to examine direct evidence of disturbance history in old-growth stands (tree-ring chronologies and fire scars) as well as local site variations. The study areas include several tracts totalling 56,000 acres in western upper Michigan (Frelich and Lorimer 1991a); a 6,000-acre watershed in the Allegheny Plateau of Pennsylvania (Hough and Forbes 1943); and 5,000 acres now included in the Pisgah Forest State Park of southern New Hampshire (Foster 1988). The Pennsylvania and New Hampshire data were originally gathered just after these stands were partly logged in the 1920s and 1930s, while the Michigan data were taken from increment cores in existing old-growth.

All three areas featured high dominance by old-growth stands. In Michigan, where stands were selected randomly regardless of current age, 70% were classified as old-growth (*fig. 3*). Most of the Pennsylvania and New Hampshire stands were dominated by trees more than 200 years old.

Species composition and disturbance history showed stronger differences among study areas. Field evidence from the Michigan and Pennsylvania sites seemed consistent with land survey evidence from the same areas. For example, shade-tolerant species strongly dominated, with long rotation periods for catastrophic disturbance ranging from 1,000 to 1,900 years. The field studies supported the indirect implication of land survey records that most stands would be uneven-aged; the hemlock-hardwood stands in Michigan averaged more than 10 age classes on each acre. As expected, a legacy of heavy past disturbance was also evident in some stands. About 30% of the Pennsylvania stands originated after catastrophic disturbance in the past 300 years, compared to 15% in Michigan.

A much different disturbance regime was evident at the New Hampshire site. White pine *(Pinus strobus)* and paper birch *(Betula papyrifera)* were major components of many stands, especially on upper slopes and ridges, and the majority were clearly even-aged. Many of the pine, birch, and hemlock stands originated after a major fire in 1665. Hurricanes were also a frequent cause of moderate to heavy disturbance and may have provided fuel for some of the fires.

Frequency of fire and wind damage may often be affected by soil and topography, although evidence is currently limited. In the Allegheny Plateau study, all the stands that clearly originated after fire were located on upper south-facing slopes. On the upper Michigan sites, fire frequency was not clearly related to soil or topography except that fire was much more common in the Huron Mountains, an area of sandier soil with numerous bedrock outcrops.

In southern New Hampshire, the extent of hurricane damage was related to the degree of slope exposure. In upper Michigan, where blowdown was caused mostly by thunderstorm downbursts and tornados, wind damage was unrelated to slope position or aspect.

Fine-scale disturbance and stand structure. Although catastrophic disturbances are generally infrequent in much of the northern hardwood region, lesser disturbances play an important role in shaping stand structure. Small gaps created by the fall of one to several large trees occur frequently in mesophytic hardwoods, covering an average of 0.4%–2.0% of the land area annually (Runkle 1985). Gap formation can therefore cause nearly complete turnover in the canopy in less than 250 years. Because frequent gap formation removes many of the large or senescent trees, old-growth hardwood stands do not have a uniform, unbroken canopy of large trees. Rather, these stands typically have an irregular, uneven-aged canopy with trees in various stages of development. In old-growth northern hardwoods in upper Michigan, large trees (greater than 18 inches dbh) generally occupy about half the canopy and mature trees (10"–18" dbh) about one-third, with the remainder occupied by gap saplings and poles (Frelich and Lorimer 1991b). Average gap sizes range from 0.01 to 0.09 acre, with the larger gap in southern mixed mesophytic forests (Romme and Martin 1982, Runkle 1985, Tyrrell 1991).

Small gap disturbances in many areas are supplemented by occasional disturbances that remove a larger proportion of the stand. In upper Michigan, disturbances removing 30%–50% of the canopy occur about every 300 years in a given stand (Frelich and Lorimer 1991a) Because of periodic disturbances of variable intensity, most northern hardwood and mixed mesophytic stands have highly irregular age distributions (Hough and Forbes 1943, Lorimer 1980, Frelich and Lorimer 1991a). In the upper Michigan study areas, only about 20% of the stands have diameter distributions approaching a "reverse-J" curve; the rest have unimodal, bimodal, or highly irregular size distributions. Thus restoration efforts should avoid a single scheme that would guide all stands toward an equilibrium size structure. The episodic nature of gap formation also sometimes involves long quiescent periods. In 47% of the Michigan old-growth stands, recent canopy gaps (those with gap trees less than 4" dbh) occupy less than 2% of the stand area. Consequently the presence of numerous recent gaps is not a feature in all or most old-growth stands *(fig. 4)*.

Old-Growth Preservation and Restoration

The occasional catastrophic disturbance in the northern hardwood region can be quite dramatic and prompts reasonable questions about whether preservation of old-growth is a mere delusion. When an intense thunderstorm in 1977 flattened 25 separate tracts in northern Wisconsin, including the state's last extensive old-growth northern hardwood stand *(fig. 1)*, the incident was often discussed locally as an example of the futility of attempting to preserve old-growth forest in the face of recurrent catastrophic disturbance. Yet the evidence reviewed earlier indicates that catastrophic disturbances in northern hardwoods were rare events over much of the region in late presettlement and historic times, and affected only a small fraction of the landscape at a given time. Although an age-class mosaic is discernible in remnant pristine landscapes, structure and age differences among adjacent patches are usually so subtle that these landscapes often appear to contain a fairly uniform matrix of mature and large trees, punctuated with occasional scars from more recent heavy disturbances.

From a management perspective, the low frequency of stand-replacement fire and massive blowdown makes preservation of the northern hardwood forest less problematic than areas with extensive tracts of fire-dependent pine or aspen forest. In these areas, difficult management options such as "limited crown fires" have been seriously discussed as a means of perpetuating the natural species composition and age-class mosaic (Heinselman 1983).

Of course, fire is not unimportant in hemlock-hardwood forests, and it may at some point be restored as a natural force. Even areas with an average 1,400 years between stand-replacement fires are expected to have more than 20% of the landscape covered with fire-origin stands. Reduced fire frequency is probably a major factor in the replacement of white pine by other species in New Hampshire's Pisgah tract (Foster 1988) and elsewhere. Surface fires, as indicated by fire scars, also may have helped favor the germination of hemlock and yellow birch (Maissurow 1941).

Those who wish to restore areas in the northern hardwood region to presettlement conditions do face a difficult management problem, however: the great change in landscape age-class mosaic. The northern hardwood region is heavily dominated today by much younger even-aged stands, mostly in the 60- to 90-year age classes. These second-growth hardwoods differ from old-growth in a number of ways, just as Thoreau suspected. Many characteristics of old-growth forests—large trees and snags, canopy gaps and gap saplings of various sizes and ages, multiple foliage layers, large fallen logs, and "tip-up" mounds—are uncommon or lacking in second-growth stands. A 70-year-old pole hardwood stand on an average site in Michigan will require another 100 years or so of natural development to attain a mean overstory diameter of 20 inches, which is typical of the majority of old-growth stands (Frelich and Lorimer 1991b). Transition from an even-aged to an uneven-aged structure will probably take an additional 50–100 years. These estimates might be lengthened considerably if the stand is not already dominated by shade-tolerant species and if a seed source for such species is not located within a few hundred feet.

Bolgiano (1989), Hunter (1989), and Runkle (1991) discuss whether development of old-growth characteristics in second-growth stands could be hastened by manipulative treatments. Though little scientific evidence is currently available, interesting parallel approaches can be found on managed national forest sites designated for timber production and other values.

Single-tree selection is often applied in

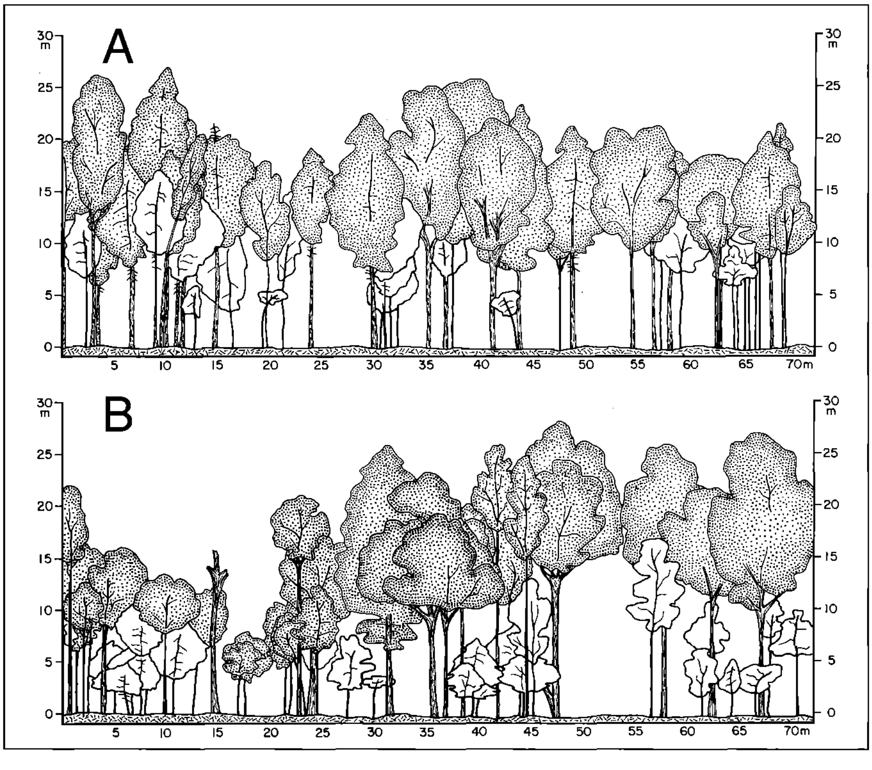

Figure 4. Although most old-growth northern hardwood stands are broadly uneven-aged and have a substantial component of small and medium-sized trees, incidence of recent canopy gaps is highly variable. In about half the stands studied in upper Michigan, recent gaps occupy less than 2% of the stand area (A); they are more frequent in balanced, all-aged stands (B) (Lorimer 1985).

second-growth northern hardwoods, although the even-aged character of the stands necessitates some modifications in technique. Erdmann's (1986) prescription for even-aged second-growth, while not originally designed for old-growth restoration, goes beyond single-tree marking and includes creation of scattered canopy gaps 25–40 feet across to encourage younger age classes and to promote a "reverse-J" diameter distribution. The Ottawa National Forest in Michigan has modified Erdmann's prescription to include retention of snags, fallen logs, and many of the larger trees for wildlife reasons and to encourage the development of more stands with old-growth characteristics (Rominske and Busch 1991).

Could analogous treatments (such as crown release around selected trees and artificial gap formation) significantly shorten the time required for second-growth stands to develop the large trees and structural features typical of old-growth, uneven-aged stands? The answer is uncertain but worth investigating. Economics, environmental effects, and public response to restoration treatments also need to be considered.

Formal experiments replicated in several habitat types may be the only way to secure definitive answers. While such experiments are probably not needed to justify silvicultural treatments applied as part of routine forest management, experimental evidence would be one important factor in considering whether restoration treatments might be appropriate in some of the second-growth stands designated as future old-growth preserves. JOF

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