FIELD NOTE

Seventy Years of Understory Development by Elevation Class in a New Hampshire Mixed Forest: Management Implications

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ABSTRACT

New England forest managers are faced with numerous environmental issues, such as global warming, nutrient depletion, and species declines that could influence the choice of appropriate silvicultural techniques and objectives. On the Bartlett Experimental Forest, New Hampshire, 70 years of change on more than 400 remeasured cruise plots by elevation classes ranging from 600 to 2,700 ft showed no evidence of environmental impacts. The major, and only dominant, agent of change was natural succession. Time-tested silvicultural approaches remain valid.

Keywords: natural succession, northern hardwoods, climate change, red spruce decline, sugar maple decline

Forest managers in New England are faced with a growing array of environmental issues that could influence appropriate silvicultural approaches and techniques, such as choice of species, regeneration of new species mixtures, rotations, and size objectives. Acid rain, calcium depletion, aluminum toxicity, sugar maple decline, and spruce decline continue to be mentioned as serious concerns in New England (Horsley et al. 2002, Lazarus et al. 2004, Campbell et al. 2007, Likens and Franklin 2009). Recent studies in eastern United States and more specifically in Vermont have suggested that tree species are migrating in latitude or elevation because of climate change (Beckage et al. 2008, Woodall et al. 2009) and are being replaced by warmer-climate forest types and species. In addition, there are concerns about perceived increases of somewhat lower value species such as red maple (*Acer rubrum* L.) (Alderman et al. 2005) and beech (*Fagus grandifolia* Ehrh.), species with fairly low site requirements.

To provide long-term information on the extent and nature of species changes in New England, remeasurement data from 1931–1932 to 2002–2003 on 403 cruise plots (mostly ¼-ac) on the Bartlett Experimental Forest, New Hampshire, were analyzed at the landscape level. This forest, a 2,600-ac tract at the time of plot establishment, ranges in elevation from about 600 to 2,900 ft of elevation. The aspect is mostly north to northeast. Soils are derived from granitic bedrock and are of low to moderate fertility.

The forest consists of three distinct zones. The lower zone, ranging in elevation from about 600 to 1,100 ft, was mostly cleared in the late 1800s for logging railroad fuel coupled with a small amount of pasturage and settlement. A few patches of mostly softwoods remained. Since 1931, portions of the area have been lightly harvested for experimental thinnings, group-selection harvests, and growth studies, together with some early fuelwood cuttings. The soils are mostly sandy, washed tills supporting beech and red maple types with some areas of shallow hardpan supporting softwoods.

The middle zone, ranging from about 1,100 to 1,800 ft, was never cleared and supports uneven-aged stands of northern hardwoods with some softwoods along the drainages. Soils are commonly well-drained, sandy-loam tills with heavily washed materials along the drainages. Since 1931, most of these stands have been experimentally lightly harvested using single-tree and small-group selection. It is possible that there was harvesting of the best softwoods during the 1800s.

The upper zone, 1,800–2,900-ft elevation (cruise plots available up to 2,700 ft), supports spruce-fir stands growing on shallow bedrock with some small areas of deeper tills underlying northern hardwood species. These stands have never been extensively harvested to our knowledge. However, all of the zones, this upper zone especially, have been subjected to repeated heavy natural disturbances such as the hurricane of 1938 and the heavy ice storm of 1998. One of the cruise plots in this zone was remeasured in 1991 rather than 2003.

This article summarizes landscape-level changes primarily in understory species composition (trees of 1.5–4.5-in. dbh) by elevation and the three zones described above. Since tree numbers vary greatly between 1931–1932 and 2002–2003 (especially in the lowest zone because of changes in stand age), species composition is expressed as percentage of stems. The understory is featured because it is most responsive to change over the previous 70 years, is not directly affected by any harvesting removals and is most indicative of future species conditions. The few plots located in recently regenerated stands (clearcuts, shelterwoods) were eliminated from the analysis. Changes in species percentages between 1931–1932 and 2002–2003 were tested with paired *t* tests.

Results

The understories in the lower zone (mostly cleared in the late 1890s) reflected appreciable change due to natural succession (Table 1). The early- to midsuccessional species (red maple, yellow birch [*Betula alleghaniensis* Britton], paper birch [*Betula papyrifera* Marsh.] and aspen [*Populus* spp.]) had declined moderately to dramatically. Tolerant species, beech and hemlock (*Tsuga canadensis* [L.] Carr.), had increased greatly in percentage composition; beech

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Table 1. Percentage species composition based on numbers of seedlings/saplings (1.5–4.5-in. dbh) by elevation class and year in a low, disturbed zone.

		Species[a]													
Elevation (ft)	Year[b]	Fagr	Beal	Acsa	Acru	Bepa	Fram	Piru	Tsca	Abba	Potr	Pist	Quru	O	Total plot area (ac)
600–800	32	2	2	4	34	14	2	6	4	6	15	4	–	7	5.8
	03	19	1	7	18	1	3	9	8	26	–	–	1	7	
800–900	32	19	9	9	22	10	2	4	9	1	10	1	–	4	8.5
	03	48	2	6	9	1	–	6	22	1	–	–	–	5	
900–1000	32	25	15	5	23	2	1	7	14	3	2	–	–	3	15.75
	03	48	3	4	3	1	1	6	27	3	–	–	–	4	
1000–1100	32	32	14	8	13	2	1	9	15	4	–	–	–	2	17.25
	03	47	2	3	1	–	–	6	34	3	–	–	–	4	

[a] Fagr , beech; Beal, yellow birch; Acsa, sugar maple; Acru, red maple; Bepa, paper birch; Fram, white ash; Piru, red spruce; Tsca, hemlock; Abba, balsam fir; Potr, aspen; Pist, white pine; Quru, red oak; O, other species.
[b] 32, 1931–1932; 03, 2002–2003.
–, less than 0.5%.

Table 2. Percentage species composition based on numbers of seedlings/saplings (1.5–4.5-in. dbh) by elevation class and year in a middle, light management zone.

		Species[a]													
Elevation (ft)	Year[b]	Fagr	Beal	Acsa	Acru	Bepa	Fram	Piru	Tsca	Abba	Potr	Pist	Quru	O	Total plot area (ac)
1,100–1,200	32	46	15	9	3	1	–	4	19	–	–	–	–	3	7.25
	03	51	2	4	2	–	1	1	31	–	–	–	–	8	
1,200–1,300	32	48	14	14	5	2	–	2	12	–	–	–	–	3	6.5
	03	44	5	10	1	–	1	2	32	–	–	–	–	5	
1,300–1,400	32	40	15	8	3	2	–	8	20	–	–	–	–	4	6.25
	03	49	6	11	–	1	1	1	22	–	–	–	–	9	
1,400–1,500	32	25	15	6	5	2	–	14	24	–	–	–	–	9	5.25
	03	40	10	5	3	2	–	4	31	–	–	–	–	5	
1,500–1,600	32	39	13	6	6	1	–	9	22	–	–	–	–	4	5.0
	03	44	3	7	2	–	–	10	25	–	–	–	–	9	
1,600–1,700	32	37	14	8	4	3	–	8	13	–	–	–	–	13	3.0
	03	54	2	2	1	–	–	8	16	–	–	–	–	17	
1,700–1,800	32	33	9	4	5	3	2	22	10	3	–	–	–	9	3.75
	03	51	7	5	–	–	1	11	8	6	–	–	–	11	

[a] Fagr , beech; Beal, yellow birch; Acsa, sugar maple; Acru, red maple; Bepa, paper birch; Fram, white ash; Piru, red spruce; Tsca, hemlock; Abba, balsam fir; Potr, aspen; Pist, white pine; Quru, red oak; O, other species.
[b] 32, 1931–1932; 03, 2002–2003.

was nearly 50% of the understory and hemlock about 30%. Based on the paired *t* test analyses, these changes in beech, hemlock, and early/midsuccessional species are highly significant ($P < 0.01$). Sugar maple (*Acer saccharum* Marsh.) and especially white ash (*Fraxinus americana* L.) have never been common on these somewhat low-quality sites. Note that white pine (*Pinus strobus* L.) and red oak (*Quercus rubra* L.) are still minimal in these low-elevation understories, although these species are common in nearby areas on outwash sands, on south-facing shallow bedrock, or on a variety of sites in southern New Hampshire.

In the middle zone (light management, always forested), change due to natural succession has been less dramatic (Table 2). These stands were close to climax forest conditions at the beginning of the cruise plot record. Yellow birch, the only common early- to midsuccessional species, showed declines to single digits (one exception). Beech showed some slight to moderate increases but appeared to be reaching a peak at about 50% composition. Statistically, these trends varied from significant (beech, $P < 0.05$) to highly significant (yellow birch, $P < 0.01$). The beech-bark disease was discovered on the Bartlett Experimental Forest in the late 1940s but had minimal effects on understory proportions of beech (Leak 2006a) and no declines in overstory proportions (Leak 2006b). Sugar maple, never abundant, showed some slight increases and decreases; there is some evidence that sugar maple regeneration in this region is disturbance related (Leak 2005). The cruise-plot data on overstory

Table 3. Numbers per acre of poletimber (4.5–10.5-in. dbh), small sawtimber (10.5–16.5-in. dbh), and large sawtimber (16.5-in. dbh and over) for red spruce in the upper zone (1,800–2,700 ft elevation) and sugar maple in the middle zone (1,100–1,800 ft. elevation) by year.

Species	Year[a]	Poletimber	Small sawtimber	Large sawtimber
Red spruce	32	64.2	7.0	0.2
	03	52.0	15.4	2.0
Sugar maple	32	16.1	6.4	2.1
	03	11.2	6.8	4.8

[a] 32, 1931–1932; 03, 2002–2003.

trees showed moderate increases (about 36%) in sawtimber-sized sugar maple (Table 3), so there was no apparent impact from sugar maple decline. (Single-tree selection harvests in this zone had minimal effects on sugar maple stocking.) Hemlock remained a strong and increasing component ($P < 0.05$) at most elevations up to the 1,700–1,800-ft level, whereas red spruce (*Picea rubens* Sarg.) decreased moderately or remained steady. These two species are key to evaluating changes in elevation due to climate variations. They both occupy similar soils (Leak 1982); however, hemlock grows best at lower elevations than red spruce and occurs only sporadically at the highest elevations on the Bartlett Experimental Forest. In evaluating climatic responses, it is important to compare species that occupy similar soils (Lee et al. 2005).

Table 4. Percentage species composition based on numbers of seedlings/saplings (1.5–4.5-in. dbh) by elevation class and year in an upper, unmanaged zone.

Elevation (ft)	Year[b]	Species[a]													Total plot area (ac)
		Fagr	Beal	Acsa	Acru	Bepa	Fram	Piru	Tsca	Abba	Potr	Pist	Quru	O	
1,800–1,900	32	49	10	6	4	5	–	9	9	–	–	–	–	8	4.25
	03	63	4	3	–	–	–	9	15	1	–	–	–	5	
1,900–2,000	32	37	2	2	5	1	–	36	7	5	–	–	–	5	3.75
	03	61	1	2	2	1	–	21	4	2	–	–	–	6	
2,000–2,100	32	31	2	1	2	1	–	50	2	6	–	–	–	5	2.75
	03	53	4	–	1	1	–	22	2	3	–	–	–	14	
2,100–2,200	32	11	5	1	3	6	–	55	2	13	–	–	–	4	2.0
	03	26	3	–	4	5	–	44	1	10	–	–	–	7	
2,200–2,300	32	14	9	1	4	3	–	53	–	10	–	–	–	6	0.75
	03	50	2	–	1	–	–	30	4	2	–	–	–	11	
2,300–2,400	32	8	3	–	2	10	–	47	1	25	–	–	–	4	1.25
	03	34	8	–	2	2	–	33	–	12	–	–	–	9	
2,400–2,700	32	4	9	–	3	29	–	29	–	22	–	–	–	4	1.25
	03	12	12	–	2	3	–	32	–	35	–	–	–	4	

[a] Fagr , beech; Beal, yellow birch; Acsa, sugar maple; Acru, red maple; Bepa, paper birch; Fram, white ash; Piru, red spruce; Tsca, hemlock; Abba, balsam fir; Potr, aspen; Pist, white pine; Quru, red oak; O, other species.
[b] 32, 1931–1932; 03, 2002–2003.

In the upper elevational zone (Table 4), hemlock declined or remained minimally present or absent above the 1,800–1,900-ft zone. If climatic warming were operative, we would expect hemlock to replace red spruce. Red spruce remained as the dominant softwood (along with balsam fir at the uppermost elevation), although its presence had declined significantly ($P < 0.05$), apparently because of inroads from beech (a highly significant increase, $P < 0.01$). Beech is not climatically limited at these elevations (Solomon and Leak 1993) and is very aggressive because of its suckering capability. Sawtimber-sized red spruce more than doubled over time (Table 3), indicating that spruce decline was not evident on the Bartlett Experimental Forest. There were scattered mature red oak and white pine on shallow bedrock at these upper elevations, especially where the aspect is slightly south; however, no significant regeneration had developed.

Management Applications

In summary:

1. Despite environmental concerns, which remain as important and legitimate areas of study, natural succession appears to have been the major agent of change affecting understory forest conditions on the Bartlett Experimental Forest, New Hampshire. Decline of red spruce and sugar maple is not evident since sawtimber proportions have increased moderately to substantially over the past 70 years. Red spruce has become somewhat less common in the understory of the upper elevation zone, but this can be attributed to the increased abundance of beech.
2. Natural succession under light management or no management has led toward much greater domination of beech and to a lesser extent hemlock. Beech has increased through time in almost every elevation zone up to 2,700 ft, and hemlock has increased in almost every zone up to 1900 ft, beyond which the species is mostly absent. If this trend is not desired, well-documented silvicultural techniques can be used, including clearcutting, group/patch selection, and low-density shelterwoods.
3. Red maple understories at low elevations decreased substantially over time, probably because of natural succession, and red maple never was a major component in the mature stands at middle and upper elevations. Red maple in this region is a midsuccessional species, especially aggressive on lower-quality sites better suited to softwoods (Leak 1982), which gradually diminishes through natural succession.
4. These findings should apply to northern hardwood-hemlock-red spruce stands in northern New England on soils derived from granite or similar bedrock of low to moderate fertility.

Literature Cited

ALDERMAN, D.R., M.S. BUMGARDNER, AND J.E. BAUMGRAS. 2005. An assessment of the red maple resource in the Northeastern United States. *North. J. Appl. For.* 22(3):181–189.

BECKAGE, B., B. OSBORNE, D.G. GAVIN, C. PUCKO, T. SICCAMA, AND T. PERKINS. 2008. A rapid upward shift of a forest ecotone during 40 years of warming in the Green Mountains of Vermont. *Proc. Natl. Acad. Sci. USA* 105(11):4197–4202.

CAMPBELL, J.L., C.T. DRISCOLL, C. EAGAR, G.E. LIKENS, T.G. SICCAMA, C.E. JOHNSON, T.J. FAHEY, S.P. HAMBURG, R.T. HOLMES, A.S. BAILEY, AND D.C. BUSO. 2007. *Long-term trends from ecosystem research at the Hubbard Brook Experimental Forest*. US For. Serv., North. Res. Stn., Gen. Tech. Rep. NRS-17. 41 p.

HORSLEY, S.B., R.P. LONG, S.W. BAILEY, R.A. HALLETT, AND P.M. WARGO. 2002. Health of eastern North American sugar maple forests and factors affecting decline. *North. J. Appl. For.* 19(1):34–44.

LAZARUS, B.E., P.G. SCHABERG, D.H. DEHAYES, AND G.J. HAWLEY. 2004. Severe red spruce winter injury in 2003 creates unusual ecological event in the northeastern United States. *Can. J. For. Res.* 34:1784–1788.

LEAK, W.B. 1982. *Habitat mapping and interpretation in New England.* US For. Serv. Northeast For. Exp. Stn. Res. Pap. NE-496. 28 p.

LEAK, W.B. 2005. Effects of small patch cutting on sugar maple regeneration in New Hampshire northern hardwoods. *North. J. Appl. For.* 22(1):68–70.

LEAK, W.B. 2006a. Sixty years of change in the sapling understories of northern hardwood selection stands in New Hampshire. *North. J. Appl. For.* 23(4):301–303.

LEAK, W.B. 2006b. Fifty-year impacts of the beech bark disease in the Bartlett Experimental Forest, New Hampshire. *North. J. Appl. For.* 23(2):141–143.

LEE, T.D., J.P. BARRRETT, AND B. HARTMAN. 2005. Elevation, substrate, and the potential for climate-induced tree migration in the White Mountains, New Hampshire, USA. *For. Ecol. Manag.* 212:75–91.

LIKENS, G.E., AND J.F. FRANKLIN. 2009. Ecosystem thinking in the northern forest—and beyond. *Bioscience* 59(6):511–513.

SOLOMON, D.S. AND W.B. LEAK. 1993. *Migration of tree species in New England based on elevational and regional analysis.* US For. Serv., Northeast For. Exp. Stn. Res. Pap. NE-688. 9 p.

WOODALL, C.W., C.M. OSWALT, J.A. WESTFALL, C.H. PERRY, M.D. NELSON, AND A.O. FINLEY. 2009. An indicator of tree migration in forests of the eastern United States. *For. Ecol. Manag.* 257:1434–1444.