Growth and Stocking of Eastern Hemlock (*Tsuga canadensis*) in New England

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Abstract

Summarization of the limited growth information in mixed-species stands in New England indicates that eastern hemlock (*Tsuga canadensis*) may be one of the fastest growing species in diameter, second only to white pine. However, on some sites hemlock diameter growth is about equal to that of associated hardwoods. Hemlock grows slowly in height and often endures long periods of suppression, which limits the usefulness of site index curves. Suppressed trees, once released, may grow relatively faster than non-suppressed trees. Hemlock stands attain high basal areas per acre, up to 240 square feet per acre, and recommended residual basal areas after thinning range from 100 to 140 square feet. Volumes may be as high as 4,500 cubic feet in 100-year-old stands, much higher than hardwood stands; however, both hemlock and hardwoods attain similar aboveground dry weights of about 85 tons per acre.

Introduction

Because of eastern hemlock's (*Tsuga canadensis*) moderate timber values, limited research has been conducted on growth and yield of the species, usually as a component of forest stands dominated by more valuable species. Hemlock, while considered a climax species, has both early- and late-successional species characteristics. Lorimer (1995) discussed stand structure of hemlock in association with both northern hardwood and northern conifer stands in the Lake States, indicating that seedling establishment can occur in open areas as well as under a closed canopy. Preferring moist sites, hemlock seedlings establish best in old growth stands and respond similar to shade tolerant species after disturbance in mature stands (Foster 1988). Hemlock averages 5-15 percent in northern hardwood stands and up to 40-60 percent in northern conifer stands (Solomon 1977, Solomon and Frank 1983). Information is available on diameter and height growth of individual trees, as well as basal area, volume growth, and stocking characteristics of stands with hemlock as a significant component. We'll present this information in summary form. Details on study methods and analytical procedures may be found in the cited literature.

Diameter Growth

In the beech-red maple ecological type in New Hampshire, hemlock grows about ¼ inch per year at the lower stand densities of 40-60 square feet per acre (Table 1) and about 1/5 to 1/6 inch per year at densities of 80 to 100 square feet (Solomon 1977). These growth rates are about double the rate of associated hardwoods such as red maple, and 50-100 percent faster than hemlock, spruce, or hardwoods in the hemlock-red spruce ecological type at the Penobscot Experimental Forest in Bradley, Maine (Solomon and Frank 1983). However, the hardwoods in the two areas are growing at similar rates. Possibly, the faster growth rates of hemlock in New Hampshire are due to the different soil/site conditions – well drained, sandy tills in New Hampshire as compared to the somewhat poorly drained soils at the Penobscot. Hemlock in northern hardwood stands is more open and free to grow while more apt to be suppressed in northern conifer stands. Hemlock is well known for its ability to endure long periods of suppression as evidenced by the occurrence of many small annual rings at the center of some trees. These diameter growth rates are comparable to a study at Harvard Forest that showed hemlock when suppressed for periods up to 40 years (and probably longer) and then released made relatively faster diameter growth than unsuppressed trees, and eventually surpassed the unsuppressed stems (Fig. 1) (Marshall 1927).

Regional level Forest Inventory and Analysis (FIA) plots indicate that basal area growth on individual hemlock trees in New England was faster than that of all other species except white pine (Fig. 2), and hemlock increased from 8-10 cm^2 in basal area growth over time from 1950 to 1980 (Hornbeck et al 1988). A larger increase in basal area growth across diameter classes was found on the Bartlett Forest during the period from 1920 to 1980 (Leak 1987a). FIA basal area growth figures for individual states also show an increase from 3-12 cm^2 in all six New England states from 1900 to 1980 (Smith et al 1990). Differences among states were somewhat inconsistent; however, in the last few decades, hemlock growth rates averaged 12 cm^2 in Maine and 9 cm^2 in New Hampshire.

Stand Growth and Stocking

Growth in basal area of spruce-fir-hemlock stands in Maine containing 22 to 55 percent hemlock does not vary greatly among residual density levels (Table 2) partly due to high levels of ingrowth at lower densities (Solomon and Frank 1983). However, survivor growth increases with increasing residual basal area, indicating that softwoods grow better and occupy a site more fully at high stand densities. Hardwood-hemlock stands in New Hampshire contain 6-12 percent hemlock (Solomon 1977). Net growth decreases with increases in residual basal area due to greater mortality, while survivor growth remains somewhat constant. Stocking guides for softwood and mixedwood stands confirm these growth relationships by placing the B-line (suggested residual density after thinning) at about 100-140 square feet of basal area per acre and 90-110 square feet, respectively (Solomon et al 1995, Fig. 3). Maximum average basal areas (A-line) reach 240 to 180 square feet for softwood and mixedwood stands, respectively. These high stocking levels are similar to those found in old-growth softwood/mixedwood stands (Leak 1987b, Table 3).

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Table 1.—Annual diameter growth of hemlock in hemlock-spruce-fir (Penobscot Experimental Forest, ME) and in beech-red maple (Bartlett Experimental Forest, NH) stands related to residual stand density. Ranges of growth are shown (in parentheses) among three cutting cycles (Penobscot) or for three levels of percent sawtimber classes (Bartlett) (Solomon and Frank 1983, Solomon 1977).

	Beech-red maple		Hemlock-spruce-fir		
Density	Hemlock	Red Maple	Hemlock	Spruces	Hardwoods
(ft²/acre)	......	......	*(inches)*	......	......
40	.29 (.23-.35)	.18 (.17-.19)	.14 (.09-.20)	.15 (.12-.19)	.17 (.16-.17)
60	.24 (.23-.24)	.14 (.12-.16)	.14 (.12-.16)	.12 (.11-.13)	.12 (.12-.13)
80	.19 (.18-.20)	.10 (.09-.11)	.13 (.12-.14)	.12 (.11-.13)	.12 (.11-.12)
100	.16 (.14-.19)	.07 (.07-.08)	.12 (.11-.13)	.11 (.11-.11)	.11 (.10-.11)
120	—	—	.10 (.09-.11)	.10 (.09-.11)	.11 (.09-.13)

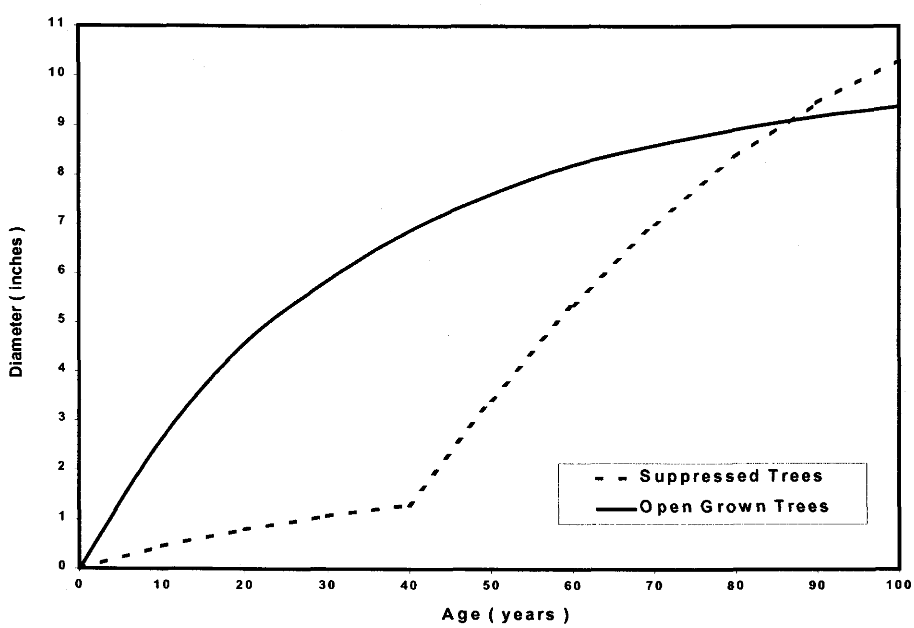

Figure 1.—The average diameter growth of unsuppressed hemlock trees contrasted with trees which were suppressed for 40 years, then released (adapted from Figure 8, Marshall 1927).

Resource managers frequently utilize forest tree models to simulate hemlock's growth and dynamics for different ecological habitats. Hemlock as a component of forest species composition is an essential part of both timber and wildlife management. The forest model FIBER (Solomon et al 1995) provides a reliable basis for simulating hemlock growth and development in both the beech-red maple and hemlock-red spruce ecological habitats (Figs. 4 and 5). A comparison of the measured and predicted basal area growth for softwood and hardwood stands indicate that hemlock development can be modeled through time.

FIA statistics, at a landscape level, indicate that hemlock growth percent based on cubic feet (gross growth minus mortality as a percent of initial volume) ranges from 1.1 percent in New Hampshire to 2.3 percent in Maine (Frieswyk

Table 2.—Net and survivor basal area and estimated volume growth (basal area X 25 ft³ per acre) by residual basal area for hemlock-spruce-fir stands in Maine contain 22-56 percent hemlock (Solomon and Frank 1983) and northern hardwood stands in New Hampshire contain 6-12 percent hemlock (Solomon 1977).

Basal area	Hemlock-spruce fir				Northern hardwoods			
	Net growth		Survivor growth		Net growth		Survivor growth	
(ft²/acre)	*(ft²/acre)*	*(ft³/acre)*	*(ft²/acre)*	*(ft³/acre)*	*(ft²/acre)*	*(ft³/acre)*	*(ft²/acre)*	*(ft³/acre)*
40	2.66 (1.96-2.86)	66.5	1.98 (1.64-2.19)	49.5	2.02 (1.84-2.22)	50.5	1.82 (1.78-1.90)	45.6
60	2.65 (2.54-2.74)	66.2	2.20 (2.14-2.31)	55.0	2.00 (1.71-2.29)	50.1	1.86 (1.76-1.92)	46.5
80	2.50 (2.38-2.61)	62.5	2.42 (2.36-2.49)	60.5	1.50 (1.15-1.69)	37.6	1.80 (1.62-1.95)	44.9
100	2.62 (2.58-2.70)	65.5	2.56 (2.53-2.59)	64.0	1.29 (0.91-1.74)	32.2	1.85 (1.69-2.02)	46.3
120	2.55 (2.32-2.71)	63.8	2.67 (2.48-2.81)	66.8	—	—	—	—

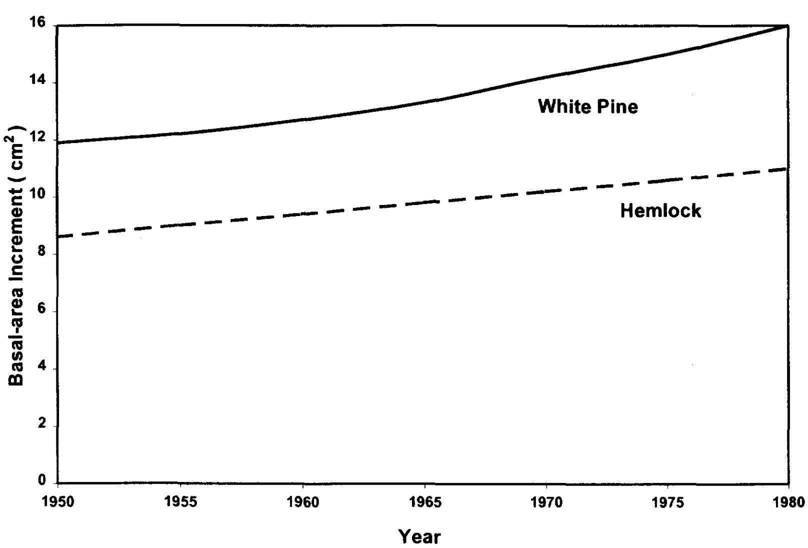

Figure 2.—Regional growth curves for major species in New England forests (adapted from Figure 1, Hornbeck et al 1988).

and Malley 1985, Griffith and Alerich 1996), considerably lower than growth percents of 3 or more commonly attained by white pine (Leak et al 1995). Cubic volumes per acre may reach 3500-4500 cubic feet per acre in 100-year-old mixedwood and softwood stands, considerably higher than volumes in most hardwood stands (Leak 1983, Fig. 6). Except for the poorly drained and enriched sites, biomass per acre appears very similar in both hardwoods and softwoods (Leak 1983, Fig. 7).

Height Growth

Hemlock height growth is relatively slow compared to most other species (Kelty 1986, Hibbs 1982, Fig. 8). Although there are site index curves for hemlock (Carmean et al 1989, Fig. 9), it is difficult to measure site index of this species since many trees are suppressed due to slow height growth. Studies of hemlock suppression demonstrate the ability of hemlock to survive under dense forest stand conditions and respond to release (Fig. 10) (Marshall 1927).

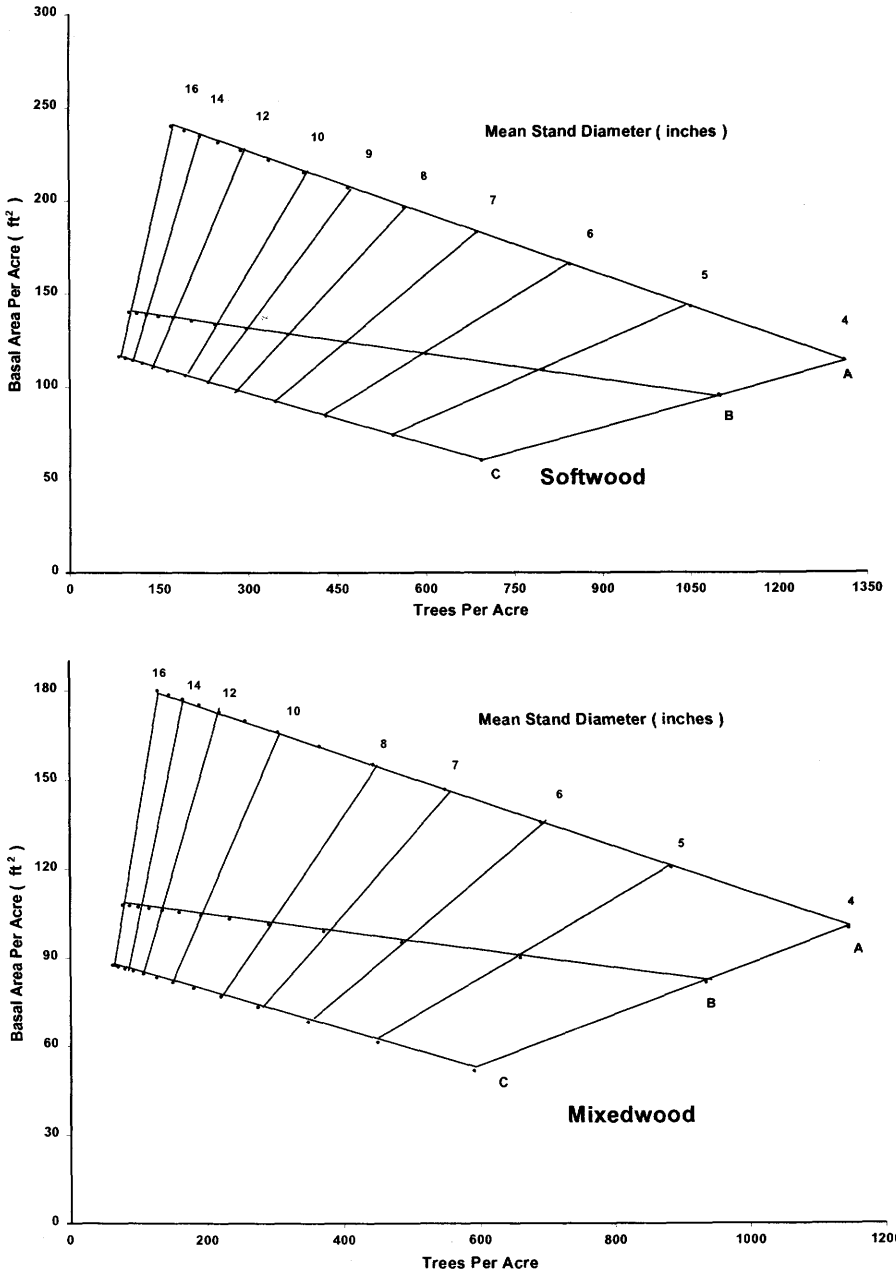

Figure 3a and b.—Stocking charts for softwood and mixedwood stands based on trees in the main crown canopy. The A line is average maximum stocking. The B line is recommended minimum stocking for adequate growth response per acre. The C line defines the minimum amount of acceptable growing stock for a manageable stand (adapted from Figures 3 and 4, Solomon et al 1995).

Table 3.—Basal area per acre by size class and percent hemlock, hardwood, and spruce for two old-growth hemlock/hardwood stands on the Bartlett Experimental Forest, NH (Leak 1987b).

	Diameter Class						Stand Composition		
Area	2-4	6-10	12-14	16-24	26+	All	Hemlock	Hardwood	Spruce
	ft^2						(%)		
Bartlett Ridge	13.9	55.0	45.0	68.9	3.3	186.7	60	24	16
Bartlett 19	17.1	77.1	51.4	83.6	3.6	232.8	60	28	11

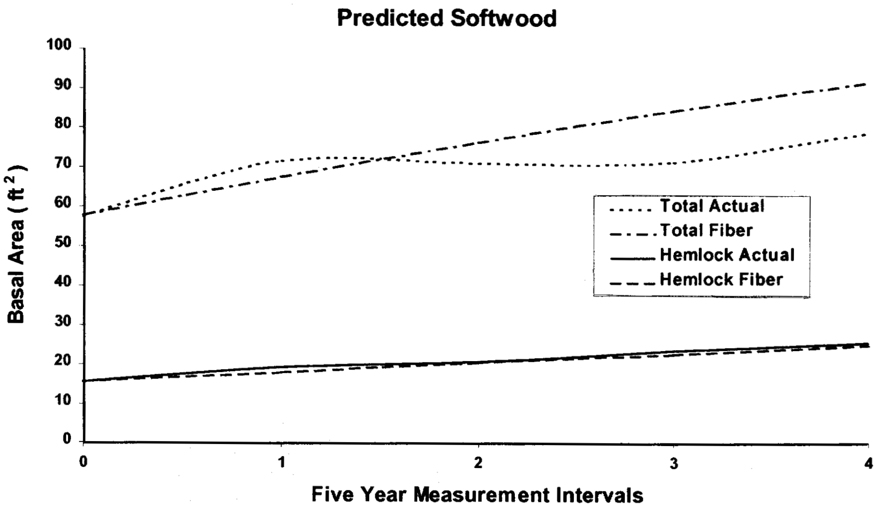

Figure 4.—Measured and FIBER (Solomon et al 1995) predicted softwood stand and hemlock basal area on Plot 32 Compartment 27 of the Penobscot Experimental Forest, Bradley, ME.

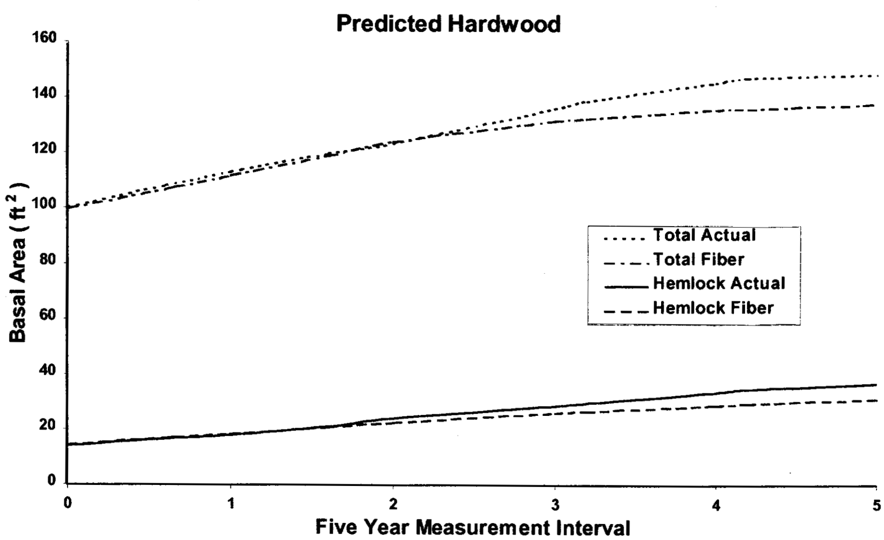

Figure 5.—Measured and FIBER (Solomon et al 1995) predicted hardwood stand and hemlock basal area on Plot 35 of the Bartlett Experimental Forest, NH Density Study.

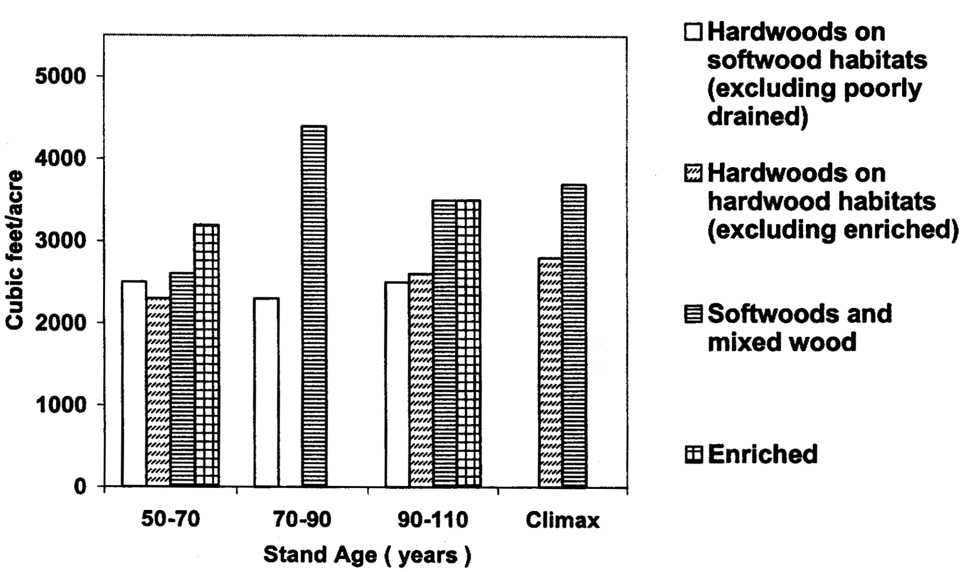

Figure 6.—Average cubic-foot volume per acre by forest habitat groups and stand age (adapted from Figure 13, Leak1983).

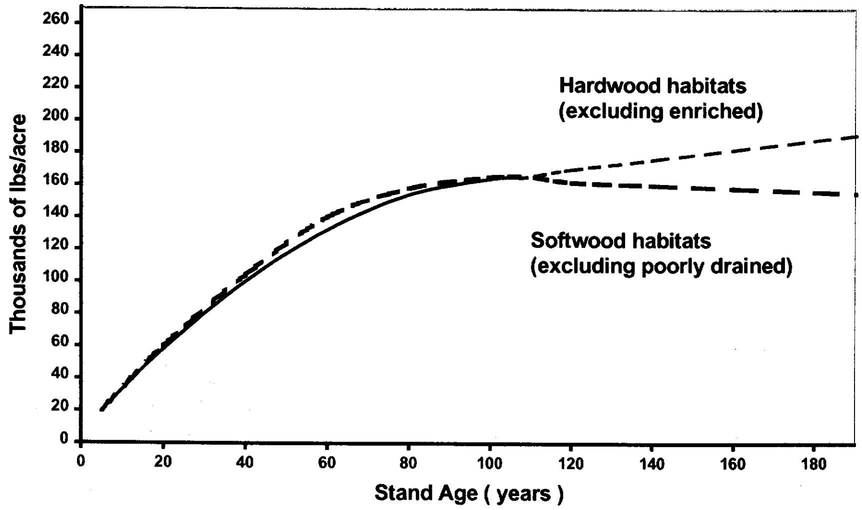

Figure 7.—Aboveground biomass (stems and branches) in dry weight over stand age by forest habitat groups (adapted from Figure 12, Leak 1983).

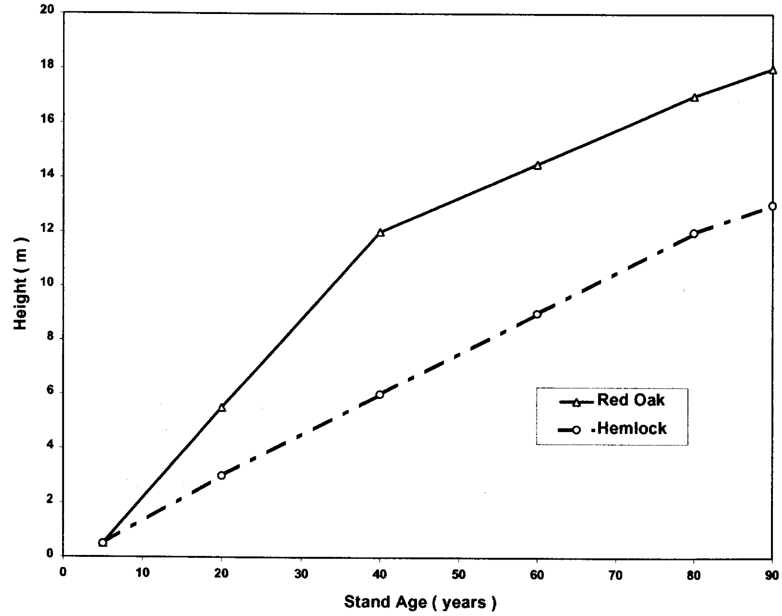

Figure 8.—Average cumulative height growth of Eastern hemlock (adapted from Figure 4a, Kelty 1986).

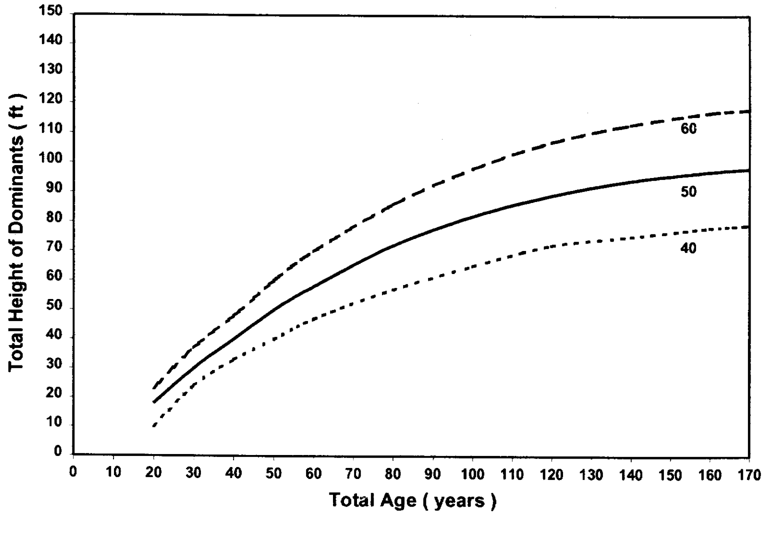

Figure 9.—Site index curves for Eastern hemlock (adapted from Figure 127, Carmean et al 1989).

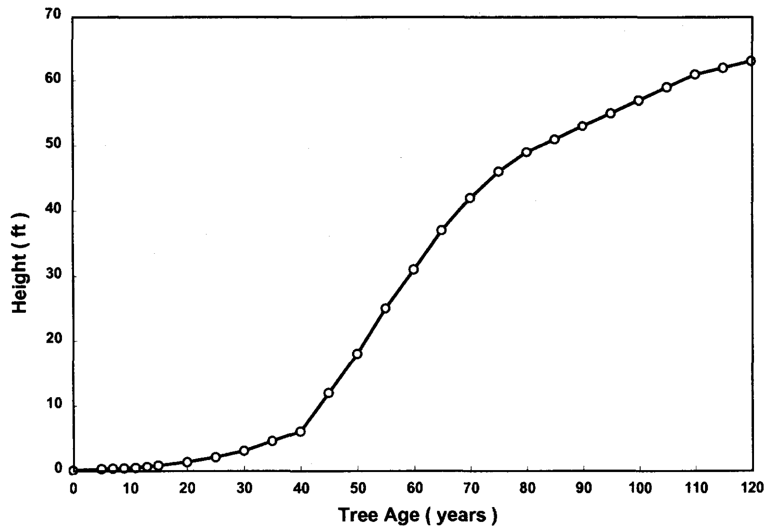

Figure 10.—Hemlock height growth after 40 years of suppression and then released.

References

Carmean, W. H.; Hahn, J. T.; Jacobs, R. D. 1989. **Site index curves for forest tree species in the eastern United States.** Gen. Tech. Rep. NC-128. U.S. Department of Agriculture, Forest Service. 142 p.

Foster, D. R. 1988. **Disturbance history, community organization and vegetation dynamics of the old-growth Pisgah Forest, south-western New Hampshire, U.S.A**. Journal of Ecology. 76: 105-134.

Frieswyk, T. S.; Malley, A. M. 1985. **Forest statistics for New Hampshire 1973 and 1983.** Resour. Bull. NE-88. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 100 p.

Griffith, D. M.; Alerich, C. L. 1996. **Forest statistics for Maine, 1995.** Resour. Bull. NE-135. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 134 p.

Hibbs, D. E. 1982. **Gap dynamics in a hemlock-hardwood forest.** Canadian Journal of Forest Research. 12: 522-527.

Hornbeck, J. W.; Smith, R. B.; Federer, C. A. 1988. **Growth trends in 10 species of trees in New England.** Canadian Journal of Forest Research. 18: 1337-1340.

Kelty, M. J. 1986. **Development patterns in two hemlock-hardwood stands in southern New England.** Canadian Journal of Forest Research. 16: 885-891.

Leak, W. B. 1983. **Habitat mapping and interpretation in New England.** Res. Pap. NE-496. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 28 p.

Leak, W. B. 1987a. **Comparison of standard and actual tree growth trends for deciduous and coniferous species in New Hampshire.** Canadian Journal of Forest Research. 17: 1297-1300.

Leak, W. B. 1987b. **Characteristics of five climax stands in New Hampshire.** Res. Note NE-336.U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Leak, W. B.; Cullen, J. B.; Frieswyk, T. S. 1995. **Dynamics of white pine in New England.** Res. Pap. NE-699. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Lorimer, C. G. 1995. **Dynamics and structural characteristics of Eastern hemlock stands.** In: Proceedings of a Regional Conference on Ecology and Management of Eastern Hemlock; 1995 September 27-28; Iron Mountain MI: 43-59.

Marshall, R. 1927. **The growth of hemlock before and after release from suppression.** Harvard Forest Bulletin No. 11. 43 p.

Smith, R. B.; Hornbeck, J. W.; Federer, C. A.; Krusic, P. J. Jr. 1990. **Regionally averaged diameter growth in New England forests.** Res. Pap. NE-637. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 26 p.

Solomon, D. S. 1977. **The influence of stand density and structure on growth of northern hardwoods in New England.** Res. Pap. NE-362. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 13 p.

Solomon, D. S.; Frank, R. M. 1983. **Growth response of managed uneven-aged northern conifer stands.** Res. Pap. NE-517. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 17 p.

Solomon, D. S.; Herman, D. A.; Leak, W. B. 1995. **FIBER 3.0: an ecological growth model for Northeastern forest types.** Gen. Tech. Rep. NE-204. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 24 p.