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Forest Ecology and Management 155 (2002) 357–367

Forest Ecology and Management

www.elsevier.com/locate/foreco

Natural disturbance regimes in northeastern North America—evaluating silvicultural systems using natural scales and frequencies

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Abstract

Many scientists and foresters have begun to embrace an ecological, natural disturbance paradigm for management, but lack specific guidance on how to design systems in ways that are in harmony with natural patterns. To provide such guidance, we conducted a comprehensive literature survey of northeastern disturbances, emphasizing papers that studied late-successional, undisturbed, or presettlement forests. Evidence demonstrates convincingly that such forests were dominated by relatively frequent, partial disturbances that produced a finely patterned, diverse mosaic dominated by late-successional species and structures. In contrast, large-scale, catastrophic stand-replacing disturbances were rare, returning at intervals of at least one order of magnitude longer than gap-producing events. Graphing the contiguous areas disturbed against their corresponding return intervals shows that these important disturbance parameters are positively related; area disturbed increases exponentially as the return interval lengthens. This graph provides a convenient metric, termed the natural disturbance comparability index, against which to evaluate both single and multi-cohort silvicultural systems based on their rotations or cutting-cycles and stand or gap sizes. We review implications of these findings for silvicultural practice in the region, and offer recommendations for emulating natural disturbance regimes.

Keywords: Biodiversity; Northern hardwoods; Spruce; Hemlock; Acadian forest; Gap dynamics; Fire; Wind; Benchmarking

1. Introduction

During the past decade, many scientists and foresters in North America have begun to embrace an ecological, natural disturbance paradigm for management (Seymour and Hunter, 1999). The degree to which on-the-ground management actually conforms to natural patterns varies widely, however, due in part to a lack of specific, quantitative guidelines for emulating natural patterns and processes. Indeed, one can encounter forest managers purporting to embrace a natural disturbance model, with statements such as ‘‘All forests are wiped out periodically; our clearcuts are no different’’. As we illustrate below, this superficial statement ignores the growing body of evidence about what the natural disturbance regimes were really like in presettlement forests before people dramatically altered them. Here, we adopt Hunter’s (1996) definition of ‘‘natural’’ as meaning ‘‘without human influence’’, and accept that the condition of the forest before European colonization is the best modern surrogate for this condition.

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PII: S0378-1127(01)00572-2

Practicing foresters lack ready access to the contemporary disturbance literature, and hence have little specific guidance on how to design and manipulate disturbance parameters in ways that emulate natural patterns. To provide such guidelines, we conducted a comprehensive literature survey of all northeastern disturbances, emphasizing papers that studied late-successional, undisturbed, or presettlement forests. We focused on the northern hardwood and mixed-conifer forest types common in Acadian region of northern New England and New York, the upper Midwest, and the Maritime Provinces of Canada. We summarize results graphically in a manner that allows forest managers to evaluate how closely any silvicultural system approximates natural conditions. We conclude by suggesting some implications of these findings relative to silvicultural practice in the northeast.

We are not necessarily advocating that all forest lands be managed under the ecological principles discussed herein; this is obviously a larger societal decision that balances biodiversity with economics. Our purpose is to advance the practice of ecological forestry beyond the application of simple principles, to a more rigorous approach that is benchmarked against what we know about the dynamics of natural forests.

2. Methods used to study disturbances

2.1. Sources of information

Sources of information about disturbance regimes are varied but few have used the combination of historical, paleoecological, dendrochronological, and other approaches recommended by Foster et al. (1996). Old-growth stands are a common source of disturbance regime information. Often current disturbances, especially canopy gaps, are measured and converted to frequencies and size ranges (Runkle, 1985). Alternatively, dendrochronology is used to determine age structures and growth patterns, both of which can be used to make inferences about past disturbances (Lorimer, 1985). The major drawback of using old-growth stands is that they are rare and not necessarily representative of the landscape. They can give a biased view of the landscape because stands severely disturbed by natural disturbance in the past historically have not been set aside. Nonetheless, old-growth stands are directly observable and contain a wealth of information.

Land survey records are another common source of information (Bourdo, 1956). They essentially provide a coarse-scale, low-resolution sample of forests as they existed just prior to extensive settlement. Deriving quantitative information about disturbance frequency requires treating the survey lines as transects and converting length of line disturbed by a particular agent (e.g. fire) into a rate, making assumptions about the length of time such evidence remains discernible (Lorimer, 1977). Most surveyors recorded only major disturbances, such as fires and windthrows, thus limiting the types of disturbances about which inferences can be drawn from the survey notes.

Palynology is another source of information about disturbances. The occurrence of charcoal and sharp changes in pollen composition signify disturbances. However, disturbances like windthrow can leave little palynological evidence (David Foster, personal communication). Although palynology offers the longest time perspective of any of the techniques, high temporal resolution is costly to obtain. Most studies use cores extracted from lakes, ponds, or wetlands that sample pollen that was deposited from a fairly large area. These records are best for landscape-scale interpretations. In contrast, the less common approach of extracting cores from small forest hollows or vernal pools can give stand-level information (e.g. Schauffler, 1998; Foster et al., 1992).

2.2. Literature search

We searched the literature for studies of disturbance regimes in the northeastern quarter of North America. The region, which we will call the northeast, extends from Nova Scotia through New Brunswick, southern Quebec and southeastern Ontario, and from northern New England westward through New York, northeastern Pennsylvania, and the upper Lake States. The forest types emphasized lie within the temperate forest zone or transitional to the boreal zone, and include northern hardwoods and mixed-species forests in the Acadian region (Seymour, 1995). Studies from the boreal zone, and fire-dependent communities such as *Populus* spp. and various *Pinus* spp. common in the Lake States, were excluded. Of the many parameters that can be used to describe disturbance regimes, size

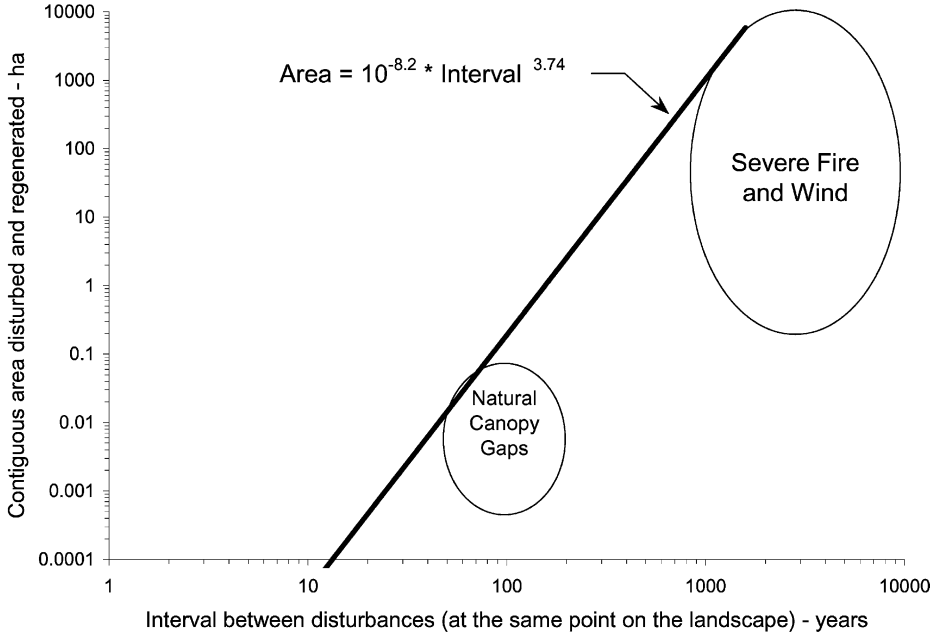

Fig. 1. Boundaries of natural variation in studies of disturbance in northeastern North American forests. The hand-fitted diagonal boundary line defines the upper limits on these disturbance parameters in combination, all of which fall in the lower right of the diagram. Upper limits of the area and return interval of severe fires and windstorms were truncated at 10^4 ha and 10^4 years, respectively.

and frequency are most directly analogous to choices made in formulating silvicultural systems (Seymour and Hunter, 1999); consequently, they are the focus of this paper. The cause or disturbance agent was also considered.

We tried to include only studies of natural disturbances, i.e. those minimally influenced by people, but some human influence was unavoidable (Cronon, 1983; Whitney, 1994). For example, although Lorimer (1977) was studying disturbances noted in early land survey records (ca. late 1700s and early 1800s) from northern Maine, he recognized that some of the recorded fires were associated with land clearing by settlers. Even old-growth forests may not be free of human influence. For example, Chokkalingam (1998) found that gap dynamics in old-growth Maine hardwood and mixed wood stands were partially related to beech bark disease, a disease complex introduced to North America from Europe around 1900 (Houston, 1975).

By including studies from a variety of locations and that used various research techniques, we have bracketed the range of frequencies and sizes associated with several disturbance types. We examined patterns in size and frequency by graphing the contiguous area disturbed over its corresponding return interval, following the model of Alverson et al. (1994). To examine natural limits of these parameters, we plotted ellipses that encompass both means and ranges from individual studies. In general, all data were included, except anomalous events thought to have human causes such as the very large (80,000 ha) fire reported by Lorimer (1977). For simplicity in illustration, we truncated the upper limits of area disturbed and return interval for stand-replacing disturbances at 10^4 ha and 10^4 years, respectively, slightly less than the reported maxima (Fig. 1).

3. Results and discussion

3.1. Patterns in frequencies and sizes of disturbances

Small canopy gaps are a common form of disturbance in several forest types, ranging from subalpine

Table 1
Summary of natural disturbance regimes in northeastern North America[a]

Type of disturbance	Disturbance agents	Range in patch size		Return interval (years)	Number of References
		Individual patches	Study means		
Natural canopy gaps	Senescence; wind; pathogens; insect herbivory	4–1135 m^2	24–126 m^2	50–200	12
Stand-replacing	Wind	0.2–3785 ha	14–93 ha	855–14300	4
Stand-replacing	Fire	2 to >80000 ha	2–200 ha	806–9000	8

[a] Includes forests in the Acadian region and Lake States dominated by northern hardwoods, red spruce, or eastern hemlock. Excludes boreal forests, forests dominated by balsam fir, and forests dominated by aspen, jack pine, white pine, or red pine in the upper Great Lakes region.

spruce-fir (Worrall and Harrington, 1988; Perkins et al., 1992; Battles and Fahey, 1996) to hardwood and hemlock-hardwood (Payette et al., 1990; Runkle, 1982, 1990; Cho and Boerner, 1991; Krasny and Whitmore, 1992; Tyrrell and Crow, 1994; Chokkalingam, 1998). Mean gap size is small, ranging from 24 to 126 m^2 (Table 1), with an overall mean of 53 m^2. Even the range of individual gap sizes peaks at a small size, 1135 m^2 (Battles and Fahey, 1996). The return interval of these gap disturbances is usually in the 50–200 year range (Table 1) in accordance with the estimate by Runkle (1982).

At the other end of the spectrum are catastrophic fires and windstorms (Table 1). Although often considered stand-replacing disturbances, they can create patches 2 ha or less (Seischab and Orwig, 1991; Whitney, 1986; Canham and Loucks, 1984; Marks et al., 1992; MacLean and Wein, 1977) or as large as 80,000 ha (Lorimer, 1977). The larger recorded sizes might not have included total destruction of the canopy throughout the burn, however. Many of the fires recorded in the land survey notes may have been influenced by early settlers (Lorimer, 1977), whereas fires recorded in the era prior to effective suppression (MacLean and Wein, 1977; Wein and Moore, 1977, 1979; Fahey and Reiners, 1981; Abrams and Nowacki, 1992) typically occurred in landscapes already significantly altered by human settlement. In contrast, sizes of patches derived from land survey records of catastrophic windstorms (Seischab and Orwig, 1991; Whitney, 1986; Canham and Loucks, 1984; Marks et al., 1992) probably were not significantly influenced by people.

3.2. Temporal and spatial boundaries of northeastern disturbances

When disturbed areas are plotted over their corresponding return intervals on a log–log scale, we found that all studies could be accurately depicted by ellipses that encompass their ranges in both space and time (Fig. 1). Data fell into two distinct clusters, corresponding to gap-phase and stand-replacing agents. Clearly, return intervals and areas disturbed are not independent, as is sometimes assumed. Gaps were small and frequent, as expected, whereas catastrophic fires and blowdowns were rare and highly variable in size. This pattern is distinctly different from the disturbance regime of the nearby boreal region where forests cycle more frequently at largescales (Cogbill, 1985).

All data appear to be bounded by a line tangent to the two ellipses (Fig. 1); the equation hand-fitted to this line indicates that the area disturbed increases exponentially as return intervals lengthen. Natural disturbances in the northeastern forest types included here fall below and to the right of the line. Combinations of space and time above and to the left of the line resulting from natural events evidently are undocumented, and thus, we conclude, outside the boundary of natural variation in this region.

Notably absent are moderate disturbance events with several-century return intervals at a medium (1–100 ha) scale. This could be an artifact of the methodology used in the studies cited herein, or a real void. The argument for a methodological explanation centers on two points. First, land surveyors may have recorded only larger, more dramatic disturbances; unfortunately, the minimum size recorded is unknown and may have varied by survey. Second, gap dynamics studies usually focus on small gaps (<1.0 ha) and, because of the techniques used, may involve small plots. Furthermore, areas that have had moderate to large disturbances may be avoided for gap dynamics studies.

The argument in support of the hypothesis that moderate disturbances were truly absent from the presettlement forest depends on assumptions about disturbance agents and how they operate in these types of forests. All known biotic disturbance agents have fairly narrow host ranges, and are typically species-specific, often attacking only old individuals in the population. Given the high levels of species and age diversity in the presettlement forest, it is easy to see how such agents would almost always produce gap dynamics at small scales. The only other possible sources of mid-size disturbances are abiotic agents (fire, wind). Interestingly, such disturbances are common in the boreal forest of eastern Canada (just to the north of the region discussed in this paper) where fire and spruce budworm (*Choristoneura fumiferana* Clem.) outbreaks cause stand-replacement over large areas every 100–250 years (Cogbill, 1985). Species which dominate this boreal region (e.g. *Betula papyrifera* Marsh., *Populus tremuloides* Michx., *Pinus banksiana* Lamb., *Picea mariana* (Mill.) B.S.P., *P. glauca* (Moench) Voss, and *Abies balsamea* (L.) Mill.) are also present and locally abundant in the northeast. But these boreal species rarely form extensive monocultures in the northeast, except after rare large-scale, stand-replacing disturbances to which they are well adapted. Where these species dominate stand composition in the northeast (e.g. extensive *Abies balsamea* "flats" in northern Maine; *Pinus banksiana* sand plains in New Brunswick), the resulting disturbance dynamics are more akin to their northerly counterparts than to the generally stable matrix of northern hardwoods (dominated by *Acer* spp., *Fagus grandifolia* Ehrh., and *Betula alleghaniensis* Britton) and long-lived conifers (*Picea rubens* Sarg., *Thuja occidentalis* L., and *Tsuga canadensis* (L.) Carr.) that typifies the Acadian region.

For the sake of simplicity in application, we treat the apparent void as a methodological artifact, thus assuming that disturbances of intermediate size and frequency are part of the natural disturbance regime but have simply gone unrecorded or have not been studied. This assumption is consistent with our hypothesis that a line tangential to the two ellipses establishes the boundary of natural variation in disturbance regimes in this region (Fig. 1).

3.3. Silvicultural implications

Silviculturists in the northeast seeking to emulate natural disturbance regimes have historically relied on general ecological principles and intuition, without really knowing how closely their management resembled natural processes. The existence of the boundary condition in Fig. 1 suggests a more rigorous approach to the process of formulating ecologically based silvicultural systems. Here, we can use the fact that return intervals and contiguous areas disturbed (i.e. the axes in Fig. 1) both have direct silvicultural analogues (Seymour and Hunter, 1999). In ecosystems where stand-replacing events dominate, the range of return intervals is directly comparable to the rotations of single-cohort stands, and their spatial extent would essentially define stand sizes. Where partial disturbances are the rule, return intervals are related to cutting-cycles for managed multi-cohort stands, and gap sizes would be similar to the small, within-stand patches where regeneration is recruited under single-tree or group selection silviculture. Any silvicultural treatment or system can thus be displayed identically to the disturbance data as in Fig. 1, and compared to the boundary condition as a natural benchmark.

We can best illustrate this approach with a simple example. During the past two decades, some industrial landowners in northern New England and the Maritimes have begun to manage modest areas under production forestry, typically by growing plantations of various *Picea* spp. on rotations of ca. 50 years (Seymour, 1995). Due to "green-up" adjacency requirements and government regulations, clearcuts (and thus plantations) average about 20 ha. When plotted on the disturbance spectrum, we see immediately that such a plantation falls well outside the boundary of natural disturbances (Fig. 2). One way to quantify its departure from the natural forest is to calculate the lower limit on the natural return interval for the same-sized area on the landscape. Substituting 20 ha into the boundary equation and solving for the interval yields a value of 347 years. The ratio of the managed

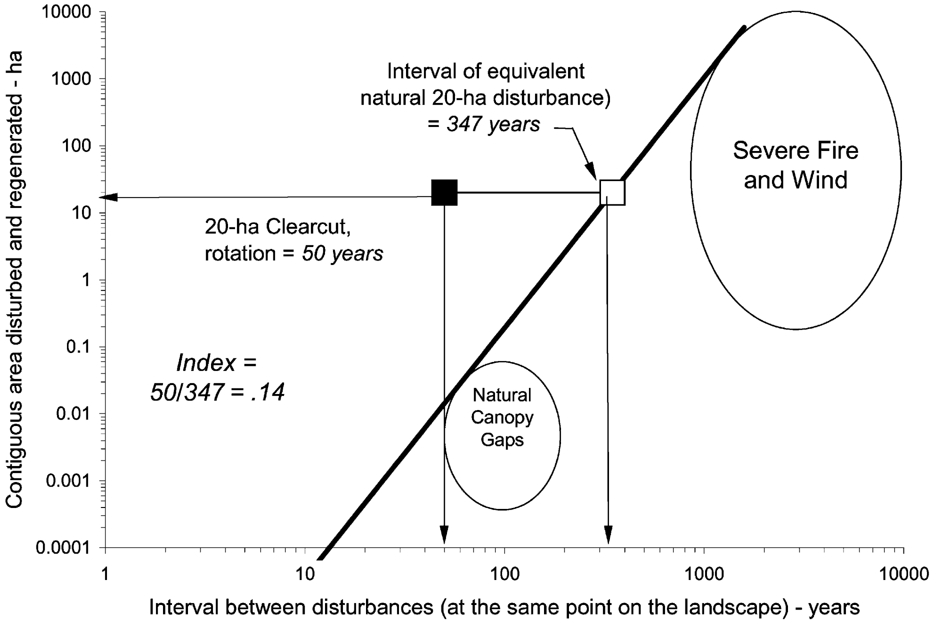

Fig. 2. Natural disturbance comparability index illustrated for a 20 ha forest plantation managed on a 50-year rotation. The index is defined as the actual rotation of the managed stand expressed as a proportion of the natural return interval of the same size patch.

rotation and its natural disturbance-frequency counterpart ($50/347 = 0.14$) can be thought of as a metric that quantifies how closely the system emulates a natural disturbance regime of comparable scale or time, where a value of 1.0 represents exact replication of the boundary condition. We term this the natural disturbance comparability index. In this example, an industrial landowner who plans to convert an entire landscape to production forestry would, in effect, be harvesting and regenerating a given place about seven times more frequently than would natural events.

This approach for benchmarking forest practices can readily be extended to other silvicultural systems; typical examples are shown in Fig. 3. Here, we have shortened the axes relative to the complete range of natural variation on the grounds that feasible silvicultural systems would fall well below the limits of 100 ha and 1000 years. Reference lines are also added corresponding to natural disturbance comparability indices of 0.05, 0.10, 0.25, and 0.50. To evaluate multi-aged (selection) systems that regenerate different patches within the stand at each harvest, we must first convert the cutting cycle (time between harvest entries) into an effective "rotation", or the time it would take to cycle through and regenerate the entire stand. Here, we must estimate the proportion of the total stand area that is regenerated at each entry, and divide this value into the cutting cycle (Nyland, 1996, p. 230). For example, a selection system that opened 10% of the stand for regeneration at each entry on a 15-year cutting cycle would effectively equate to a 150-year rotation for a given spot in this stand.

Typical multi-aged systems fall within natural limits. For example, a group selection system designed to perpetuate some species with low shade tolerance using openings ranging between 0.04 and 0.10 ha, repeated on effective rotations of 80–120 years, lies near the upper limit of natural processes. Single-tree selection systems with return intervals of 100–150 years with opening sizes of 0.001–0.01 ha, are comparable to natural tree-fall gaps.

Single-cohort systems based on natural regeneration without reserve trees (i.e. trees left for structural enhancement after the overwood removal) all tend to fall somewhat outside the natural boundary unless the rotation is very long. The natural return interval for a 2 ha patch, the minimum size area that would be

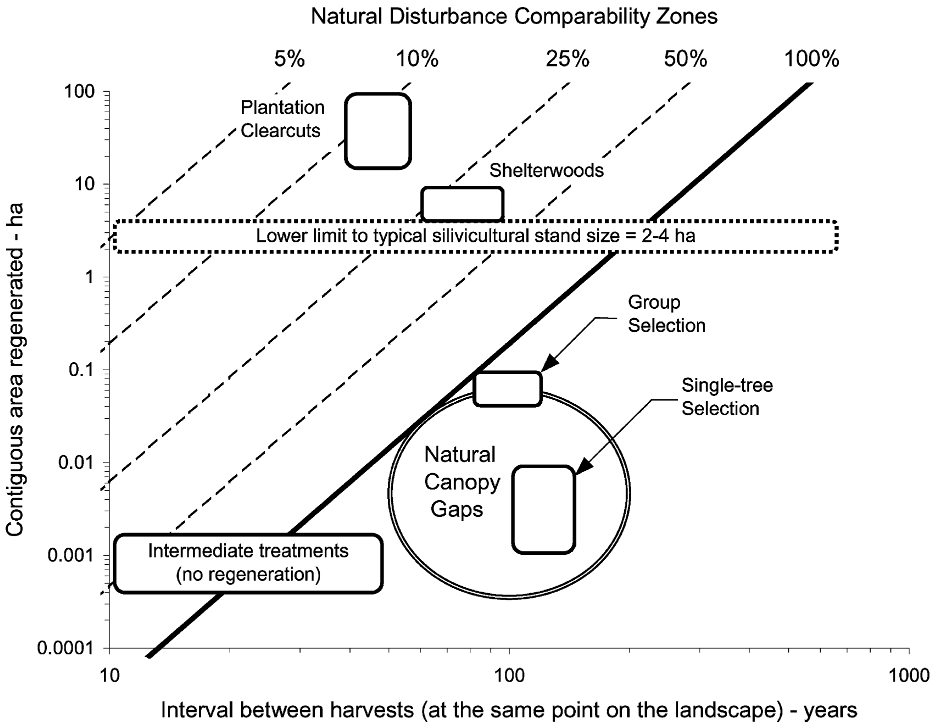

Fig. 3. Natural disturbance comparability zones (defined as in Fig. 2) displayed against typical northeastern silvicultural systems. Note that the upper limit of natural canopy gaps (ca. 0.1 ha) is at least one order of magnitude smaller than the smallest stand size (2 ha).

considered a stand in this region, is 188 years (from Fig. 1)—considerably longer than what most foresters would consider to be a long rotation in the region (Seymour, 1995). Natural disturbances recurring at a 100-year interval did not exceed 0.19 ha, at least one order of magnitude smaller than the minimum size stand. Thus, the common practice of making small patch clearcuttings of 1–3 ha has surprisingly little ecological justification when judged against this benchmark, unless some diversity in age or vertical structure is left within the patch.

The degree to which single-cohort systems can be mitigated or ‘‘softened’’ by varying degrees of structural retention at the final harvest (Franklin et al., 1997) is in the forefront of silvicultural research and debate in the northeast, as it is elsewhere (Carey et al., 1999). If the goal is to emulate most northeastern natural disturbance regimes faithfully, then the majority of the landscape must be under some type of continuous-canopy, multi-aged silviculture that maintains ecologically mature structures at a finely patterned scale. Two-cohort stand structures resulting from variable retention (Franklin et al., 1997) practices represent a fairly wide band on the continuum between simplified single-cohort and complex multi-cohort structures. Thus, ecological robustness of two-cohort systems appears to be directly related to the magnitude of retention of both living and dead trees as biological legacies. Leaving a few scattered reserve trees (under 2–3 m^2 of basal area per ha) could offer only limited benefits, whereas 10–15 m^2 per ha of reserves might be impossible to distinguish from a true multi-cohort structure.

Intermediate treatments such as thinnings, which by definition do not lead to regeneration, form small canopy openings that are quickly reoccupied by vigorous residual trees. Any gaps below ca. 0.002 ha (equal to the crown area of an average tree in a stand with a density of 500 trees per ha) usually do not result in the initiation of new cohorts and thus should not be evaluated using this framework. By ignoring such small gaps, we remain consistent with some studies cited above that attempted to eliminate such events from the disturbance chronology by adjusting the threshold growth responses accordingly (e.g. Frelich and Lorimer, 1991; Nowacki and Abrams, 1997).

What if our assumptions when drawing the line bounding the ellipses are wrong? Two types of possible errors illustrate the consequences. First, what if the ellipses themselves changed, perhaps due to new studies or application to a new region or different set of forest types? In these situations the solution is to construct a new boundary line and use it to calculate new comparability index values. This is a simple solution but obviously would affect the estimation of where a particular practice fell relative to natural conditions. Second, what if the void to the right of the boundary line is real, rather than an artifact of research bias as the tangential line assumes? In such a situation, the boundary line is no longer appropriate because some areas to the right of the line or on the line itself, such as the point used in the illustration of how to calculate the index, would not be within the range of natural conditions. In this case, the index could still be used, but the natural point of comparison in the graph would be the nearest point on the ellipse that corresponded to that size opening. Thus, both types of errors result in changes to absolute values, but the approach of comparing a particular practice to the natural disturbance regime remains valid.

3.4. Landscape considerations

Evidence reviewed above supports the conventional wisdom that disturbances were frequent throughout the presettlement landscape of the northeast. There is much less consensus, however, regarding the finding that the effects of common disturbances were quite dispersed, and occurred at scales at least one order of magnitude below that of the smallest stands that are presently delineated by foresters for silvicultural purposes. Extensive, single-cohort stands were uncommon in the presettlement forest of the northeast; for example, Lorimer (1977) estimated that stands less than 75 years old occupied 16% of the landscape in northern Maine ca. 1820. Widespread application of single-cohort silviculture on rotations of under 100 years thus creates a landscape that has no natural pre-cedent for the types of forests we reviewed. Management that deliberately produces such stands thus cannot claim to be emulating natural disturbances, as in the common industrial situation where multiple, short rotations are planned, or where such stands dominate the landscape.

Furthermore, basing regeneration rates on natural disturbance frequencies alone (e.g. 1% per year), without accounting for the scale of the disturbance, greatly oversimplifies the natural pattern where landscape-level, stand-replacing disturbances are much rarer than small, within-stand patches. If we ignore this relationship between space and time, then management activities might have negative consequences on landscape structure. Consider the example of a landowner who limits stand sizes between 4 and 20 ha and manages everything in single-cohort stands on 100-year rotations. Although this system seems benign relative to the more aggressive industrial plantation example in Fig. 2, it would effectively eliminate the small-scale, within-stand gap processes that dominated the natural forests in this region. The long-term consequence is an unnatural landscape that becomes homogenized in both time and space. This example raises questions about strategies that are designed to address biodiversity issues strictly at the landscape-scale using a continually shifting mosaic of variable-size, single-cohort stands managed on ecologically short rotations. Such a landscape will not contain a natural diversity of conditions unless silvicultural systems make substantial provisions for retaining within-stand structure during the regeneration harvest. Once single-cohort stands occupy over ca. 15–25% of the landscape, every stand that is converted or maintained in a single-cohort structure contributes toward an increasingly artificial landscape pattern.

The stand-level benchmarking approach (Fig. 3) can readily be extended to evaluate a forest structure at the landscape level if the age structures of stands are known and the management plan is site specific. Disturbance comparability indices could be calculated for each stand, and a weighted average could be determined for various sized landscape units. Using a triad model for landscape allocation (Seymour and Hunter, 1999), a network of ecological reserves (Norton, 1999) could then be designed to counterbalance limited areas allotted to production forestry. To enhance ecological robustness, the production forests and reserves would be embedded within a diverse matrix of stands managed according to the principles outlined here.

4. Recommendations

The discussion above should help to clarify for northeastern practitioners what sorts of silvicultural systems to favor in order to emulate natural disturbance regimes, and by implication, which to avoid. The following specific recommendations should help to clarify our working hypotheses.

1. For the purpose of silvicultural prescription, think of northeastern landscapes in terms of relatively large stands with substantial within-stand diversity in age, not as many small, uniform single-cohort stands. Match stand boundaries with large-scale, enduring physiographic and edaphic features; do not designate stands simply on the basis of the present age structure and species composition if these are substantially altered from the presettlement condition, as is common. Doing the latter could reinforce a landscape pattern that could become increasingly artificial and self-perpetuating. Use a within-stand, gap-based paradigm to manage the regeneration process (Coates and Burton, 1997).
2. Regenerate new cohorts at rates $= 0.7-1.3\%$ per year. This will produce average canopy residence times of 75–150 years (not including any early suppression period), which were apparently typical of presettlement forests (e.g. Frelich and Lorimer, 1991; Dahir and Lorimer, 1996). Set an operational cutting cycle, then multiply by the chosen regeneration rate to determine how much total gap area to create in each harvest.
3. When starting with stands exhibiting mid- to late-successional structures and reasonable species diversity, create a range of gap sizes ranging from the crown area of a single large tree up to a maximum of ca. 0.2 ha. Above 0.1 ha, gaps will admit enough light to ensure some representation of commercially important, shade-intolerant species, if that is an objective. Avoid harvesting all the largest or most valuable trees in a single entry, as this tends to create a network of large, interconnected patches (Lorimer, 1989; Lorimer and Frelich, 1994). Rather, try to form distinct gaps around senescent individuals or clumps using vigor and risk classifications (Seydack, 1995).
4. In more uniform stands that lack much structural or species diversity, larger patches created by more intense harvests may be necessary to avoid short-term financial loss. In these cases, long-term restoration, rather than maintenance, is the goal. Take advantage of every opportunity to conserve legacy trees and advance regeneration of longer-lived species. This will mimic the natural successional pattern that would eventually restore the later-successional condition if no harvesting occurred, and will expand future treatment options.
5. Finally, the practice of multi-aged silviculture does not risk loss of early-successional communities that depend on infrequent catastrophic disturbances. Most such disturbances will occur regardless of human activity, so there is no justification for emulating them. In addition, landscapes in regions such as the Lake States have substantial areas of forest communities that naturally depend on stand-replacing disturbances (e.g. pine forests) that are intermingled among the more stable communities (e.g. northern hardwoods-hemlock) discussed in this paper. Using a natural disturbance paradigm to manage both types of communities would result in a naturally diverse landscape comparable to the presettlement era. Given that people cannot prevent most abiotic disturbances, management should strive to complement the natural background levels, not duplicate them; otherwise, the overall disturbance rate will be unnaturally high. The balanced response to catastrophic events is to salvage economic losses when they occur, with due attention to biological legacies such as surviving living trees, standing snags, and coarse woody material.

Acknowledgements

Background research for this paper was supported by Conservation Fellowships from the Pew Charitable Trusts to Malcolm Hunter Jr. and the first author. We further acknowledge the contributions of Robert Mitchell, Malcolm Hunter Jr., Laura Kenefic, and two anonymous reviewers whose comments greatly improved the content and presentation of this material.

Publication 2421 of the Maine Agriculture and Forest Experiment Station.

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