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Sixty years of management and natural disturbance in a New England forested landscape

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Abstract

Changes in species composition of overstory trees (percent of basal area) and size class were monitored over 60 years on 441 cruise plots located on the Bartlett Experimental Forest, a 1052 ha experimental forest in the White Mountains of New Hampshire. The plots were analyzed by elevation class, landtype (deciduous and coniferous), and year (1931–32, 1939–40, and 1991–92) within managed and unmanaged stands. The primary changes in species composition over the 60-year period were due to natural succession, which resulted in marked increases (doubling) of the eastern hemlock (*Tsuga canadensis* (L.) Carr.) component, and consistent decreases in paper birch (*Betula papyrifera* Marsh.), yellow birch (*B. alleghaniensis* Britton) (at medium or low elevations), and aspen (*Populus* spp.). Timber management resulted in small decreases in the beech (*Fagus grandifolia* Ehrh.) and red spruce (*Picea rubens* Sarg.) component and slight increases in sugar maple (*Acer saccharum* Marsh.). Natural disturbances (beech-bark disease and hurricane damage) had only minor effects on species occurrence. No consistent evidence of red spruce (*Picea rubens* Sarg.) decline was detected. Eastern hemlock, a climatically sensitive species in northern New England with a limited elevational range, increased dramatically at moderate to low elevations, but showed little tendency to invade the highest elevation class; apparently, the warming trend reported elsewhere in New Hampshire is not occurring, or the species are not responding in terms of changes in elevational distribution. The results emphasize the resilience of New England forests and their resistance to exogenous disturbance.

Keywords: Forest ecosystem; Succession; Migration; Climate change

1. Introduction

Current emphasis in forest management and ecology is at the landscape ecosystem level (sensu Barnes et al., 1982) rather than the stand or community level. In both research and practice, this means that attention is focused on trends and impacts over time throughout an entire forested landscape resulting from the combined effects of perturbations and interactions involving smaller land units or land types that reflect characteristic combinations of climate, landform, soils, and vegetative communities. However, there are few examples in New England of long-term ecosystem-level changes where we have detailed knowledge of both the underlying small-scale disturbances and the influential environmental factors.

The Bartlett Experimental Forest, a 1050 ha tract of deciduous and coniferous forest in New Hamp-

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shire, provided an opportunity to examine ecosystem-level changes in vegetative conditions over a 60-year period with full knowledge of the natural and human-related disturbances during that period as well as the environmental characteristics of the tract. The primary disturbances were timber management (55% of the tract), beech bark disease (*Nectria coccinea var. faginata* Lohm. Wats. & Ayers), and hurricane damage – all operating against well-defined directional changes in species composition due to natural succession (Leak, 1991). The primary environmental characteristics were the elevation/climate complex gradient and ecological landtype (Avers et al., 1994). The purpose of the study, then, was to determine the ecosystem-level impacts of management, natural disturbance, succession, and tract characteristics on changes in species and structure of the tree vegetation over a 60-year period.

2. Methods

In 1931–32, the Bartlett Forest was gridded with about 500 permanent 0.1 ha square cruise plots spaced about 200 by 100 m apart. After an initial measurement of all woody stems larger than 3.8 cm diameter breast height (dbh), a majority (441) of the plots were remeasured by 1-inch (2.54 cm) dbh classes and species in 1939–40 (following the well-known 1938 hurricane) and 1991–92.

During the early '80s, the forest was mapped by ecological landtypes or habitats (Leak, 1982): 16 land unit types based on characteristic combinations of local topography, rock type, and parent materials supporting distinctive vegetative communities. From this map, the landtype of each cruise plot was determined. For purposes of this study, the landtypes were combined into two broad categories: (1) shallow (to pan or bedrock), water-laid, or rocky soils supporting mixed deciduous/coniferous stands with a coniferous climax, and (2) washed tills, fine tills, and enriched soils supporting deciduous stands with a deciduous climax (Fincher and Smith, 1994).

For analysis, the cruise plots were segregated into four elevation/vegetation zone classes (Leak and Graber, 1974; Cogbill and White, 1991): 200–350 m, 350–500 m, 500–650 m, and 650–820 m (close to the highest elevation on the forest) (Table 1, Fig. 1). The lowest elevation class contains stands that were heavily cut or clear-cut during the late 1800s

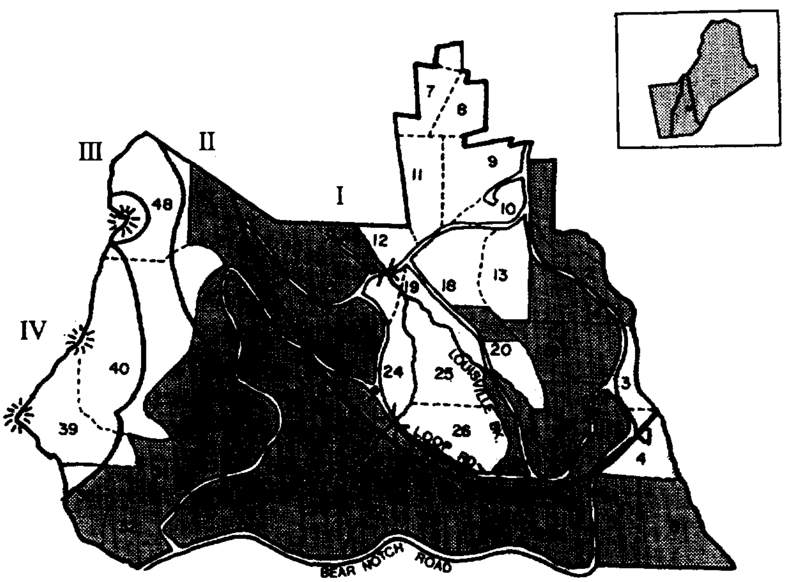

Fig. 1. The Bartlett Experimental Forest with elevation classes (I–IV) and managed (shaded) and unmanaged areas.

Table 1
Numbers of plots on the Bartlett Experimental Forest by elevation class, managed and unmanaged stands, and deciduous and coniferous ecological landtypes

Elevation class	Managed		Unmanaged		Totals
	Deciduous	Coniferous	Deciduous	Coniferous	
I (200–350 m)	44	64	24	84	216
II (350–500 m)	71	39	2	11	123
III (500–650 m)	37	15	5	25	82
IV (650–820 m)	0	0	0	20	20
All	152	118	31	140	441

for railroad fuel, and are now about 100 years old. The three upper elevation classes contain stands that were lightly cut for the best coniferous stems (spruce and a few pine) in the late 1800s; these stands are of irregular age and contain trees more than 200 years old.

About 577 ha of the forest (55%) were cut for experimental purposes during the 60–year analysis period using single-tree selection, diameter-limit cutting, group selection, clearcutting, shelterwood, and thinning. The details are described below. For analysis, the plots were segregated into two groups: managed and unmanaged (Table 1); cells with less than 15 plots were included in the analysis, but not reported in the results due to excess variability.

The data were tested by multivariate analysis of variance with repeated measurements (time period): the dependent variables were percent of basal area by species and size group in each of three time periods (1931–32, 1939–40, 1991–92). The size groups were poletimber (including saplings, trees 3.8 to 26.7 cm dbh), sawtimber (26.8 to 44.5 cm dbh), and large sawtimber (over 44.5 cm dbh), as well as all sizes combined. We used percent of basal area in defining the dependent variables because we were interested in the competitive position or relative dominance of species rather than absolute increases or decreases. The two independent variables were elevation class (4 levels) and landtype (2 types). Managed and unmanaged stands were analyzed separately because initial conditions differed appreciably due to the way stands were selected for management treatments; however, differences between managed and unmanaged areas in the direction of species trends provided some useful comparisons.

3. Disturbance history

To better understand the events influencing 60-year changes on the Bartlett Forest, a description of the disturbance events (management (Table 2), beech-bark disease, and hurricane damage) is required.

The individual-tree selection, diameter-limit and other partial cuts (379 ha total) were begun in the 1950s and early 1960s mostly as part of a compartment management study designed to test the long-term effects and feasibility of such treatments; some miscellaneous other partial cuttings (e.g. thinnings) are included in this category. Many of the stands were on deciduous landtypes and contained about 50% beech (*Fagus grandifolia* Ehrh.) or more together with sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), some hemlock (*Tsuga canadensis* (L.) Carr.), and other species. The initial cuts, which removed about 1/3 of the volume, primarily took beech, especially the larger ones, which were infected by beech-bark disease. Red maple (*Acer rubrum* L.) also was consistently marked; whereas, valuable timber species such as sugar maple and yellow birch were marked only when overmature or defective. A fairly complete record on one of the compartments harvested for a second time in 1975 indicated that the effects of treatment were to maintain a constant proportion of beech, reduce the amount of large sawtimber, and regenerate mostly tolerant species with a high proportion of beech suckers (Filip, 1978).

The group-selection cuttings (130 ha), begun in 1937, were repeated in the 1950s and 1960s on a pair of compartments (46 ha). The overall effect was to

Table 2
Harvesting on the Bartlett Experimental Forest

Cutting methods	Area (ha)	Percent	Period
Selection, partial cutting [a]	379	36	1951–1984
Group selection	130	12	1937–1966
Clearcut, liquidation	51	5	1934–1969
Shelterwood	17	2	1984
Unmanaged	475	45	1890–present
Total	1052	100	

[a] Includes thinning and diameter-limit cutting.

increase the proportion of non-tolerant species in the regeneration to 1/4 to 1/3 of the composition (Leak and Filip, 1977) as well as to reduce the proportion of large sawtimber. The clearcuttings, one applied in 1934–35, two in the early 1960s, and a commercial clear-cut in the 1950s (a total of 51 ha), increased the proportion of non-tolerant regeneration to about 3/5 (Leak and Wilson, 1958) and, of course, eliminated the sawtimber and poletimber components. An initial shelterwood seed cut (17 ha) in the 1980s completed the array of cutting operations. This recent cut has had little effect as yet on species mix, but eliminated poletimber and small sawtimber of both deciduous and coniferous species in the cutting area.

The influence of beech-bark disease on marking practices was described above. This disease infects beech stems predisposed to attack by the beech scale insect (*Cryptococcus fagisuga* Lind.) (Houston, 1983). This complex became widespread in the Bartlett area during the early 1940s. Special studies on the Bartlett Forest from 1952 to 1958 (Bjorkbom, 1959) indicated that about 70 to 90% of the beech contracted the disease, while about 90% supported light to heavy populations of the beech scale – a precursor to the disease. Mortality in New Hampshire due to beech-bark disease in the 1970s was estimated at up to 30% (Miller-Weeks, 1983). A preliminary study on the Bartlett Forest suggested that the disease had significant impacts on beech composition in mid- to lower-elevation stands containing hemlock (Twery and Patterson, 1984).

Hurricane damage on the Bartlett Forest from the 1938 storm destroyed about 9 and 11% of the deciduous and coniferous stems, respectively. However, higher elevation sites sustained more damage – up to 18 and 35% of the deciduous and coniferous stems. Damage was reported as greatest in large stems and managed areas. Among the deciduous species, the highest incidence of windthrow was in red maple, paper birch, and white ash (Leak et al., 1994).

Two other natural disturbances may be occurring on the Bartlett Forest: red spruce decline associated

Table 3
Percent of basal area by species, tree sizes (pole P, sawtimber S, large sawtimber L) and year for managed and unmanaged stands on the Bartlett Experimental Forest, with tests among years by tree size class

Sp.	Pole			Saw			Large saw			All			Tests for year			
	1931	1940	1992	1931	1940	1992	1931	1940	1992	1931	1940	1992	P	S	L	All
Managed stands																
BE	13.0	12.8	11.3	18.9	18.6	18.0	4.1	4.8	2.8	36.0	36.2	32.1	*	–	*	*
YB	9.3	7.9	3.3	6.2	6.5	5.9	1.8	2.1	1.1	17.3	16.5	10.3	*	–	*	*
SM	4.4	3.6	2.6	5.5	5.6	6.5	2.2	2.7	4.5	12.1	11.9	13.6	*	–	*	*
RM	6.5	6.1	2.4	3.2	4.1	7.9	0.4	0.5	1.8	10.1	10.7	12.1	*	*	*	*
PB	3.9	2.8	1.5	2.9	3.7	2.3	0.2	0.3	0.1	7.0	6.8	3.9	*	*	*	*
WA	1.2	1.0	0.6	1.2	1.7	1.6	0.1	0.1	1.2	2.5	2.8	3.4	*	–	*	*
ASP	1.3	0.7	0.3	0.2	0.3	0.2	0.0	0.0	0.1	1.5	1.0	0.5	*	–	–	–
EH	3.8	4.1	8.1	3.7	4.5	6.9	0.5	0.5	2.9	8.0	9.1	17.9	*	*	*	*
RS	2.3	2.1	1.0	1.4	1.5	1.3	0.0	0.1	0.2	3.7	3.7	2.5	*	–	*	*
BF	0.4	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.5	0.4	0.2	*	*	–	*
Unmanaged stands																
BE	7.7	7.7	7.3	6.1	6.5	8.0	0.7	0.9	0.6	14.5	15.1	15.9	–	*	*	*
YB	6.9	5.9	2.4	5.4	5.5	4.9	0.5	0.9	1.2	12.8	12.3	8.5	*	*	*	*
SM	3.4	2.8	1.3	2.8	3.0	3.9	0.6	0.6	1.1	6.8	6.4	6.3	*	–	*	–
RM	11.1	11.3	5.6	4.7	5.8	12.4	0.5	0.7	2.4	16.3	17.8	20.4	–	–	–	–
PB	8.8	8.0	1.6	5.3	5.7	4.2	0.3	0.7	0.8	14.4	14.5	6.6	*	–	*	*
WA	1.4	1.3	0.2	0.9	1.2	1.8	0.1	0.1	0.9	2.4	2.6	2.9	–	–	–	–
ASP	5.1	2.8	0.1	0.5	0.4	0.7	0.0	0.0	0.1	5.6	3.2	0.9	–	–	–	–
EH	4.1	4.0	6.7	4.0	4.3	6.8	0.3	0.4	3.7	8.4	8.7	17.2	*	–	–	*
RS	8.5	8.7	7.0	3.1	3.1	6.5	0.0	0.1	0.7	11.6	11.9	14.2	–	–	–	–
BF	2.0	1.9	1.6	0.2	0.3	0.2	0.0	0.0	0.0	2.2	2.2	1.8	–	–	–	–

* = 0.05 level.

with acid deposition (Shortle and Smith 1988; Hornbeck et al., 1988), especially at higher elevations; and migration of tree species upslope from climatic warming. Past research in New England has suggested that a 2-°C rise in average temperature has eliminated mid-slope red spruce in certain areas and been responsible for an upward displacement of the lower elevational boundary of this species by about 400 m (Hamburg and Cogbill, 1988). Evidence of these disturbances on the Bartlett Forest has not been confirmed by additional studies (Leak, 1987; Solomon and Leak, 1994), but both will be considered in interpreting the ecosystem-level changes described below.

4. Results

Results are separated into two broad categories: forest-wide changes and the effects of elevation and

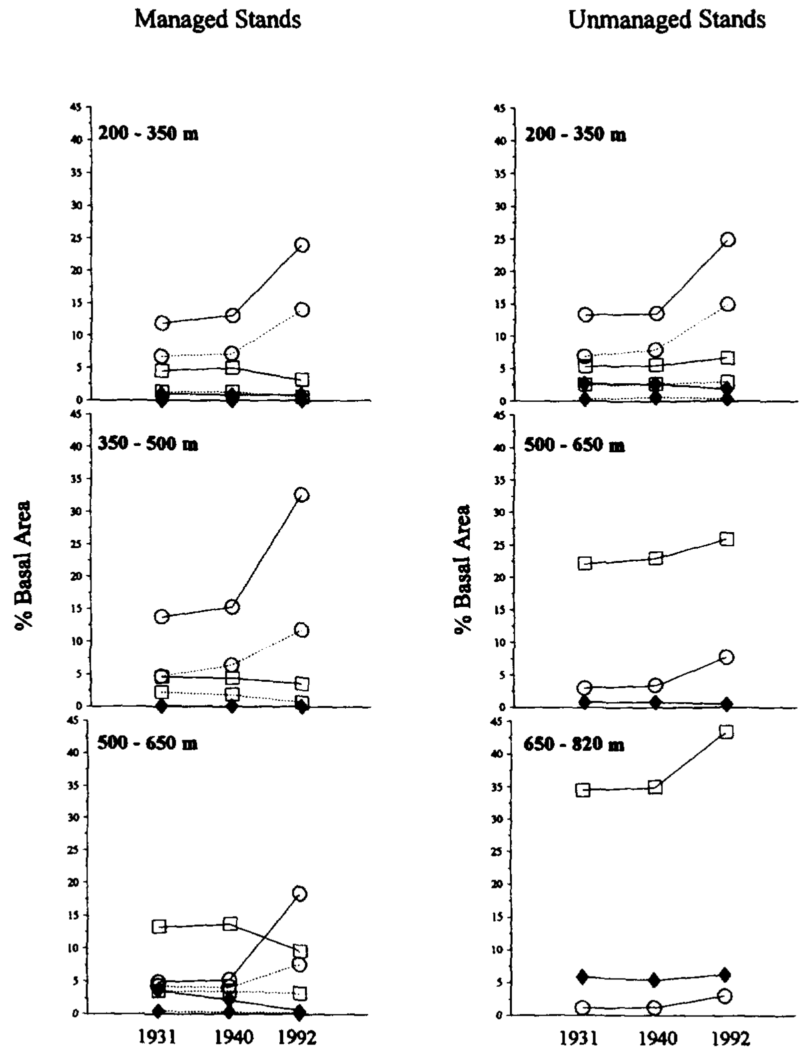

Fig. 2. Change in percent basal area of conifer species (Red Spruce □, Balsam Fir ♦, Eastern Hemlock ○) in managed and unmanaged stands over the three sampling periods 1931, 1940, and 1992. Solid lines represent species change on conifer landtypes, dotted lines represent species change on deciduous landtypes.

landtype. Within each category, patterns of species' occurrence are examined as well as changes over time as influenced by known forms of disturbance.

4.1. Forestwide changes

Beech, sugar maple, eastern hemlock, and red spruce are the common tolerant or climax species on the Bartlett Forest. On appropriate sites and without severe external disturbances, these species tend to increase over time to become major stand components (Leak, 1991). Declines in these species generally would denote significant external impacts from cutting, windthrow, disease or other environmental impact – something that moves the species composition back toward an earlier successional stage. On a forest-wide basis (Table 3; Figs. 2 and 3), these species increased, remained about steady, or declined slightly in either the managed or unmanaged areas. Despite the beech-bark disease and concentrated tim-

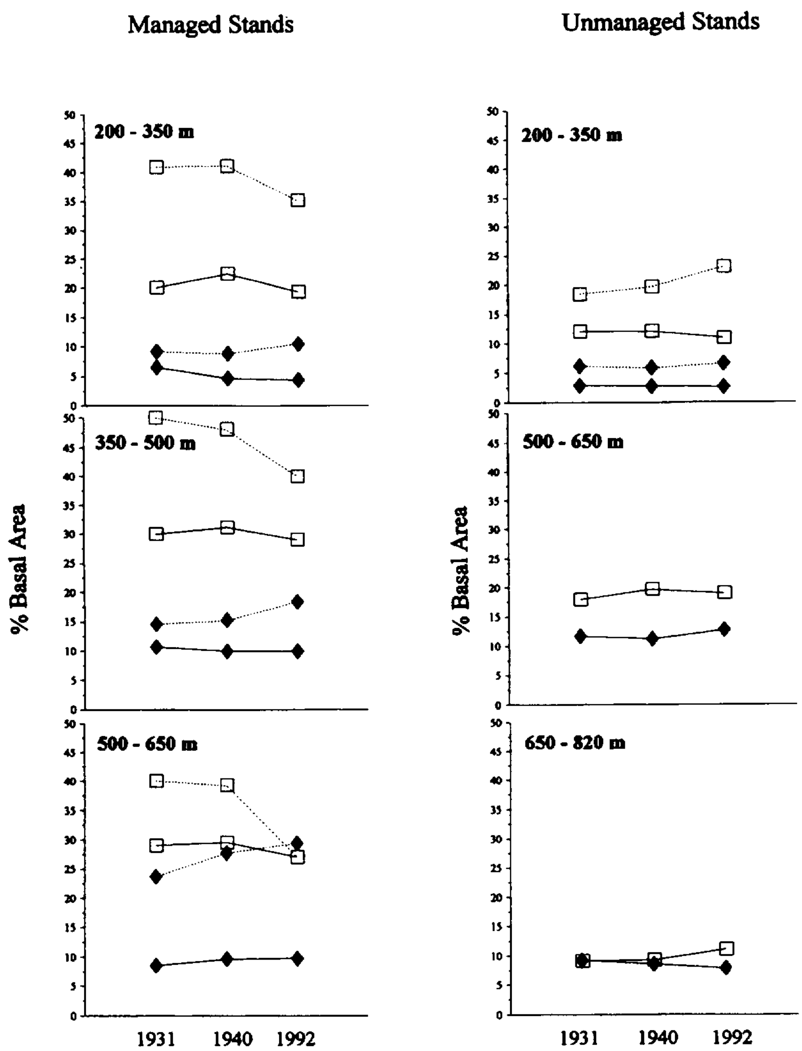

Fig. 3. Change in percent basal area of tolerant deciduous species (Beech □, Sugar Maple ◆) in managed and unmanaged stands over the three sampling periods 1931, 1940, and 1992. Solid lines represent species change on conifer landtypes, dotted lines represent species change on deciduous landtypes.

ber marking, beech (all sizes together) increased slightly in the unmanaged stands and declined by only 4% (from 36.0 to 32.1) under management. Sugar maple increased by $1\frac{1}{2}$% (from 11.9 to 13.6) under management since it was favored for retention in timber marking operations. In unmanaged stands, where red spruce was fairly abundant, the species increased by about $2\frac{1}{2}$% (non-significant); in managed stands, there was a slight decline. Apparently spruce decline is not evident on a forestwide basis. Eastern hemlock was the only tolerant species that showed a major increase over time: more than doubling in percent composition on both the managed and the unmanaged areas. In the late 1800s, hemlock in some areas of the White Mountains, was heavily cut for bark tannin; the current increase in this species may represent a long-term successional rebound from these early removals.

Red maple, yellow birch, and white ash (*Fraxinus americana* L.) are species of intermediate tolerance.

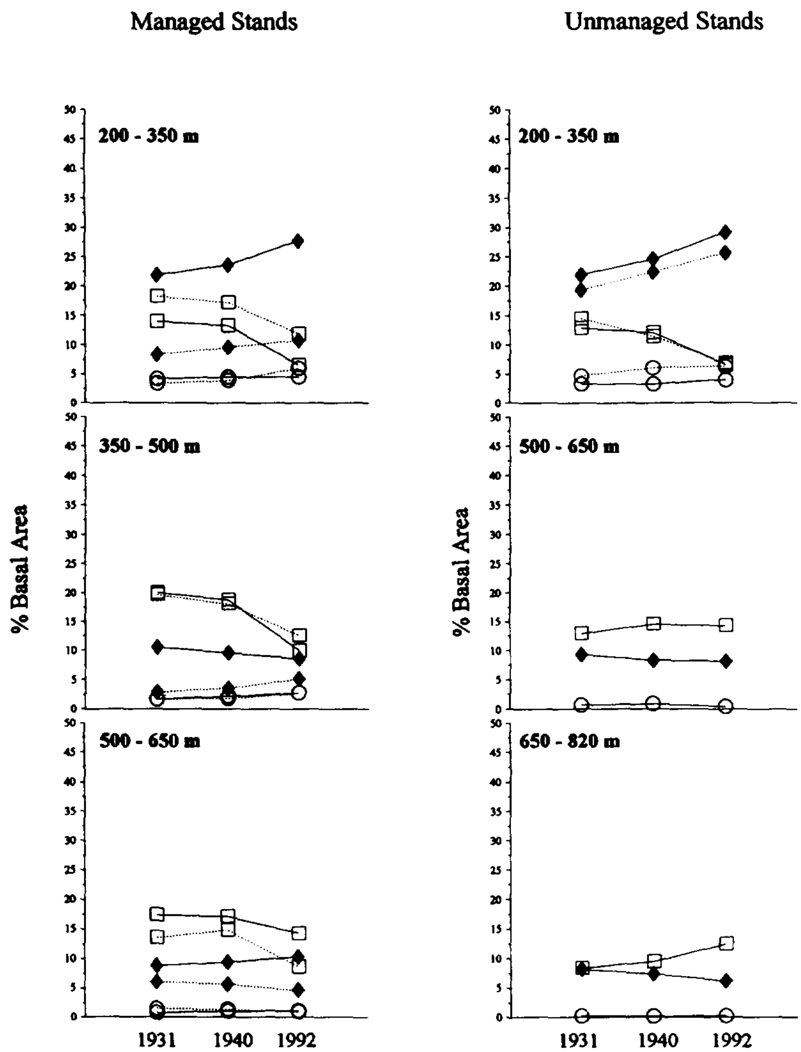

Fig. 4. Change in percent basal area of mid-tolerant deciduous species (Yellow Birch □, Red Maple ♦, White Ash ○) in managed and unmanaged stands over the three sampling periods 1931, 1940, 1992. Solid lines represent species change on conifer landtypes, dotted lines represent species change on deciduous landtypes.

These mid-successional species tend to decline slowly over time in old, unmanaged stands; yet, they will regenerate in small openings created by cutting or natural disturbance. Of the three, red maple is the more tolerant, aggressive, and faster growing. Forestwide, yellow birch declined markedly in both managed and unmanaged areas, a somewhat unusual phenomena because its longevity is greater than that of the other two intermediates; timber cutting may have played some role in the reduction of large yellow birch under management. Red maple and white ash increased under managed and unmanaged conditions (non-significant) despite the fact that white ash was highly favored for retention in timber operations while red maple was heavily marked (Table 3, Fig. 4). All three species showed marked declines in poletimber percentages, indicating that natural or human disturbance was too light to cause significant amounts of regeneration and ingrowth.

As expected, the shade intolerant species (paper

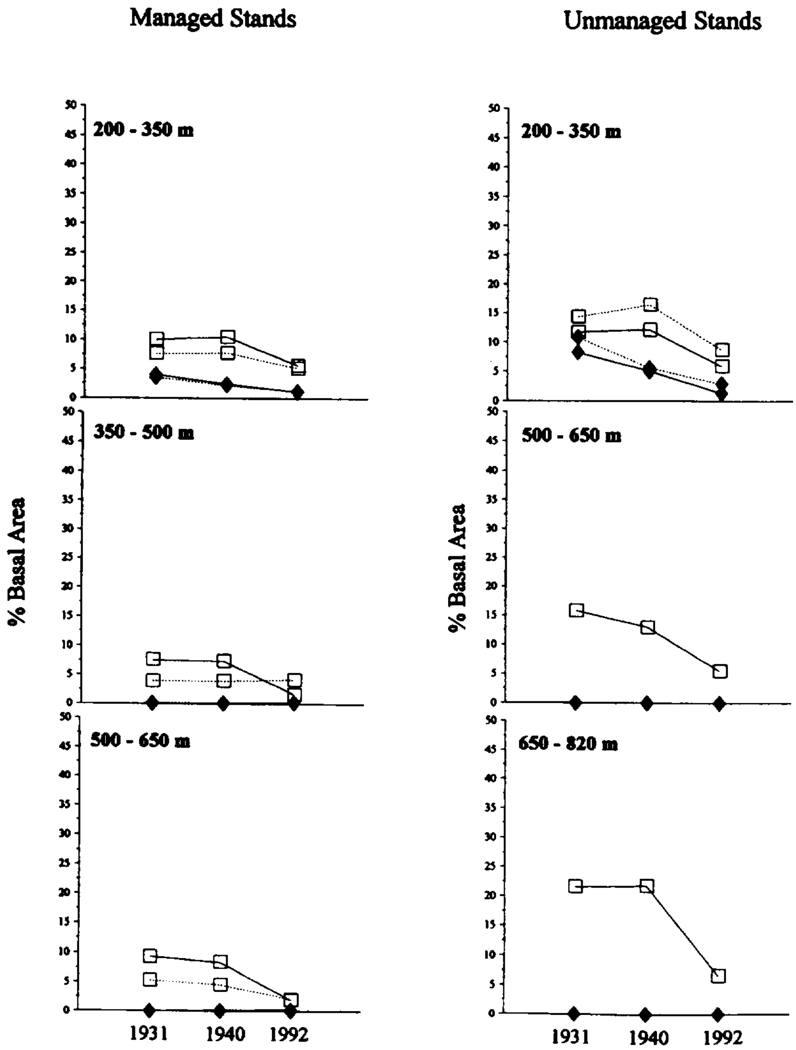

Fig. 5. Change in percent basal area of intolerant deciduous species (Paper Birch □, Aspen ◆) in managed and unmanaged stands over the three sampling periods 1930, 1940, 1992. Solid lines represent species change on conifer landtypes, dotted lines represent species change on deciduous landtypes.

birch (*B. papyrifera* Marsh.) and minor amounts of aspen (*Populus* spp.)) declined over time (Table 3, Fig. 5). Paper birch, which seldom exceeds 100 years of age, showed declines comparable to yellow birch, which easily reaches 250–300 years old.

Nearly all species showed declines in proportions of poletimber (Table 3), which is common in a maturing forest. However, hemlock increased and beech declined only slightly, indicating that these species will become more predominant as succession proceeds. Red maple sawtimber increased sharply, especially in unmanaged stands; otherwise, changes in structure over the 60-year period were not striking.

Differences between the 1931 and 1940 percentages (Table 3) primarily reflect the impact of the 1938 hurricane. Despite the intensity of this storm, the overall effects of windthrow appear minor: losses or gains of 1 or 2%.

4.2. Elevation and landtype

Percentage composition of most species differed between landtypes (deciduous and coniferous), elevation, and year. Differences were most significant on the managed area (Table 4) as compared with the unmanaged (Table 5, Figs. 2–5), partly due to a more uniform distribution of plots on the former.

Table 4
Percent of basal area by species, elevation class (E), year (Y), and deciduous (D) or coniferous (C) landtype (T) for managed stands on the Bartlett Experimental Forest, with significance test (* = 0.05) among factors and interactions with year

Sp.	200–350 m						350–500 m						500–650 m						T	E	Y	TY	EY
	1931		1940		1992		1931		1940		1992		1931		1940		1992						
	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C					
BE	40.9	20.0	41.0	22.4	35.1	19.3	50.0	30.0	48.1	31.2	40.1	29.0	40.0	29.0	39.2	29.5	40.0	27.0	*	*	*	–	–
YB	18.3	14.0	17.2	13.3	11.9	6.6	19.7	20.1	18.1	18.8	12.6	10.0	13.6	17.4	14.8	17.1	8.6	14.3	–	*	*	–	*
SM	9.2	6.5	8.9	4.7	10.5	4.4	14.6	10.7	15.2	9.9	18.4	9.9	23.7	8.5	27.7	9.6	29.4	9.7	*	*	*	*	–
RM	8.4	21.9	9.6	23.6	10.8	27.7	2.9	10.6	3.5	9.6	5.1	8.6	6.0	8.8	5.6	9.4	4.6	10.3	*	*	*	–	*
PB	7.6	10.0	7.7	10.4	5.1	5.6	3.9	7.5	3.9	7.3	4.1	1.6	5.3	9.3	4.6	8.4	2.0	1.9	*	*	*	*	–
WA	3.4	4.2	3.9	4.5	6.0	4.5	1.7	1.7	1.8	2.2	2.7	2.7	1.5	0.8	1.3	1.0	0.9	1.1	–	*	*	–	–
ASP	3.5	4.0	2.2	2.4	1.2	1.1	0.1	0.0	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.2	–	*	*	–	*
EH	6.8	11.9	7.2	13.1	14.0	24.0	4.7	13.8	6.4	15.3	11.8	32.6	4.3	4.9	4.1	5.2	7.6	18.4	*	*	*	*	–
RS	1.3	4.5	1.3	5.0	0.5	3.1	2.2	4.6	1.8	4.4	0.6	3.5	3.5	13.3	3.5	13.7	3.2	9.6	*	*	*	*	–
BF	0.0	1.0	0.0	0.8	0.0	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.4	3.6	0.3	2.2	0.1	0.5	*	*	*	*	*

Table 5
Percent of basal area by species, elevation class (E), year (Y), and deciduous or coniferous landtype (T) for unmanaged stands on the Bartlett Experimental Forest, with significance tests (* = 0.05 level) among factors and interactions with year

Sp.	Deciduous			Coniferous									T	E	Y	TY	EY
	200–350 m			200–350 m			500–650 m			650–820 m							
	1931	1940	1992	1931	1940	1992	1931	1940	1992	1931	1940	1992					
BE	18.4	19.6	23.0	12.1	12.1	10.9	17.9	19.7	19.0	9.1	9.3	11.1	*	–	*	–	–
YB	14.5	11.5	6.9	12.9	12.1	6.6	12.9	14.6	14.3	8.4	9.5	12.5	–	–	*	–	*
SM	6.2	5.9	6.6	2.9	2.8	2.6	11.7	11.2	12.7	9.2	8.6	7.9	–	*	–	–	–
RM	19.3	22.4	25.7	21.9	24.6	29.2	9.3	8.3	8.2	8.2	7.4	6.4	–	*	–	–	*
PB	14.3	16.4	8.7	11.7	12.1	5.9	15.8	13.0	5.5	21.6	21.8	6.6	–	–	*	–	–
WA	4.7	6.1	6.3	3.3	3.3	4.0	0.7	0.9	0.4	0.2	0.2	0.3	–	*	–	–	*
ASP	10.8	5.6	2.9	8.2	5.0	1.3	0.2	0.0	0.0	0.0	0.0	0.0	–	–	–	–	*
EH	6.9	7.9	14.9	13.3	13.5	24.8	3.0	3.4	7.8	1.1	1.2	3.0	–	*	*	–	*
RS	2.5	2.6	2.9	5.3	5.5	6.6	22.1	23.0	25.9	34.5	34.9	43.4	*	*	–	–	–
BF	0.3	0.6	0.3	2.7	2.6	1.8	0.8	0.8	0.5	5.8	5.4	6.2	–	–	–	–	–

The differences between landtypes were as expected: generally more red spruce and hemlock on the coniferous landtypes, and more hardwoods on the deciduous types – with some notable exceptions. Red maple, paper birch, and yellow birch were more or equally abundant on the coniferous landtypes as on the deciduous. These are common mid-successional associates of coniferous species, partly dependent on the natural disturbances characteristic of coniferous stands on certain sites. Note that yellow birch, a species that markedly declined forestwide, actually increased on the two highest elevation classes in the coniferous unmanaged area (i.e. there was a significant elevation × year interaction); this was due to the small natural disturbances in these high elevation conifer stands. Paper birch, which declined on these sites, would have required larger-scale disturbances to maintain its competitive position (Hill, 1989).

Certain species illustrated marked responses to elevational gradients. Hemlock declined with increased elevation, and was only occasionally found in the highest elevational belt above 650 m (unmanaged stands); red spruce showed a corresponding increase. Because of its abundance at lower elevations and limited elevational range, hemlock could be an excellent indicator of climatic change; change in elevational limits is a logical indicator of climatic change (Hamburg and Cogbill, 1988). Any significant climatic warming should be reflected by an upward extension of hemlock's elevational limits. Over time, however, hemlock increased dramatically at lower elevations, but showed very little tendency (an increase from 1.1 to 3.0%) to invade the unmanaged upper elevations. Red spruce showed increases of over 8% (non-significant) at the highest elevation in the unmanaged, coniferous zone but declined by about 4% in the second highest zone in managed stands. Red maple (an aggressive species forestwide) either declined or showed only moderate increases in the two highest elevational bands.

5. Discussion

Changes in species composition over the 60-year period resulted from the combined effects of management, natural disturbance (windthrow, disease), and succession. In addition, the pattern of change provided clues on the possible impacts of atmospheric deposition and climatic change. Despite the extent of natural and man-made disturbance on the Bartlett Forest, natural succession was the dominant factor affecting species trends as described below.

Timber management had a minor effect on species trends. Beech declined by about 4% on the managed areas because it was intensively marked – a consequence of its low value and high incidence of infection by the beech-bark disease. Sugar maple, a species retained in marking operations, increased by about $1\frac{1}{2}$% on managed areas. Other species either favored by timber marking (e.g. yellow birch and white ash) or disfavored (e.g. red maple) were unaffected by management except perhaps for a slight impact of cutting on large yellow birch sawtimber. Timber management apparently had little positive overall effect on the regeneration of less tolerant species, although individual clearcuttings and group selection operations are known to increase the proportions of early- to mid-successional species.

Natural disturbances (beech-bark disease and windthrow) likewise had a minimal effect on species trends. Beech increased slightly in unmanaged stands. Possibly, the increase would have been greater without the disease; but the species certainly is not threatened. Windthrow from the 1938 hurricane resulted in shifts of no more than 1–2% in species proportions.

Natural succession caused marked changes in hemlock. The species roughly doubled in both managed and unmanaged stands, becoming the second most abundant species. Increases in the poletimber component indicated that this trend will continue. Red maple also showed consistent increases of 2 or 3% forestwide, and up to 6 or 7% at lower elevations. However, the decline in poletimber proportions indicates that red maple will eventually decline under current levels of disturbance.

Hemlock showed little tendency toward increased dominance in the highest elevational band (650 to 820 m), indicating that climatic warming, if present, has had little impact upon species occurrence. Spruce decline due to atmospheric deposition was not apparent: the forestwide proportion of spruce increased by about $2\frac{1}{2}$% in unmanaged stands, and by about 8% in high-elevation unmanaged areas. These trends are consistent with meteorologic and precipitation chemistry records from the nearby Hubbard Brook Experimental Forest. Records on maximum and minimum temperatures since 1957 at Hubbard Brook show no evidence of increasing or decreasing trend over time (Federer et al., 1990). Analysis of a 19-year record (1963–1982) of precipitation chemistry collected at Hubbard Brook showed no significant trends in hydrogen ion and nitrate concentrations, but decreases of 34% in sulfate, 34% in ammonium, 63% in chloride, 79% in magnesium, and 86% in calcium (Likens et al., 1984).

The results of this study emphasize the resistance of New England forests to exogenous disturbance, and the role of natural succession as the dominant factor affecting long-term change in these forested landscapes.

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