Eastern Hemlock Response to Even- and Uneven-Age Management in the Acadian Forest: Results from the Penobscot Experimental Forest Long-Term Silviculture Study

John C. Brissette[1] *and Laura S. Kenefic*[2]

Abstract

Eastern hemlock (*Tsuga canadensis* (L.) Carr.) is an important tree species in the mixed-species conifer forests of northern New England and adjacent Canada. Hemlock is very tolerant of understory conditions; consequently, it responds differently to various silvicultural treatments. In a long-term study at the Penobscot Experimental Forest in east-central Maine, shelterwood silviculture reduced the hemlock component in regenerating stands compared to parent stands, while hemlock increased in abundance and dominance under selection silviculture. On sites where hemlock is common, managers have some control over its prevalence through silviculture.

Introduction

Much of Maine and New Brunswick, as well as Nova Scotia and Prince Edward Island, are within the Acadian Forest Region (Rowe 1972). The region is boreal ecotone with a relatively cool, moist climate. The Acadian and closely related Great Lakes-St. Lawrence Forest Region of southern Quebec are of very mixed species composition; predominately conifers, especially on sites where drainage is impeded. The major conifers of the Acadian Region include spruces, red (*Picea rubens* Sarg.), white (*P. glauca* (Moench) Voss), and to a lesser extent black (*P. mariana* (Mill.) B.S.P.); balsam fir (*Abies balsamea* (L.) Mill.); northern white-cedar (*Thuja occidentalis* L.); eastern white pine (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.); and eastern hemlock (*Tsuga canadensis* (L.) Carr.). Common hardwoods include red maple (*Acer rubrum* L.); paper birch (*Betula papyrifera* Marsh.); gray birch (*B. populifolia* Marsh.); and aspen, both quaking (*Populus tremuloides* Michx.) and bigtooth (*P. grandidentata* Michx.).

In the Acadian Region, stand replacing fires are less frequent than in other boreal and temperate forests (Wein and Moore 1977, 1979). Common natural disturbances are insect epidemics and wind storms that often cause sporadic and partial stand mortality. Such disturbances may occur only once during the life span of the relatively short-lived balsam fir, but several times during the life of spruce, hemlock, northern white-cedar or pine. Expect for the pines, these species are all very shade tolerant and natural regeneration following disturbance is prolific (Baldwin 1977, Piene and Anderson 1987, Brissette 1996). The pattern of natural disturbance and silvics of the commercial species make this forest type amenable to either even- or uneven-age management and most of their associated silvicultural systems.

The Penobscot Experimental Forest (PEF) is located in the towns of Bradley and Eddington, in Penobscot County, Maine. It is 4,000 acres in size and centered at approximately 44°52'N, 68°38'W. The PEF was established in 1950 for the purpose of conducting timber management research in northern conifers. At the time of establishment, the area was a mix of even-aged and apparently uneven-aged stands. Even-aged stands were 60 to 100 years old (Safford et al. 1969). Only a few acres had ever been cleared for agriculture. Cutting was relatively light in the 20 to 40 years before the area became the PEF with some pine, spruce, and hemlock sawlogs harvested. Glacial till is the principal parent material with soil types varying from well-drained loams and sandy loams on low-profile ridges to poorly and very poorly drained loams and silt loams in the flat areas between the ridges.

Between 1952 and 1957, an experiment was established on the PEF to compare the effects of even- and uneven-age management on stand growth, yield, species composition, and value. Even-age management is represented by clearcut and shelterwood silvicultural systems. Some of the shelterwood treatments were also precommercially thinned, or spaced. Uneven-age management is represented by selection silviculture. Diameter-limit cutting is also included in the treatment array. One goal of the experiment is to determine how to increase the component of spruce in stands. Thus, whenever possible for a particular treatment, spruce is left as a seed source or simply to grow and increase in dominance in the stand.

The objective of this paper is to present 40-year results describing how eastern hemlock has responded to shelterwood and selection silviculture in the long-term experiment on the PEF.

Materials and Methods

Treatments were assigned to compartments at random and replicated twice, each replicate or compartment averaging 25 acres. Periodic measurements of stand composition and structure are taken on a series of permanent plots established in each compartment on a grid with a random start. The plots consist of two concentric circles of different sizes with the same plot center. All trees with a dbh $\geq$0.5 in are measured on the interior 1/20 ac plots. All trees with dbh $\geq$4.5 in are measured on the entire 1/5 ac plots. The number of such plots average 18 per compartment. Regeneration inventories are taken on three milacre (0.001 ac) plots located on the circumference of each 1/20 ac plot. Regeneration is defined as a seedling or sprout $\geq$6 in tall but with a dbh <0.5 in. Measurements are taken before and after cutting and at about 5-year intervals between harvests.

---

[1] USDA Forest Service, Northeastern Research Station
271 Mast Road, Durham, NH 03824

[2] USDA Forest Service, Northeastern Research Station
RR1 Box 589, Bradley, ME 04411

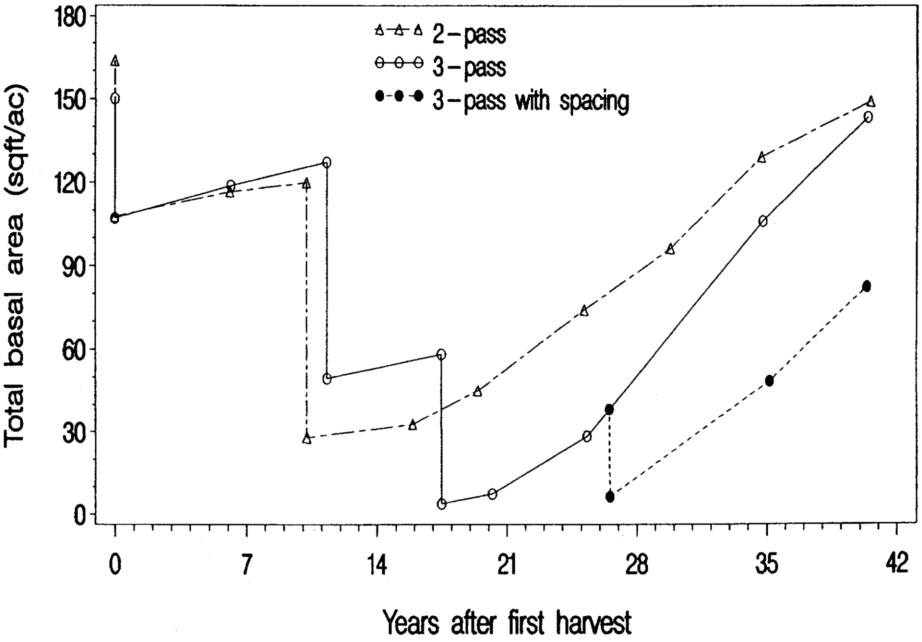

Figure 1.—Harvest and growth history of compartments managed under shelterwood silviculture at the Penobscot Experimental Forest.

In the experiment there are two uniform shelterwood treatments (Figure 1). In one the overstory was removed in two passes or stages. In the other the overstory was harvested in three stages; subsequently these compartments were split, one-half was spaced the other was not. Because advanced regeneration of understory-tolerant species, such as spruce, balsam fir, and hemlock, is usually abundant in the Acadian forest, the principal objective of removing the overstory in stages is to release that regeneration. Shelterwood silviculture also provides a measure of control over species composition in the regenerating stand, primarily by limiting the establishment and growth of intolerant species during the period of overstory removal. Nevertheless, more regeneration is established during the overstory removal phase, and that fact was considered when the shelterwood harvests were planned in this experiment.

Table 1.—Structural goals for compartments under selection management at the Penobscot Experimental Forest.

Cutting cycle	q-factor[1]	Residual basal area	Residual max dbh
		(ft^2/ac)	*(in)*
5 years[2]	1.96	115	19
10 years[2]	1.96	100	18
20 years[3]	1.96	80	16

[1] Calculated for 2-in dbh classes, all species combined

Additional constraints:

[2] Harvest <50 percent net periodic growth until optimal structure is achieved

[3] Harvest <75 percent net periodic growth until optimal structure is achieved

Three variations of selection silviculture are represented. All employ a combination of single-tree and group selection cutting, but differ by harvest interval, residual basal area, and maximum diameter goals (Table 1). Target diameter distributions were defined using the BDq method (Guldin 1991).

Results and Discussion

Even-age

Prior to initiating the shelterwood treatments hemlock accounted for over 20 percent of the basal area in the 2-pass compartments (Figure 2) and about 30 percent in the 3-pass compartments (Figure 3). Because spruce was favored as a seed source over all other species during the overstory removal phase, the proportion of hemlock tended to decline during the period under both shelterwood treatments.

A notable difference between the two shelterwood treatments was that under the 2-pass treatment, non-merchantable trees were left during the final overstory removal, while all trees >2 in dbh were cut in the 3-pass treatment. Thus, among trees >0.5 in dbh, there was about 30 ft^2 of basal area per acre following overstory removal in the 2-pass treatment but less than 10 ft^2 in the 3-pass treatment (Figure 1). Following overstory removal in the 2-pass compartments, hemlock accounted for over 3 ft^2 of basal area, almost entirely in residual, unmerchantable trees. There was very little basal area of hemlock following overstory removal in the 3-pass compartments and what was present was advanced regeneration >0.5 in dbh.

After an initial decline in the proportion of hemlock basal area in the 2-pass shelterwood compartments, growth of the residual trees and of advance regeneration returned

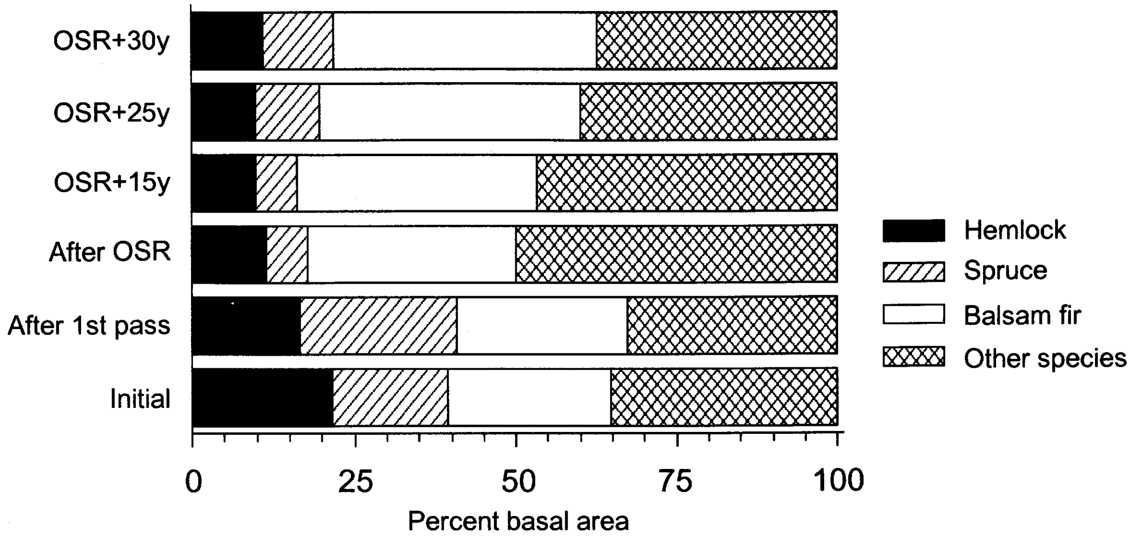

Figure 2.—Species composition history for 2-pass shelterwood compartments at the Penobscot Experimental Forest. OSR = overstory removal.

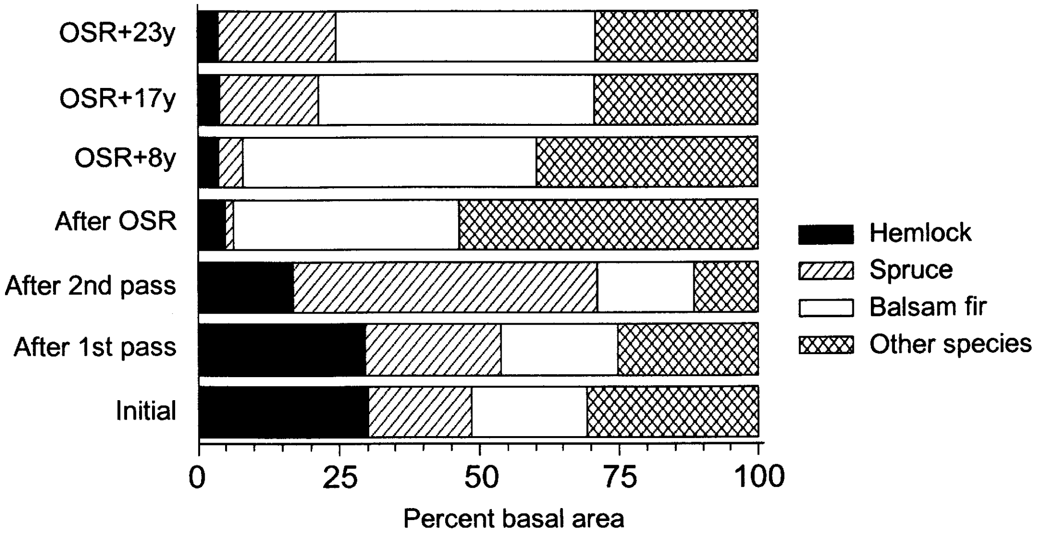

Figure 3.—Species composition history for 3-pass shelterwood compartments (without subsequent spacing) at the Penobscot Experimental Forest. OSR = overstory removal.

hemlock to what it was immediately after the overstory was removed, or about 60 percent of what it was prior to treatment (Figure 2). However, in the 3-pass compartments without spacing, hemlock has not recovered from a similar decline and its proportion has remained constant at about 5 percent (Figure 3). The proportion of hemlock in the spaced stands is even less. Hemlock is very well adapted to understory conditions (Spurr and Barnes 1980); the decline of hemlock after overstory removal is likely due to stress-induced mortality among advance regeneration and, in the 2-pass compartments, suppressed residual trees caused by the relatively sudden opening up of the stands. That stress was greater in the 3-pass compartments than in the 2-pass treatment where some shelter was retained in the residual trees.

At this point in the study, stand basal area of the two treatments is almost the same (Figure 1), even though the regenerating stands under the 2-pass treatment were released about 7 years earlier and had a substantial initial basal area advantage over the 3-pass stands. Clearly, the residual trees have suppressed stand growth. Although the proportion of hemlock is relatively small in both treatments, it is constant or increasing slightly with time. Thus, hemlock is apparently growing at near the average stand growth rate. Without intermediate treatments such as thinning, the proportion of hemlock in both treatments will increase because trees of more light-demanding and shorter-lived species will die as the stands continue to grow and mature.

Uneven-age

A review of the structural development of the PEF selection stands is critical to understanding the behavior of the component species. Without exception, the stands have not yet attained the target structural goals. Pre-cut basal area has been less than the post-cut goal in every entry in the 5-year stands, with only a few pre-cut inventories slightly exceeding the post-cut goal in the 10-year stands (Figure 4). Results from the 20-year cutting cycle show better agreement between target and actual basal area. However, they also reveal a very heavy cut, greater than 50 percent of the total stand basal area, that undoubtedly changed age structure and growth dynamics in these stands.

Evaluation of diameter distributions for all species combined reveals that structural imbalances have developed over the past 40 years under all three cutting cycles. Although the diameter distributions were initially close to the specified goals, surpluses of large trees and deficits in the pole and sapling classes have become apparent. The two most likely explanations for this deviation from the specified target diameter distributions are: (1) past marking practices which removed older trees from the smaller classes while leaving vigorous upper canopy trees, and (2) slow rates of ingrowth into the merchantable classes (Seymour and Kenefic 1998). The former problem appears to be due to poor age-size relationships in the stands, while the latter may result from the rapid closure of single-tree canopy openings.

The diameter distributions of the eastern hemlock component of the selection stands confirm that this species exhibits the stand-level patterns of change described above; that is, the number of trees in the pole classes dropped over time while sawtimber accumulated (Figure 5). Although deficits have developed in the pole classes, abundance and stocking of balsam fir, hemlock, and spruce regeneration far exceed the numbers needed to ensure their presence in the future stands (Brissette 1996). Furthermore, those seedlings are growing into the larger size classes. For example, the number of hemlock saplings in the 1 in dbh class increased over the 40-year period under all cutting cycles (Figure 5). Moreover, the magnitude of this increase is greatest under the longer cutting cycle (lower residual basal area).

In the plan for the long-term study, species compositional goals (expressed as percentage of basal area of trees >0.5 in) were specified with the objective of increasing the proportion of spruce while decreasing hemlock and balsam fir. The goals for hemlock (15-25 percent) and spruce (35-55 percent) led researchers to mark hemlock for harvest and leave spruce where possible. While the spruce component has increased under all cutting cycles, results for hemlock are mixed (Figure 6). Hemlock has flourished under selection cutting on a 5-year cycle, despite repeated attempts to reduce the hemlock component in these stands. Furthermore, analysis of the age structure for the two 5-year stands shows that the hemlock component is extremely uneven-aged, with trees distributed across the range of age classes (Kenefic and Seymour 1999 [see also Kenefic and Seymour in this volume]). Red spruce, on the other hand, is restricted primarily to an age class that originated 100-120 years ago. Thus, as indicated by recruitment across age classes, hemlock exhibits compositional stability but spruce does not.

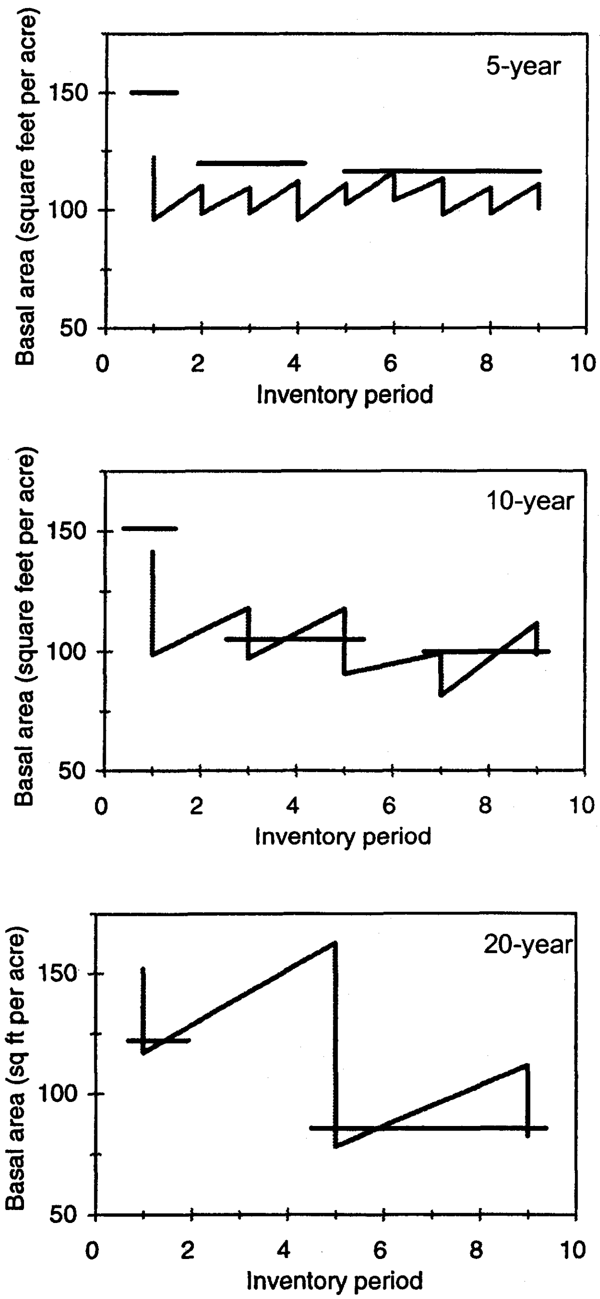

Figure 4.—Harvest and growth history of selection management compartments managed under three cutting cycles at the Penobscot Experimental Forest. (Horizontal lines indicate residual basal area goals.)

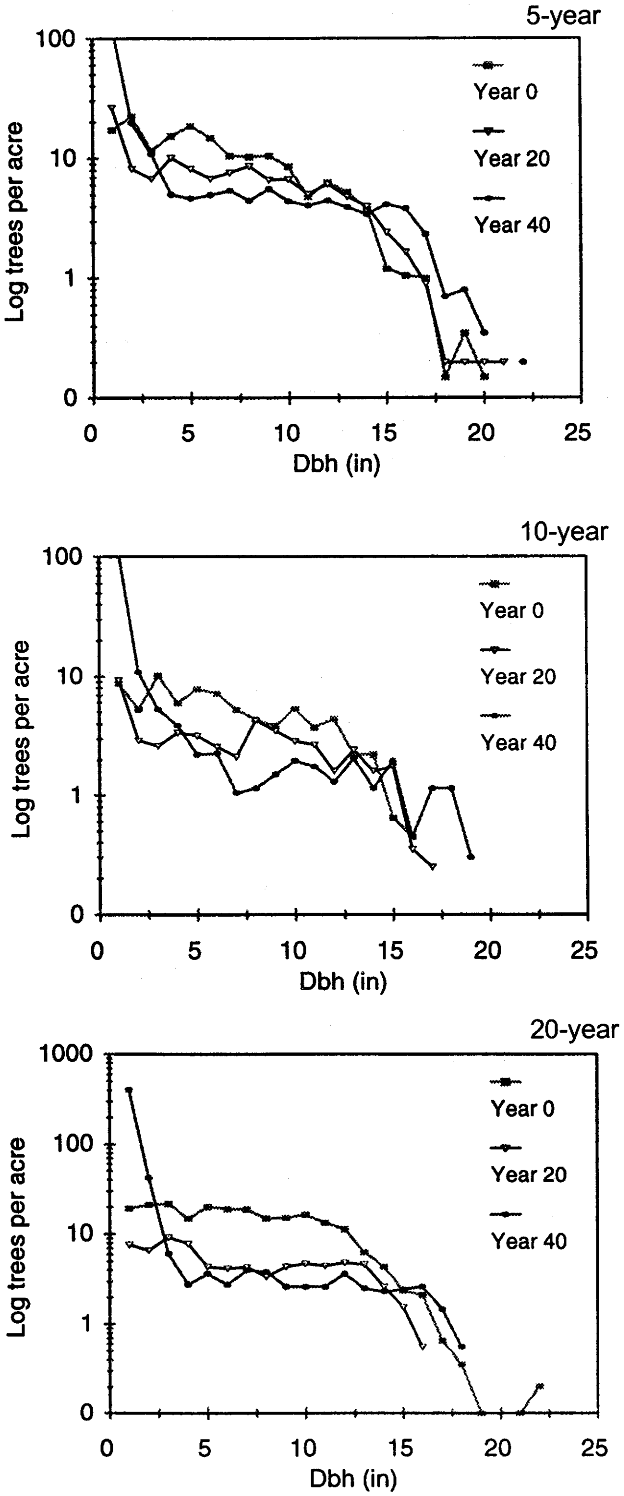

Figure 5.—Diameter distributions for hemlock under selection management with three cutting cycles at the Penobscot Experimental Forest.

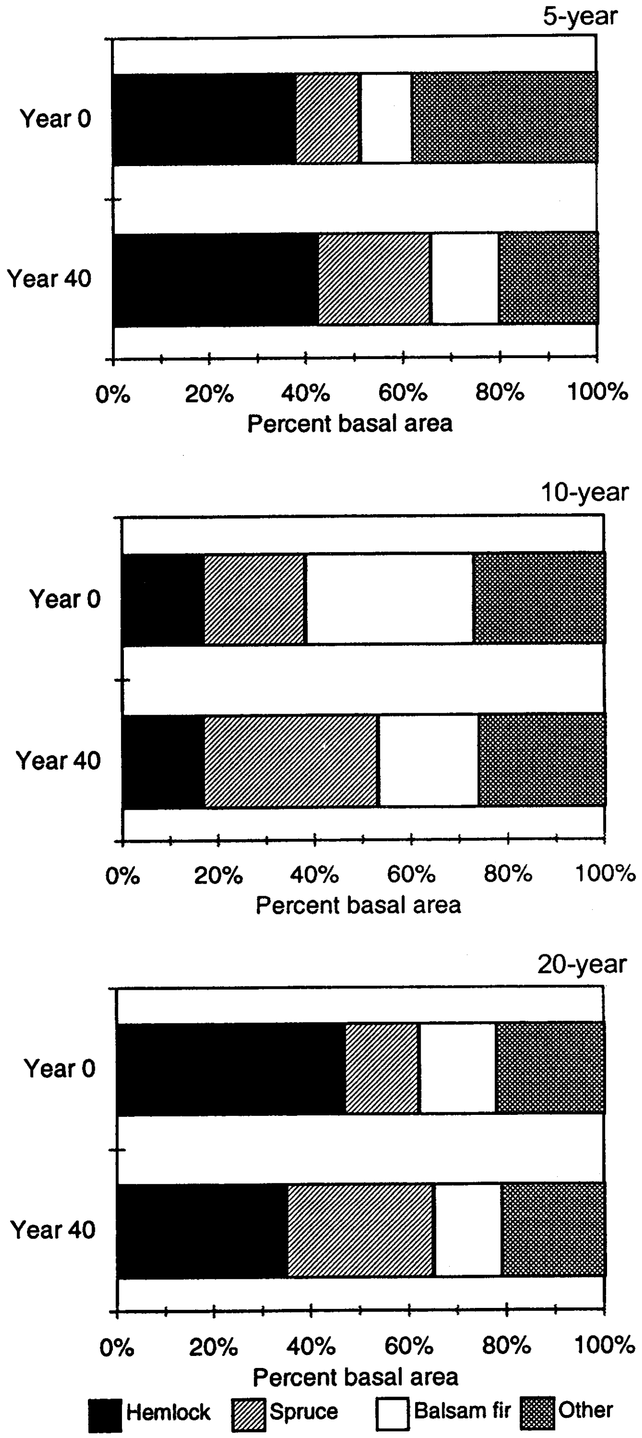

Figure 6.—Species composition history of selection management compartments managed under three cutting cycles at the Penobscot Experimental Forest. (Goals: Eastern hemlock 15-25%, spruce spp. 35-55%, Balsam fir 15-25%.)

Conclusion

Hemlock is well adapted to establish and grow in understory conditions typically found in the Acadia Forest Region. Consequently, it is an important component of many stands. The proportion of hemlock in a stand is determined to a large extent by openings in the overstory, either through natural disturbance or by manipulation during the regeneration phase of forest management. Results of the long-term study on the PEF show that extensive overstory removal, as with shelterwood silviculture or a stand-replacing natural disturbance, results in the regenerating stand having an even-aged structure and a relatively small proportion of hemlock. However, sporadic, small openings in a mature forest canopy leads to uneven-aged structure and favors hemlock to such an extent that it may become the dominant species in the stand. The persistence of eastern hemlock in the PEF selection stands has led us to conclude that this species is well suited to selection cutting in the mixed-species northern conifer forest type. The increase in the proportion of hemlock in the 5-year stands, where small canopy openings and high residual basal area predominate, is particularly noteworthy. Abundant regeneration under all cutting cycles and continuous recruitment of eastern hemlock (as evidenced by the species-specific age structures for the 5-year stands), indicate that this species regenerates prolifically and regeneration patterns suggest that the hemlock component of the PEF selection stands is sustainable, an important consideration when applying uneven-aged silviculture. Clearly, silviculture is a powerful tool managers can use to either limit or increase the proportion of hemlock in stands in the Acadian Forest.

References

Baldwin, V. C. 1977. **Regeneration following shelterwood cutting in a New Brunswick softwood stand.** Information Report M-X-76, Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, NB. 19 p.

Brissette, J. C. 1996. **Effects of intensity and frequency of harvesting on abundance, stocking and composition of natural regeneration in the Acadian Forest of eastern North America.** Silva Fennica. 30(2-3): 301-314.

Guldin, J. M. 1991. **Uneven-aged BDq regulation of Sierra Nevada mixed conifers.** Western Journal Applied Forestry. 6: 27-32.

Kenefic, L. S., Seymour, R. S. 1999. **Pattern of tree growth and structural development in uneven-aged northern conifer stands in the Acadian forest of Maine.** In: Emmingham, William H., comp. Proceedings of the IUFRO Symposium on Uneven-aged Silviculture; 1997 September 15-19, Corvallis, OR: 554-568.

Piene H.; Anderson, W. F. A. 1987. **Ten-year growth response to spacing in young balsam fir stands, Cape Breton Highlands, Nova Scotia.** In Murray, T.S.; Cameron, M.D., eds. Precommercial thinning workshop. Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, NB: 76-85.

Rowe, J. S. 1972. **Forest regions of Canada.** Publication 1300. Department of the Environment, Canadian Forestry Service, Ottawa. 172 p.

Safford, L. O. ; Frank, R. M.; Little, E. L. 1969. **Trees and shrubs of the Penobscot Experimental Forest, Penobscot County, Maine.** Res. Pap. NE-128. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 27 p.

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

Spurr, S. H.; Barnes, B. V. 1980. **Forest ecology, third edition.** John Wiley & Sons, New York. 687 p.

Wein, R. W.; Moore, J. M. 1977. **Fire history and rotations in the New Brunswick Acadian Forest.** Canadian Journal of Forest Research. 7(2): 285-294.

Wein, R. W.; Moore, J. M. 1979. **Fire history and recent fire rotation periods in the Nova Scotia Acadian Forest.** Canadian Journal of Forest Research. 9(2): 166-178.