Integrating Natural Disturbance Parameters into Conventional Silvicultural Systems: Experience From the Acadian Forest of Northeastern North America

Robert S. Seymour[1]

ABSTRACT

With rare exceptions, the presettlement Acadian forest of northeastern North America was driven by gap dynamics; true stand replacing disturbances were quite uncommon, with recurrence intervals of many thousands of years. After centuries of human exploitation, stand age structures have become simplified, and commercial timber rotations are a fraction (15 to 40 percent) of the lifespan of the common late-successional tree species. Adapting silvicultural systems to strengthen their ecological foundation thus confronts the challenge of converting single- or two-cohort stands to more complex structures via various combinations of regeneration and retention. This paper reviews the region's research and management experience with two fundamentally different approaches to this challenge: regeneration in distinct, relatively small gaps vs. uniform stand-wide regeneration under different levels of overwood reserve trees. A hybrid system is described that combines the proven benefits of shelterwood with the restoration advantages of group selection; in American terminology, the system is an irregular group shelterwood with reserves, similar to the German *Femelschlag* in which gaps are created and gradually expanded over several cutting cycles. Two illustrations of how this (or any) silvicultural system can be benchmarked against natural stand dynamics are provided.

KEYWORDS: Ecological forestry, restoration silviculture, red spruce, shelterwood, selection, conversion, *Femelschlag*.

INTRODUCTION

Foresters in northeastern North America who seek to practice ecologically-based silviculture face many challenges, ranging from incomplete knowledge of ecosystem processes to resisting financial pressures that lead to unsustainable harvesting. This paper attempts to blend our rapidly advancing knowledge of disturbance ecology with existing silvicultural knowledge and experience. My goal is to illustrate how two key attributes of natural disturbances—recurrence interval and patch size—can be readily accommodated by contemporary modifications to a traditional, though little used, silvicultural system.

DISTURBANCE ECOLOGY OF NORTHEASTERN FORESTS

Large-scale commercial forestry in northeastern North America is centered in the northern New England States (Maine, New Hampshire, Vermont) and the Canadian Maritimes (mainly New Brunswick and Nova Scotia). Unlike southern and central New England, much of this region was never settled or cleared for agriculture, and thus remains as a large, virtually unbroken block of contiguous forest stretching from the eastern coast of New Brunswick through the Adirondack Mountains of New York. Two major forest types predominate here, each with many subtypes and local variants in response to edaphic and climatic variation: the so-called "spruce-fir" forest, that contains assemblages of red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.), and the "northern hardwood forest," dominated historically by sugar maple (*Acer saccharum* Marsh.) American beech (*Fagus grandifolia* Ehrh.), and yellow birch (*Betula alleghaniensis* Britton). Common associates include red maple (*Acer rubrum* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), eastern white pine (*Pinus strobus* L.), and northern white-cedar (*Thuja occidentalis* L.).

---

[1] Curtis Hutchins Professor of Silviculture, Department of Forest Ecosystem Sciences, University of Maine, Orono, ME 07769-5755, USA.
Email: Seymour@apollo.umenfa.maine.edu

These species can live for 300 years or more, and most are quite shade-tolerant, typically reproducing by advance regeneration that may exist for many decades in the understory before canopy accession (Seymour 1995). Although they can grow and develop well in single-cohort stands and are commonly managed this way today, such structures were uncommon before human exploitation began in the 18th century. Owing to abundant precipitation throughout the growing season, stand-replacing fires were very infrequent, as were stand-replacing windstorms, with estimated return intervals of many centuries to millennia (Lorimer and White 2003). As a consequence, gap dynamics were the most common natural disturbance, which led naturally to a forest structure dominated by late-successional, multi-aged stands (Seymour et al. 2002).

HISTORY OF HUMAN EXPLOITATION AND MANAGEMENT

Centuries of human exploitation for forest products, first for large sawlogs and later (ca. 1900) for smaller-diameter pulpwood, have radically changed the forest structure. Remnants of the primary, old-growth forest are quite rare, and many, such as the Big Reed Reserve in northern Maine owned by The Nature Conservancy, have been reserved from commercial logging and studied intensively by ecologists (e.g., Fraver 2004). The typical commercial forest landscape is dominated by stands that are younger and more even-aged than during presettlement. Changes in species composition have been less dramatic; nevertheless, typical stand compositions have shifted from the slower-growing, late-successional species to those that are favored by frequent harvest disturbance, such as red maple, paper birch (*Betula papyrifera* Marsh.), aspen (*Populus* spp.), and balsam fir. It is not uncommon to find legacies of the presettlement forest remaining in many stands, such as large cull trees and small, long-suppressed saplings of late-successional species absent from the overstory, but these are usually a byproduct of their low commercial value, not a conscious act of retention.

When I arrived in Maine in the late 1970s, the landscape was dominated by well stocked, even-aged spruce-fir stands that, I was told, had originated after the devastating spruce budworm (*Choristoneura fumiferana* Clem.) outbreak ca. 1913-19. Careful reconstructions of these stands using records and increment cores, coupled with review of early descriptions of the original forest and early harvesting (e.g., Cary 1894, Hosmer 1902) invariably revealed that these even-aged stands had originated by some heavy, often repeated, timber harvests ca. 1880-1925. Only pure fir stands (which were originally neither common nor extensive) seemed to have a unique budworm origin (Seymour 1992). Many of these dense, even-aged, and ecologically immature spruce-fir stands were again clearcut during the 1980s, partly in response to the budworm outbreak of that time. Many industrial landowners treated large areas of the regenerating third-growth forest with herbicide release and precommercial thinning, with little attempt to favor red spruce over fir. Now, as these stands approach commercial size, there are large areas of 25-year-old, spaced, nearly pure fir stands, where 150 years before stood old-growth red spruce-yellow birch forests with fir as a minor component.

SILVICULTURE FOR ECOLOGICAL RESTORATION

Challenges

Any serious attempt at ecological forestry (see Seymour and Hunter 1999) in this region must confront the simplified age structures and altered compositions of repeatedly harvested stands using a patient restoration approach. The goal of such a restoration strategy is to re-create a forest dominated by diverse multi-aged stands, with at least some having a late-successional component that is deficient in the commercial forest. In the Acadian region, this problem is arguably more difficult than in regions like the Pacific Northwest where the natural stand-development patterns follow a single-cohort model, and the challenge is merely softening clearcuts with structural retention measures. In the Northeast, leaving scattered islands or reserve trees in clearcuts or uniform shelterwoods of >10 ha, although valuable in some respects, often fails to address the more fundamental mismatch of even-aged silviculture with natural processes.

During the past decade or so as ecological forestry concepts have entered mainstream thinking, I believe that most academics and scientists share a common view about the difference of our present forest from that of presettlement. Practitioners are generally more skeptical, not necessary of the underlying science, but of its relevance to their day-to-day existence. Further, just as the consciousness of ecological forestry is being raised, there has been a wholesale sell-off of large parcels formerly held by forest industry to timberland investors whose time horizons are much shorter and who expect double-digit returns. Relative to the goals of restoration and ecological sustainability, much of this former industrial forest just needs a “rest,” yet it is faced with ever-increasing pressure to generate income from the remaining growing stock. My own experience suggests that stewards of public forests, especially those under management by state forestry agencies in the United States, have resisted such pressures and tend to be more receptive to restoration silviculture than many privately owned forests.

Possible Restoration Pathways

Conceptually, the challenge of converting even-aged stand structures to more complex ones is straightforward: a series of regular harvest entries, spaced out over a relatively long conversion period (e.g., 50 to 100 years), each regenerating only a relatively small portion of the stand. Of course, this is easier said than done, especially if the stand is already understocked from prior harvests. Nyland (2003) discusses two different ways to approach this problem: uniformly distributed reductions in overstory density at each cutting versus creation of distinct canopy gaps. As diagrammed by Nyland, the first option begins as a light, uniform shelterwood establishment cutting and ends (after 5 cutting cycles) as single-tree selection. The second option can be categorized as patch or group selection throughout. Both assume equal cutting cycles and an age-balanced stand at the end of the conversion period.

The shelterwood method is commonly recommended in this region for regenerating spruce-fir, northern hardwood, and white pine-red oak forests (Hannah 1988, Seymour 1995) and is viewed by many foresters as the best way to restore degraded stands to higher timber productivity. Although sometimes considered an alternative to even-aged management because it involves "partial cutting" at the establishment stage, shelterwood management is at best a two-aged system depending on the density of reserve trees, if any. As practiced by most private owners, establishment cuttings are uniformly applied and fairly heavy (40- to 60-percent removals); furthermore, reserve trees left after overstory removal are not numerous (generally <10 percent of the original stocking) and thus do not significantly affect the dominant younger cohort. So, although uniform shelterwoods may be an effective method to improve species composition and provide economic returns, they fail as a system for restoring multi-aged stand structures.

Group selection cutting is much less common than shelterwood, but is gaining popularity in formerly high-graded northern hardwood forests with an overabundance of beech regeneration. The improved light environment of even small gaps gives sugar maple and the birches an advantage over the vegetative beech reproduction, as long as advance regeneration of maple is established and birch seed reaches the disturbed gaps (Seymour 1995). Group selection is quite uncommon in spruce-fir forests; examples are limited to some public ownerships and small private woodlots. Although preferable to shelterwood for ecological restoration, group selection cutting has several drawbacks. If the matrix between groups is not treated, the overall harvest can be very light and thus problematic economically. Not treating the matrix, however, risks losing volumes of valuable but short-lived species, such as balsam fir, paper birch, and aspen, that might not survive until the next entry.

Principles and Specifics

To convert uniform stands to more irregular, multi-aged structures, one must consciously regenerate a portion of the stand at each entry while keeping the canopy of the surrounding matrix relatively intact and thus, unregenerated. A comprehensive review of natural disturbance rates in this region (Seymour et al. 2002, fig. 1) suggests that the area regenerated should average about 1 percent per year, equivalent to a 100-year return interval. Assuming the goal is a balanced within-stand age structure at the end of the conversion period, one simply multiplies the annual disturbance rate by the cutting cycle, just as one would do in a forest of even-aged stands under area regulation (Nyland 1996). Adopting a cutting cycle of 20 years thus would dictate that each entry regenerate 20 x 1% = 20% of the stand at each entry. Furthermore, regeneration should occur in small gaps (under 0.1 ha) in order to remain within the bounds of natural disturbance parameters (Seymour et al. 2002). Finally, to restore late-successional characteristics, reserve trees must be retained in the gaps as they are regenerated; otherwise, there will obviously be no trees over age 100 when the conversion is complete. Ideally, reserve trees are retained permanently and should consist primarily of long-lived species from the main canopy. As they grow to ecological maturity and eventually die, they will restore an important late-successional structural component that is typically absent from managed forests; they will function as biological legacies (Franklin et al. 1997, Seymour and Hunter 1999) and replenish the pool of large, woody material on the forest floor.

I believe that the guiding principle of such a silvicultural system should be a stand structure based on area, not tree size. Such a guide takes the form of a within-stand age structure, rather than a tree size structure such as the negative exponential diameter distribution commonly associated with balanced single-tree selection cutting (O'Hara 1996, Seymour and Kenefic 1998, Smith et al. 1997). Specifically, an area-based structure defines what percentage of the stand is regenerated at each entry, along with a distribution of patch (gap) sizes that comprises this area. An area structure requires the forester to consider the regeneration process explicitly at each entry, and thus avoids the historical pitfalls of size-based, multi-aged systems that did not lead to adequate ingrowth of the desired species and were thus abandoned throughout North America during the 1950s in favor

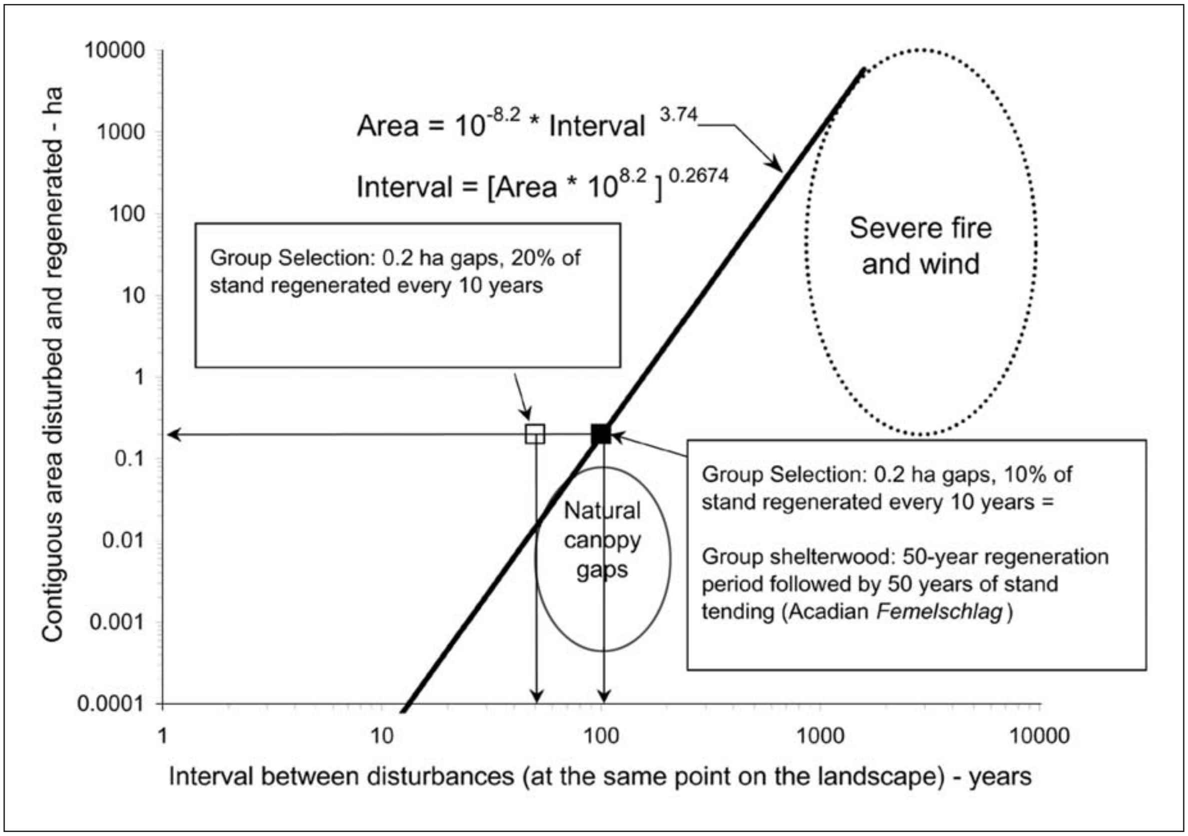

Figure 1—Evaluating the natural disturbance comparability of two gap-oriented silvicultural systems, using the reference metric from Seymour et al. (2002).

of single-cohort systems (Curtis 1998; Seymour, in press; Smith 1962).

Uniform vs. Gap-oriented Spatial Patterns

Relative to the goal of restoring age diversity, I believe that Nyland's (2003) first option, repeated uniform cuttings, is not practical in our region and, arguably, does not work ecologically. First, Acadian forests tend to develop dense understories of advance regeneration under even light canopy disturbances; hence the appeal of the simple uniform shelterwood method for production systems based on natural regeneration. After a uniform cutting to 60-percent relative density as recommended by Nyland (2003), the understory will invariably fill up with tolerant advance growth. Further, light uniform removals from the overstory serve only to release this regeneration, not establish new cohorts as required. In effect, the understory quickly reaches a stem-exclusion condition (Oliver and Larson 1996), and the stand never contains more than two cohorts. At best, a third cohort might establish after the final overstory removal in areas disturbed by harvesting equipment, but this is a common feature of all systems. For conversion systems to work over time, the dominant matrix must be kept at sufficient density to prevent regeneration over most of the stand at a given time; regeneration should occur only in defined gaps created at each entry.

Another important drawback of uniform patterns is the fact that the light cuttings required for true restoration, typically no more than 10- to 20-percent removals, are quite impractical operationally if distributed evenly throughout the stand. Concentrating such light entries, as done in gap-oriented systems, promotes harvesting efficiency and costs should be little more than for clearcutting if haul roads are in place. Gap systems also allow other silvicultural treatments (e.g., enrichment planting to restore species, early stand tending) to be conducted efficiently.

A Hybrid Silvicultural System: The Acadian *Femelschlag*

In 1994, a team of forest scientists and wildlife ecologists from the University of Maine faculty set out to design a long-term experiment in ecological forestry known as the Forest Ecosystem Research Program (FERP). This program would complement the existing, conventional silvicultural systems on the Penobscot Experimental Forest maintained by the USDA Forest Service Northeastern Research Station since 1950 (Sendak et al. 2003). We based our silvicultural systems on the disturbance rates, patterns, and structural features of natural forests as best we understood them. One system chosen was a traditional light group-selection cutting that removed 10 percent of the stand in small gaps on a 10-year cutting cycle while retaining 30 percent of the initial growing stock within the gaps as permanent reserve trees. Although such a system arguably mimics natural dynamics closely, the overall harvest rate is so light that is was difficult to carry out logistically and economically.

In an attempt to formulate a more operationally feasible system without sacrificing its ecological basis, we devised a hybrid between group selection and uniform shelterwood. The key concept is to apply the well-known principles of shelterwood regeneration in a patch-wise fashion within the stand, rather than uniformly throughout, leaving reserve trees in the groups after they are fully regenerated. Instead of stand age structure changing *temporarily* as in a uniform shelterwood, group shelterwood systems vary *spatially*, and at times contain all stages of the shelterwood sequence: unregenerated matrix awaiting treatment, two-storied patches following establishment cutting, and free-to-grow sapling regeneration after removal of the overstory except scattered reserves. In order to make harvesting as efficient as possible and to retain some intolerant species in the regeneration, we chose a gap size of 0.2 ha, slightly larger than most natural gaps (Seymour et al. 2002). Further, we designated about 10 percent of the initial growing stock as permanent reserve trees, making this a “group shelterwood with reserves.” We chose to carry out the conversion cuttings in five entries spaced 10 years apart, and then allow the stand to develop without regeneration cutting for another 50 years. This equals a 1-percent annual disturbance rate over the entire 100-year conversion period, but is effectively “front-loaded” during the first 50 years at 2 percent per year. Unlike a classical group selection system with a constant cutting cycle, this system explicitly does not attempt to achieve any sort of balanced within-stand age structure, just a diverse, irregular one that nevertheless represents quite a departure from the initial single-cohort structure.

The most accurate description of this system using contemporary North American silvicultural terminology would be an “irregular group shelterwood with reserves.” *Group* comes from the spatial pattern of the cuttings and is needed to distinguish it from a uniform application. *Irregular* comes from the extended regeneration period relative to a more conventional shelterwood, and describes the uneven height structure of the resulting regeneration. *With reserves* comes from the retention of trees from the original cohort beyond the regeneration period, for reasons unrelated to the regeneration process itself. European foresters have long applied such a system, known in Germany as the *Femelschlag*, in which the groups under regeneration are expanded at each entry until they coalesce (Spurr 1956). In his classic description of European silvicultural systems, Troup (1928) describes several regional variants of the *Femelschlag* widely practiced at that time for converting even-aged stands to more irregular structures. We have also adopted this approach in our FERP experiments, and have thus chosen to describe our system as the Acadian *Femelschlag*.

Some Application Details: Locating Skid Trails, Initial Gaps, and Reserve Trees

We elected to harvest within the matrix between groups during the first entry, mainly to presalvage balsam fir, paper birch, and aspen that were reaching their natural life span. In the matrix, we were very careful not to remove any large dominant trees that would make permanent canopy gaps and thus create unwanted nuclei of regeneration. Skid trails were designated to connect the gaps, and occasional spur trails were needed to treat the intervening matrix. In future entries when gaps are expanded, trails will be relocated through the matrix where necessary to avoid damaging established reproduction.

Initial gaps were located in two different stand conditions. In patches of well-established advance regeneration resulting from partial canopy breakup in the two decades prior to initiating the experiment, the overstory was removed completely except for the requisite reserve trees. Areas of these existing gaps were estimated in the field and sketched on a stand map. Additional gaps were located as needed throughout the more intact matrix until the requisite area (20 percent of the total stand) was achieved. In this latter case, the cut within the gap attempted to leave a shelterwood overstory basal area of 14-18 m^2/ha (60 to 80 ft^2/acre) to provide shade and seed for new recruitment. These overwoods will be removed in the second entry (except permanent reserve trees) as the gaps are expanded.

Reserve trees were designated at the same time the stand was marked for cutting. Any tree with obvious wildlife usage (e.g., large cavities) was designated; others were selected from the larger d.b.h. classes of long-lived, and sometimes uncommon, species. Since our goal was to permanently retain 10 percent of the stand, and the target residual basal area, including gaps, was about 23 m^2/ha (100 ft^2/acre), we used a 10 basal area factor (English) wedge prism to distribute reserve trees such that no place in the stand was lacking at least one "in" tree.

Quantifying What Is "Natural" as a Silvicultural Benchmark

Silviculturists in the Northeast seeking to emulate natural disturbance regimes have historically relied on general ecological principles and intuition. To overcome this obstacle, we created a simple metric based on a comprehensive review of disturbance literature for the region that allows foresters to assess how closely their silvicultural systems approach natural patterns (fig. 1). The axes of the diagram—intervals between disturbance and contiguous areas disturbed—both have direct silvicultural analogues (Seymour and Hunter 1999). For systems that do not regenerate the entire stand in one entry (e.g., group selection), the frequency should be thought of as the time required to regenerate the entire stand, assuming patches do not overlap. This is given by the formula: frequency (or effective rotation) = (cutting cycle, in years)/(proportion of stand regenerated at each entry). The fitted line that bounds the upper limit of the disturbance data becomes the space-time benchmark point for any system.

Consider a group-selection system that regenerates 20 percent of the stand at each entry, in patches averaging 0.2 ha, on a 10-year cycle. The return interval (effective rotation) is thus 10/20% = 50 years. Next, compute the natural return interval of a 0.2-ha patch: Interval = $[0.2 \text{ x } 10^{8.2}]$ 0.2764 = 101 years (from fig. 1). The ratio of the planned return interval to its natural analogue is termed the natural disturbance comparability index, in this case 50/100 = 0.5, meaning that such a system would effectively regenerate this stand in gaps of this size about twice as rapidly as natural disturbances would. Note that lengthening the cutting cycle to 20 years, or reducing the patch size to 0.014 ha, would place the system exactly on the line. The Acadian *Femelschlag* described above also falls exactly on the line because the entire "rotation" (the time between the beginning of gap creation in two successive applications of the system to the same area) is effectively 100 years (50 years of group regeneration cutting followed by 50 years of stem exclusion stand development during which only intermediate treatments are applied).

It is also instructive to compare the planned age distribution of the irregular group shelterwood with that of undisturbed old-growth stands in the region. The age structure of the shelterwood will be, by design, distinctly bimodal: five closely spaced cohorts that span a range of about 40 to 50 years resulting from the expanding gap cuttings, plus a population of much older reserve trees chosen from the initial stand. For example, if the stand were 90 years old at the beginning (as in the case of one of the FERP experimental blocks), by the time the regeneration process is complete, these reserves will be 140+ years old, and nearly 200 after one complete cycle when the stand is again ready for regeneration cuttings.

Figure 2 shows the age structure of three old-growth red spruce stands in the Big Reed Reserve in northern Maine as reconstructed by Fraver (2004). Note that all are somewhat bimodal, two distinctly so, indicating that recruitment in such stands is episodic and irregular. Note that irregular group shelterwood systems with reserves—with extended periods of stand regeneration in patches, followed by periods of stem exclusion—arguably emulate this structure more faithfully than the classic balanced single-tree or group selection stand with continuous, temporally constant recruitment. In the group shelterwood, the managed cohorts would be analogous to those under age 100 in the natural forest, and the reserve trees would be analogous to the old-growth trees over the managed rotation (ca. 100 years). In practice, a managed stand would have more growing space allocated to cohorts under age 100 and less to the old-growth legacy, assuming legacy trees would never be harvested.

CONCLUSIONS

Irregular group shelterwoods with permanently retained reserve trees offer great promise as a viable method to restore age diversity and "naturalness" to Acadian forests that have become simplified from over a century of heavy cutting. Like any silvicultural system, however, they are not a panacea for all conditions, even where landowners are committed to ecological restoration. In pure, single-cohort stands dominated by early successional species, restoration of later-successional species which may invade the understory is the main ecological objective, and uniform shelterwoods (with reserves) may offer the only way to capture the value in the present stand before it reaches maturity. In this case, restoration of age structure can then begin during the next rotation, where the presence of more long-lived species offers more options. Conversely, in stands that have been managed to retain multi-aged, late-successional qualities, some form of selection cutting with more regular entries and smaller gaps may be more appropriate.

ACKNOWLEDGMENTS

Funding for this Forest Ecosystem Research Program has come primarily from the Maine Forest and Agriculture Experiment Station. This paper benefited substantially from reviews by Laura Kenefic, David Ray, and Robert Wagner.

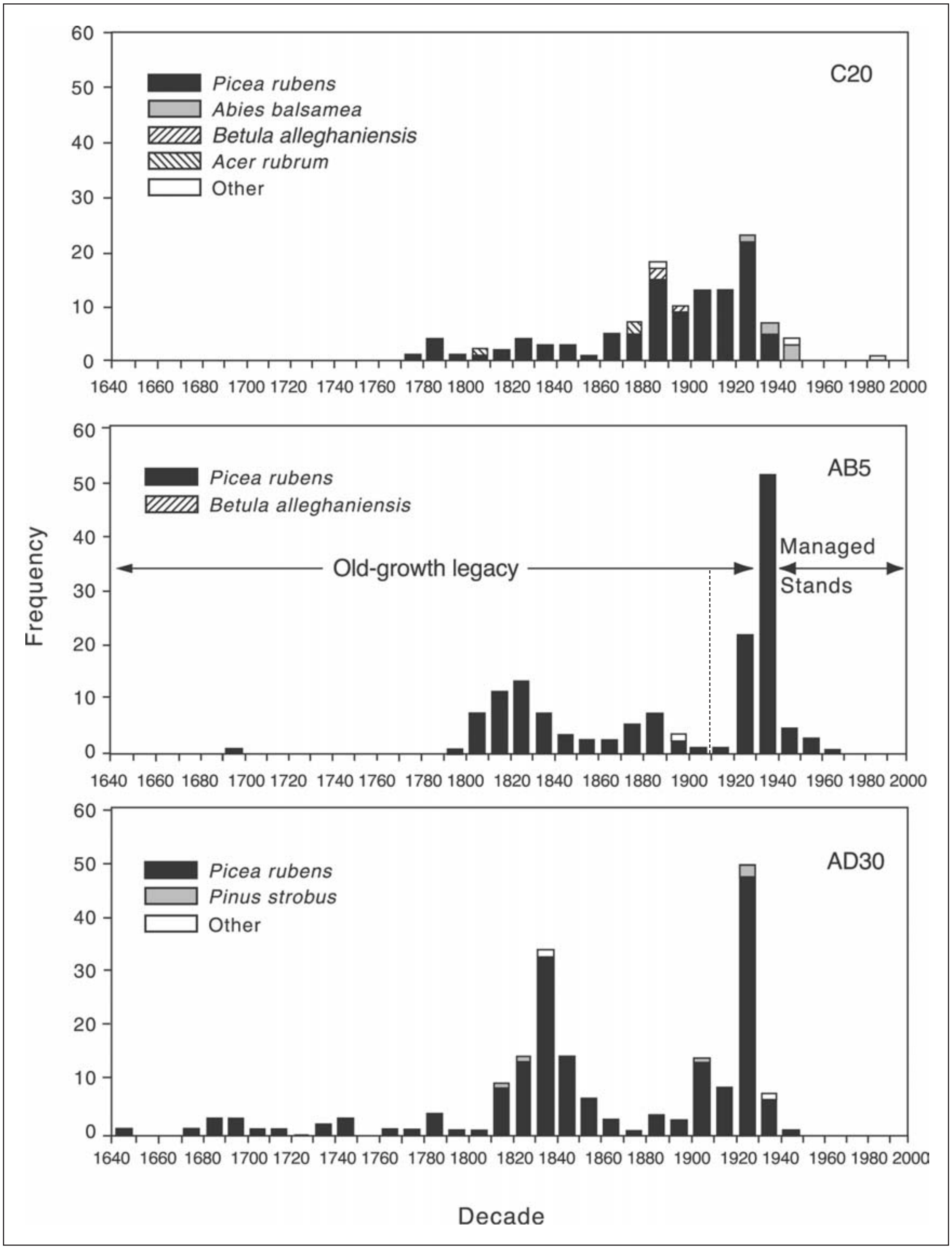

Figure 2—Age-structures of three old-growth red spruce stands in the Big Reed Reserve, T. 8 R. 10, Maine (Fraver 2004), showing the very irregular patterns of canopy recruitment over three centuries. Group shelterwood silvicultural systems can mimic this pattern, assuming the 1-100 cohorts represent the managed (harvested) stand, and those over 100 are reserve trees that provide the biological legacy. In practice, a managed stand would have more trees in the "managed" component and fewer in the old-growth legacy.

REFERENCES

Cary, A. 1894. On the growth of spruce. Second annual report, Maine Forest Commissioner, Augusta, ME: 20-36.

Curtis, R.O. 1998. "Selective cutting" in Douglas-fir: revisited. Journal of Forestry. 96(7): 40-46.

Franklin, J.F.; Berg, D.R.; Thornburgh, D.A.; Tappeiner, J.C. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. In: Kohm, K.A.; Franklin, J.F., eds. Creating a forestry for the 21st century. Washington, DC: Island Press: 111-139.

Fraver, S. 2004. Spatial and temporal patterns of natural disturbance in old-growth forests of northern Maine, USA. University of Maine. 185 p. Ph.D. dissertation.

Hannah, P.R. 1988. The shelterwood method in northeastern forest types: a literature review. Northern Journal of Applied Forestry. 5: 70-77.

Hosmer, R.S. 1902. A study of the Maine spruce. In: 4th Rep. Maine Forest Commissioner, Augusta, ME.

Lorimer, C.G.; White, A.S. 2003. Scale and frequency of natural disturbances in the northeastern United States: implications for early successional habitat and regional age distributions. Forest Ecology and Management. 185: 41-64.

Nyland, R.D. 1996. Silviculture: concepts and applications. New York: McGraw-Hill. 633 p.

Nyland, R.D. 2003. Even-to uneven-aged: the challenges of conversion. Forest Ecology and Management. 172: 291-300.

O'Hara, K.L. 1996. Dynamics and stocking-level relationships of multi-aged ponderosa pine stands. Forest Science. 42(4): Monograph 33.

Oliver, C.D.; Larson, B.C. 1996. Forest stand dynamics. New York: John Wiley and Sons, Inc. 520 p.

Sendak, P.E.; Brissette, J.C.; Frank, R.M. 2003. Silviculture affects composition, growth, and yield in mixed northern conifers: 40-year results from the Penobscot Experimental Forest. Canadian Journal of Forest Research. 33: 2116-2128.

Seymour, R.S. 1992. The red spruce-balsam fir forest of Maine: Evolution of silvicultural practice in response to stand development patterns and disturbances. In: Kelty, M.J.; Larson, B.C.; Oliver, C.D., eds. The ecology and silviculture of mixed-species forests. A festschrift for David M. Smith. Norwell, MA: Kluwer Academic Publishers: 217-244. Chapter 12.

Seymour, R.S. 1995. The Northeastern Region. In: Barrett, J.W., ed. Regional silviculture of the United States. 3rd ed. New York: Wiley and Sons: 31-79.

Seymour, R.S. [In press]. Silviculture: lessons from our past, thoughts about the future. In: Palik, B.; Levy, L., eds. Great Lakes Silviculture Summit, proceedings. Gen. Tech. Rep. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station.

Seymour, R.S.; Hunter, M.L., Jr. 1999. Principles of ecological forestry. In: Hunter, M.L., Jr., ed. Maintaining biodiversity in forest ecosystems. New York: Cambridge University Press: 22-61. Chapter 2.

Seymour, R.S.; Kenefic, L.S. 1998. Balance and sustainability in multi-aged stands: a northern conifer case study. Journal of Forestry. 96(7): 12-17.

Seymour, R.S.; White, A.S.; deMaynadier, P.G. 2002. Natural disturbance regimes in northeastern North America – evaluating silvicultural systems using natural scales and frequencies. Forest Ecology and Management. 155: 357-367.

Smith, D.M. 1986. The practice of silviculture, 8th ed. New York: Wiley and Sons. 527 p.

Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1997. The practice of silviculture: applied forest ecology. 9th ed. New York: Wiley and Sons. 537 p.

Spurr, S.H. 1956. German silvicultural systems. Forest Science. 2: 75-80.

Troup, R.S. 1955. Silvicultural systems. 2nd ed. New York: Oxford Universiyt Press. 216 p.