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Early-successional dynamics of single-aged mixed hardwood stands in a southern New England forest, USA

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Abstract

The pattern of stand development was studied in two mixed-species single-aged stands that originated after true clearcutting at the Great Mountain Forest in northwestern Connecticut. One stand was located on a mesic swale-till site and the other on a more xeric thin-till site. At the time of cutting all sprout growth and advanced regeneration was eradicated, except for 1-year-old red oak (*Quercus rubra*) seedlings. Twenty-eight years after the stands originated trees were stratified by shade tolerance such that the canopies were dominated by the intolerant species (paper birch *Betula papyrifera*, gray birch *B. populifolia*, pin cherry *Prunus pensylvanica*) with mid-tolerant species (black birch *B. lenta*, black cherry *P. serotina*) becoming prevalent. The number of stems was decreasing but the basal area was steadily increasing. The pattern in species-specific growth rates and crown position were common to both sites; but there were also differences between the sites in the sizes of trees and positioning of the mid-tolerant trees in the canopy. At age 28 the more mesic swale-till site had fewer, taller trees, with pioneer species more typical of northern hardwood climates. On this site red oak was doing poorly, all gray birch and eastern white pine (*Pinus strobus*) had died, black birch and black cherry were beginning to dominate the canopy of the stand, and a significant understory of beech (*Fagus grandifolia*) had developed through the encroachment of root suckers from the stand edge. Sugar maple (*Acer saccharum*), white ash (*Fraxinus americana*) and eastern hemlock (*Tsuga canadensis*), all significant components of the swale-till site before clearcutting, were noticeably absent. On the thin-till site red oak had not attained the canopy of the stand but was still a significant component of the mid-story with red maple (*A. rubrum*). However, black birch was self-thinning more rapidly on the thin-till site than that of the swale-till suggesting that red oak and red maple might well dominate the canopy within another 20 years. In general, the diameter growth rate of the thin-till site currently lags behind the swale-till by approximately 10 years. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: *Acer rubrum*; Clearcut; Forest succession; New England; *Quercus rubra*; *Betula lenta*; *B. papyrifera*; *Prunus pensylvanica*; Shade tolerance; Stand development; Stratification

1. Introduction

The mixed hardwood forests of southern New England have complex patterns of stand dynamics.

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Frequently, 10 or more species are present in the same stand resulting from the range overlap of species typically found towards the south (e.g. oaks *Quercus* spp.; hickories *Carya* spp.) and north (e.g. American beech, *Fagus grandifolia* Ehrh.; maples, *Acer* spp.) (Kittredge, 1988). Patterns of stand development can emerge because of competitive interactions and species autecology that are sufficiently predictable (Smith et al., 1997). However, the variation in forest structure at any particular place depends on subtle variations in site condition and disturbance regime (Oliver and Larson, 1996). The climate, soil type, type of disturbance (magnitude and frequency), and the nature of regeneration origin (advance growth, sprout and root sucker, wind dispersal, buried seed bank) all influence species establishment and their competitive interactions.

Understanding the development pattern of these mixed-stands is potentially bewildering because of the wide range of tree sizes of the various species in a small area (Oliver, 1978). Successful management of regenerating mixed-stands depends upon the ability to predict not only the growth and composition of the young stand, but also the differentiation of species in the canopy (O'Hara, 1986). Vertical stratification of the canopy by species and their differentiation in shade tolerance has been reported in many mixed stands of eastern and western North America (Marquis, 1967; Oliver and Stephens, 1977; Oliver, 1978; Wierman and Oliver, 1979; Clutterbuck and Hodges, 1988; Kelty, 1986; Fajvan and Seymour, 1993; Cobb et al., 1993; Palik and Pregitzer, 1993). Some researchers have shown that this phenomenon is caused by differences in establishment time such that the tallest stems are the oldest in the stand (Hibbs, 1983). However, in many stands the tallest stems and the shortest stems are of the same age (Oliver, 1978, 1980; Smith and Ashton, 1993). In these stands species-specific growth rates lead to stratification such that the tallest stems are also the fastest growing. Often these fast growing stems are also the most shade-intolerant (Marks, 1974), whereas, more shade-tolerant trees occupy the lower strata (Bormann and Likens, 1979). In New England stands can initially be dominated by paper birch (*Betula papyrifera* Marsh) and red maple (*Acer rubrum* L.) which relinquishes the canopy to red oak (*Quercus rubra* L.) at about 30 years (Oliver, 1978). Red oak can remain the dominant trees up to 100 years after initiation of the stand but they can eventually be replaced by eastern hemlock (*Tsuga canadensis* L.) and American beech (Hibbs, 1983). Thus, in the absence of large disturbances, the dominant species in the canopy of mixed stands shift from shade-intolerant to shade tolerant with age.

The relative dominance and canopy stratification of these species depend in part on the magnitude of the stand-initiating disturbance (Oliver and Stephens, 1977). Most studies have examined canopy stratification either at a particular time after stand initiation (Kelty, 1986, 1989) or by recreating the pattern of stand development using stem tree-ring analysis (Oliver, 1978; Wierman and Oliver, 1979; Kittredge, 1988). However, the most informative method of examining stand dynamics is to monitor spatial and temporal patterns of permanently identified individuals (Hibbs, 1983; Stephens and Ward, 1992; Fajvan and Seymour, 1993).

Although, many studies have demonstrated species stratification in single-aged stands in certain kinds of forests, only studies by Stephens and Ward (1992) and Smith and Ashton (1993) have examined within-region differences in stratification related to changes in site productivity and effects of disturbance type. In the study by Smith and Ashton (1993) height growth and canopy stratification were monitored for 18 years in stands that originated after the creation of true clearcut strips on different soils. Smith and Ashton (1993) noted that the near absence of many species of the previous stand suggested that most broadleaved species of their study, except for the birches and pin cherry, were dependent on starting as advance regeneration. The objective of our study was to further elaborate upon the work done by Smith and Ashton (1993) by comparing temporal and spatial patterns of regeneration stratification 28 years after establishment in the same stands. Based on the work by Oliver (1978), after 30 years species such as red oak and red maple would be dominant in the stand canopy on glacial till sites in general. Consequently we examined whether this phenomenon changed between swale-till and thin-till sites and whether the interaction of early successional species promoted or suppressed the potential dominance of red oak that was released as 1-year old seedlings when the clearcut strips were created.

2. Methods and materials

2.1. Site description

The study was done at the Great Mountain Forest in northwestern Connecticut (latitude 42°00′N; longitude 73°20′W). This region receives 1260 mm of precipitation on average and has a frost free season of 123 days. The mean January temperature is −7°C and the mean July temperature is 19°C (Winer, 1955). The two sites were located at an elevation of 390 m on extremely rocky fine sandy loam soils of the Hollis series derived from gneiss and schist (USDA Soil Conservation Service., 1970). Soils have been described in more detail by Smith and Ashton (1993). The thin-till site (xeric) was level with an average depth to bedrock of 0.5 m while the swale-till site (mesic) was concave upward with an average depth to bedrock of 1.9 m.

The pre-existing stand, which developed naturally after a heavy cutting for charcoal in 1885, contained a mixture of species (red oak, red maple, sugar maple (*A. saccharum* Marsh), eastern hemlock, black cherry (*Prunus serotina* Ehrh.), yellow birch (*B. alleghaniensis* Britton) and white ash (*Fraxinus americana* L.), many of which were of sprout origin, and typical of northern Appalachian forest of eastern North America. The thin-till site had a stand that was 18 m tall and dominated by red oak, red maple and eastern hemlock, while the swale-till site had a 21 m tall red maple, sugar maple, beech and eastern hemlock stand (Table 1) (Smith and Ashton, 1993).

2.2. Experimental design

One rectangular-shaped clearcut opening was created in the early spring of 1967 with the greatest length (100 m) along an east-west axis. The north-south axis (25 m) was slightly longer than the adjacent trees were tall. The two sites, each about 30 m in east-west length were located 30 m in different parts of the strip clearcut. The extreme east and west ends of the clearcut strip were left as 5 m wide buffers to reduce the effects of the complex shading of the adjacent uncut forest. Both sites were fenced around the edges to prevent herbivory by deer. With the exception of one-year-old red oaks from a mast crop the previous year, all advanced growth and sprout growth from stumps was removed. To minimize soil disturbance, this was done manually for stumps and with basal application of herbicide (2,4,5 – D) for advance regeneration in June immediately after creation of the clear cut strips. These eradication treatments did not prevent subsequent root suckering of beech from the edges. All regeneration, except beech root suckers, eastern hemlock and the 1-year-old red oak seedlings, became established within the first 3 years after creation of the clearcut strip.

Table 1
Species composition of pre-existing stands in percentages of basal area, total number of trees sampled and mean species diameter at breast height (dbh), with standard errors of the mean in parentheses[a]

Species	Site					
	Thin till			Swale till		
	Basal area (%)	Total number of trees sampled	Mean dbh (cm)	Basal area (%)	Total number of trees sampled	Mean dbh (cm)
Red Oak	38	6	48.62 (4.27)	7	1	45.72
Black Cherry	11	6	26.67 (4.90)	5	1	40.64
White Ash	0		–	6	2	30.48 (5.08)
Red Maple	20	25	22.55 (5.10)	32	17	23.16 (1.65)
Beech	13	18	16.08 (1.96)	12	7	20.67 (3.81)
Yellow Birch	1	1	15.24	1	1	20.32
Hemlock	17	35	13.21 (1.24)	11	10	17.78 (3.05)
Sugar Maple	0		–	26	23	16.56 (1.83)
	100			100		
Total stand basal area	45.5 m^2/ha			31.94m^2/ha		

[a]The species are ranked in decreasing order of overall dbh.

In 1986, 80 square plots 9.3 m^2 in area (10 ft×10 ft) were laid out in a grid on each site. There were straight rows of 10 plots each along the east-west axes and straight columns of eight plots each along the north-south axes. For every tree in both 1986 and 1995 the plot number, species, and diameter at breast height (dbh) were recorded. The basal area of each tree was calculated from the diameter measurements. The height of the tallest individual tree of each species in each plot was measured with a clinometer or 7 m telescoping range pole to the nearest 1/10 m. These measurements were used to determine inter- and intra-species differences in basal area, growth, and stem densities both within and between sites over time. Although, there were no replicate sites for the two soil types, the long time span of the study and comprehensive sampling design provided a way to examine correlated changes among species and species replacement not possible with measurements made at only one time (Herben, 1996).

2.3. Statistical analysis

In all of the analyses diameter refers to the diameter of all stems on the site whereas height refers to only the tallest individual of each species in each 9.3 m^2 plot. The height and normalized diameter measurements were analyzed, using JMP software, with a three-way ANOVA with year, site, and species as the main effects and either height or diameter as the dependent variable (Table 2). A post-ANOVA Tukey multiple comparisons test was used to determine significant differences among the means of the year-site-species combinations of height and diameter (8 species×2 years×2 sites=32). The species were divided into three shade tolerance classes (following Smith and Ashton, 1993) for the analysis. The intolerant species were paper birch, and pin cherry (*P. pensylvanica* L.f.); the mid-tolerant species were black cherry, black birch, yellow birch, and red oak; and the tolerant species were red maple and beech. This tolerance ranking was originally based on the silvical information provided in Fowells (1965) and Burns and Honkala (1990). Gray birch (*B. populifolia* Marsh.) was also considered an intolerant species but was left out of the ANOVA because it was not present on the swale till site both years. Histograms were created to depict mean height and diameter at breast height (dbh) of species by site and year, and to show the frequency of diameter size classes by tolerance class.

Table 2
Three- and two-way analyses of variance on diamter at breast height and height for trees growing in the clearcut strips

Source of variation	Degrees of freedom	*F* value and level of significance	
		Diameter at breast height	Height
Main effects			
Site	1	71.30[c]	53.07[c]
Species	7	94.17[c]	63.48[c]
Year	1	95.11[c]	29.12[c]
2-way interactions			
Site×species	7	3.41[b]	6.04[c]
Site×year	1	0.34 ns	0.72 ns
Species×year	7	1.17 ns	1.56 ns
3-way interaction	7	0.46 ns	0.74 ns

Significance levels: [b], $p<0.01$; [c], $p<0.001$.

3. Results

The ANOVA for dbh and height showed that the three main effects and the two-way interactions site-species was significant, but the site-year interaction, species-year, and three-way interaction were not significant (Table 2).

In 1995 there were 11 species present on the thin-till site and eight species on the swale-till site (Table 3). White pine (*Pinus strobus* L.) and eastern hemlock were present on the thin-till site, but they were not numerous enough to analyze. The most obvious change between 1986 and 1995 was that there were fewer trees that were larger in 1995.

A Tukey multiple comparisons test revealed that the mean diameter for the swale-till site was significantly larger than that of the thin-till site in both years. However, the mean diameter on the swale-till site in 1986 was not significantly larger than that of the thin-till site in 1995 (Table 3). In fact, the Tukey test indicated that there were significant differences in diameter for only black birch, yellow birch and red oak on the 1986 swale-till site compared to the 1995 thin-till site suggesting an approximate 10-year lag in overall diameter growth between sites.

Table 3
Basal area, mean diameters, and stem density for all species for both sites and years. The change in percentage of stems from 1986 to 1995 was calculated as the difference between the two years in number of stems per hectare divided by the number of stems in 1986

Species	Thin till						Swale till					
	Basal area		Diameter		Density		Basal area		Diameter		Density	
	(%)	m^2/ha	Mean	Standard deviations	#/ha	stems (%)	(%)	m^2/ha	Mean	Standard deviations	#/ha	Stems (%)
1986												
Black birch	13.3	1.70	2.48	1.99	2150	16.7	23.2	3.61	4.86	3.60	1261	19.7
Black cherry	4.5	0.57	4.69	2.50	264	2.1	5.3	0.83	6.09	3.15	227	3.5
Beech	2.0	0.26	1.36	0.74	1400	10.9	1.5	0.23	2.18	1.28	467	7.3
Paper birch	43.5	5.58	3.89	2.32	3469	27.0	36.3	5.64	6.49	2.67	1459	22.8
Pin cherry	12.4	1.59	6.11	2.89	446	3.5	13.4	2.08	7.91	3.14	368	5.8
Red oak	10.1	1.29	2.26	1.39	2353	18.3	12.8	1.99	3.46	1.69	1714	26.8
Yellow birch	2.9	0.37	1.61	1.21	1156	9.0	4.3	0.67	3.74	2.50	425	6.7
Red maple	0.9	0.12	1.88	0.94	345	2.7	0.6	0.09	2.03	1.19	212	3.3
Gray birch	6.9	0.89	4.08	2.22	527	4.1	2.4	0.37	4.81	0.84	198	3.1
Hemlock	0.8	0.10	3.56	1.98	81	0.6	0.0	0.00	0.00	0.00	0	0.0
White pine	1.8	0.23	1.71	1.26	649	5.1	0.2	0.03	2.41	0.44	57	0.9
Average 1986			2.79[c]	2.16					4.69[b]	3.00		
Total	100.0	12.70			12840	100.0	100.0	15.53			6388	100.0
1995												
Black birch	16.7	3.18	4.60	3.26	1278	15.9	28.9	5.58	6.40	4.70	1133	27.4
Black cherry	9.6	1.83	7.40	5.38	284	3.5	8.1	1.56	8.80	4.05	212	5.1
Beech	3.3	0.63	2.30	1.19	1217	15.2	3.3	0.64	3.10	1.74	666	16.1
Paper birch	35.4	6.75	6.30	3.02	1765	22.0	35.2	6.81	9.90	3.85	765	18.5
Pin cherry	7.6	1.46	8.66	2.96	223	2.8	10.6	2.05	11.10	3.25	198	4.8
Red oak	15.5	2.94	4.10	2.12	1744	21.8	9.4	1.83	5.20	2.29	722	17.5
Yellow birch	2.7	0.53	2.80	1.67	629	7.8	3.7	0.71	5.40	3.06	241	5.8
Red maple	2.1	0.40	3.28	2.31	325	4.1	0.8	0.16	2.80	1.43	198	4.8
Gray birch	4.2	0.81	7.07	2.66	183	2.3	0.0	0.00	0.00	0.00	0	0.0
Hemlock	1.5	0.28	6.13	2.92	81	1.0	0.0	0.00	0.00	0.00	0	0.0
White pine	1.1	0.21	2.83	1.28	284	3.5	0.0	0.00	0.00	0.00	0	0.0
Average 1995			4.53[b]	3.09					6.42[a]	4.29		
Total	99.6	19.02			8012	100.0	100.0	19.33			4136	100.0
Change from 1986 to 1995												
Black birch	3.4	1.48	2.12	1.27	−872	−40.6	5.7	1.98	1.54	1.10	−127	−10.1
Black cherry	5.1	1.25	2.71	2.88	20	7.7	2.7	0.73	2.71	0.90	−14	−6.3
Beech	1.2	0.37	0.94	0.45	−183	−13.0	1.8	0.40	0.92	0.46	198	42.4
Paper birch	−8.2	1.17	2.41	0.70	−1704	−49.1	−1.1	1.17	3.41	1.18	−694	−47.6
Pin cherry	−4.7	−0.13	2.56	0.07	−223	−50.0	−2.8	−0.03	3.19	0.11	−170	−46.2
Red oak	5.4	1.65	1.84	0.73	−609	−25.9	−3.4	−0.16	1.74	0.60	−992	−57.9
Yellow birch	−0.1	0.16	1.19	0.46	−527	−45.6	−0.6	0.04	1.66	0.56	−184	−43.3
Red maple	1.2	0.28	1.39	1.37	−20	−5.9	0.2	0.07	0.77	0.24	−14	−6.7
Gray birch	−2.7	−0.08	2.98	0.44	−345	−65.4	−2.4	−0.37	−4.81	−0.84	−198	−100.0
Hemlock	0.7	0.18	2.57	0.94	0	0.0	0.0	0.00	0.00	0.00	0	0.0
White pine	−0.7	−0.02	1.11	0.01	−365	−56.3	−0.2	−0.03	−2.41	−0.44	−57	−100.0
Average			1.74	0.92					1.73	1.29		
Total	0.6	6.31			−4828	−37.6	0.0	3.80			−2252	−35.3

Letters (a>b>c) denote differences among sites for both years mean stem diameter from Tukey tests ($p<0.05$).

Trends in basal area/hectare showed that although total basal area/hectare was greater in 1986 on the swale-till site than on the thin-till site, it was virtually identical in 1995 with 19 $m^2 ha^{-1}$ on both sites (Table 3). Paper birch was the most dominant species in terms of absolute basal area on both sites. Black birch was the second most dominant, and it had become almost equivalent to paper birch on the swale-till site. The basal area increased on both sites for all species except gray birch and pin cherry. In terms of the percentage of basal area, all three intolerant species decreased in dominance. The basal areas of black birch, black cherry, beech and red maple increased, both absolutely and in terms of percentage on both sites, while red oak increased on the thin-till site but decreased on the swale-till site.

The change in stem densities was highly variable among species, but the number of stems decreased by 38% on the thin-till site and 33% on the swale-till site (Table 3). In both years the thin-till site had approximately 50% more stems than the swale-till site. The number of black cherry, red maple, and beech stems changed only slightly, except that the number of beech stems on the swale-till site actually increased due mostly to root suckering. Many more black birch stems died on the thin-till site than on the swale-till site, whereas many more red oak stems died on the swale-till site than on the thin-till site. The number of stems of the three intolerant species and yellow birch all declined by more than 40% on both sites.

Although, white pine and gray birch had completely disappeared from the swale-till site, the relative positions of the other species in the canopy were similar in the 2-years 1986–1995 within each site (Fig. 1). Almost 30 years after the clearcut strips were created, heights of the intolerant trees were still tallest, the mid-tolerant trees were intermediate, and the tolerant trees were shortest (Fig. 1). A Tukey test revealed that the trees were taller and differences between species greater on the swale-till site than the thin-till site for both 1986 and 1995. Paper birch and pin cherry were always in the tallest height class. Among the mid-tolerant trees the height order varied by site. In descending order of height on the swale till site were black birch, black cherry, yellow birch, and red oak whereas on the thin till site were black cherry, black birch, red oak, and yellow birch. On the swale-till site gray birch was shorter than several of the mid-tolerant species in 1986, and by 1995 it had disappeared. Apart from gray birch the intolerants showed the greatest height growth over the 9-year-period with some of the mid-tolerant and tolerant species showing little to no height growth.

The mean diameters of the species followed a pattern similar to the heights except that black cherry was larger than paper birch on the thin till sites (Fig. 1). The multiple comparisons test showed that the intolerant species, pin cherry and paper birch, as well as the mid-tolerant black cherry, were significantly larger than all the other species on both sites.

Frequencies of all trees show distributions skewed to the right such that the mode of the distribution was always smaller than the mean diameter of each site (Fig. 2). Mid-tolerant trees were the most numerous on both sites, in part because there were more species in the group and in part because the average number of mid-tolerant trees/species was higher (Fig. 2). For both sites the mode of the diameter was largest for the intolerant trees, intermediate for the mid-tolerant trees, and smallest for the tolerant trees. On both the sites there was more variation in diameter size for the intolerant and mid-tolerant species than the tolerant species, and there was more variation in the diameter size on the swale-till site than on the thin-till site. The different tolerance classes could be separated by the variation in diameter size. The intolerant trees were clumped between 5 and 18 cm dbh, the tolerant were clumped between 2 and 8 cm, and the mid-tolerant trees ranged between 2 and 18 cm dbh.

4. Discussion

Since 1986, the mean diameter and height of all the species still present on both the sites has increased, the number of stems has decreased, and the height stratification among species of the canopy has increased. Although, the numerical increase in diameter was identical on both sites, the increase was proportionately larger on the thin-till site because the mean diameter was smaller.

The number of small trees is decreasing on both sites because, with the exception of beech suckers, no new stems are entering the stand. Many of the small stems in 1986 have either grown larger or died by

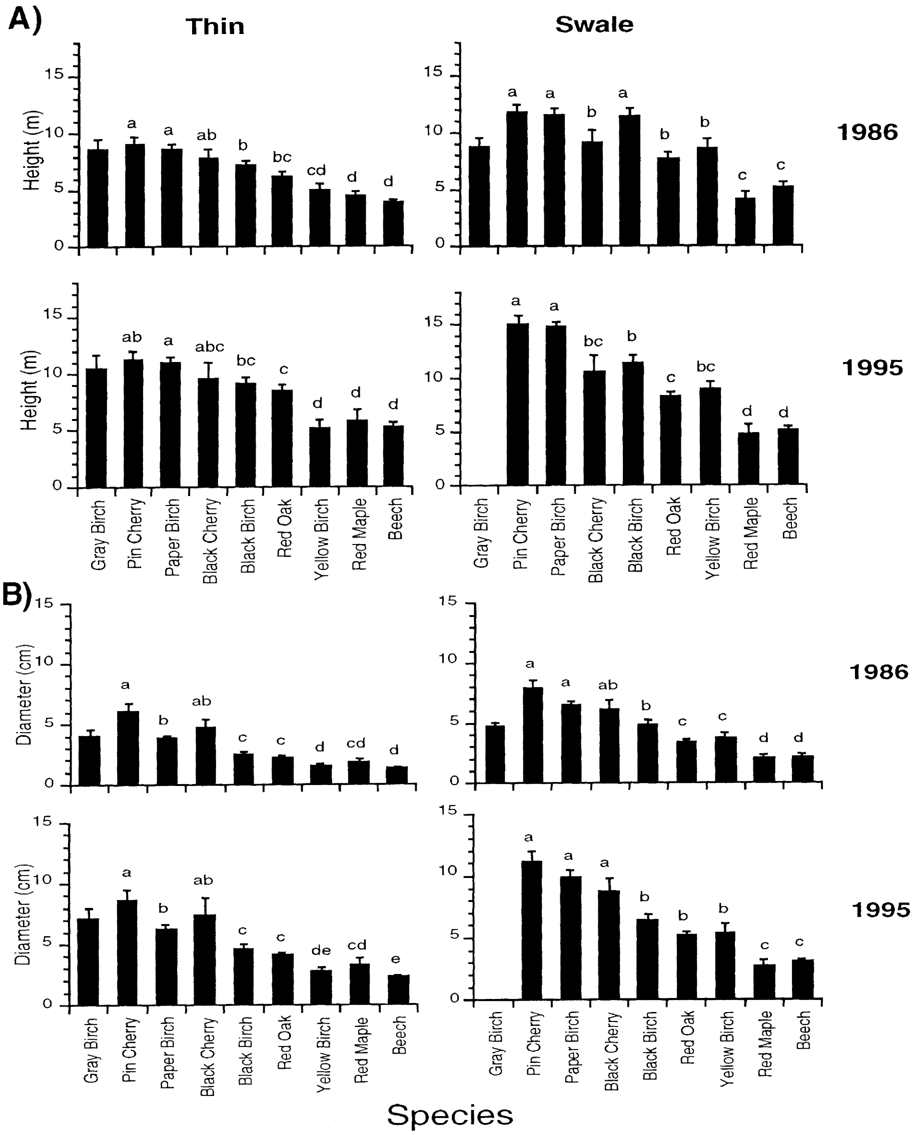

Fig. 1. (A) Comparisons among sites for each year (1986, 1995) of mean height of the tallest trees of each species within each grid square for nine species of trees at the Great Mountain Forest. (B) Comparisons among sites for each year (1986, 1995) of mean diameter of all trees of each species within each grid square. The species are graphed in order of increasing shade tolerance. Bars indicate the mean=1 SE. Different letters denote differences between species within a site and year as determined by multiple comparisons tests ($p<0.05$).

1995. Since most of the remaining small stems are either mid-tolerant or tolerant species; they can grow slowly in the understory and still survive (Oliver and Larson, 1996).

Even after nearly 30 years of stand development, the canopies of the two sites are still dominated by the intolerant species pin cherry and paper birch with mid-tolerant and tolerant species below them in that order. In another 60 years these sites could possibly resemble those 80-year old stands at the Great Mountain Forest described by Kelty (1986), that are dominated by the mid-tolerant species of red oak and black birch, but there will be a noticeable absence of white ash, sugar maple and eastern hemlock.

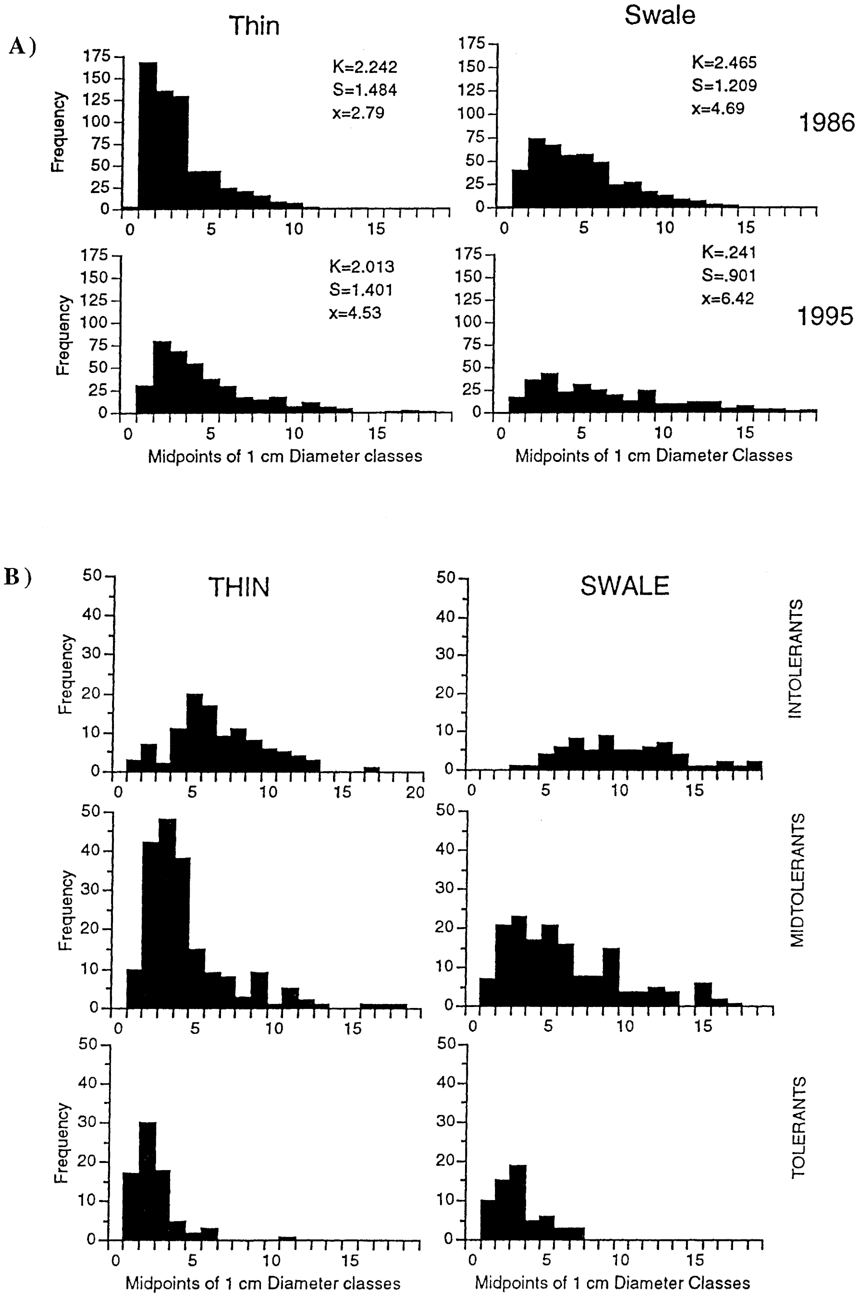

Fig. 2. (A) Frequency distributions of 1 cm diameter classes for all trees on the two sites by year. K=kurtosis, S=skewness, x=mean diameter. (B) Frequencies of 1 cm diameter classes by tolerance classes in 1995.

In the stand development model proposed by Hibbs (1983) for mixed-hardwood forests pin cherry dominates the canopy for the first 15 years with a shift to red maple and paper birch and then eventually red oak by age 50. However, early successional stands measured by Oliver (1978) were first dominated by red maple and black birch with a shift in dominance to red oak after about 30 years. Neither models describe the stand development patterns observed in this study. It does not seem likely that red oak will dominate the stands of our study by 30 years as observed by Oliver (1978), who was dealing with red maple and red oak that had arisen from older advanced regeneration and sprout growth. All advanced regeneration except first year seedlings had been removed in this study so no competitive advantage was accorded to advance regeneration or sprout growth. Also, the oaks appear more dominant in the mixed-hardwood forests of eastern Connecticut (Oliver, 1978; Kittredge, 1988; Stephens and Ward, 1992) than those of the Great Mountain Forest (Winer, 1955). This difference in forest composition may result from the fact that the Great Mountain Forest is more closely associated, both climatically and geologically, with the cooler and moister Berkshire mountains, to the north in Massachusetts, more than the rest of Connecticut (Winer, 1955). This climatic difference is accentuated on the better swale-till site where certain species are disappearing because they are either weaker competitors (e.g. red oak, white pine), or in the case of sugar maple and white ash, their advance growth was eradicated. The more mesic loving black birch appears to be doing well on the swale-till site, as does the understory encroachment by beech.

For our study, it has yet to be determined which species will replace the dying intolerant trees but on both sites it is likely to be black cherry and black birch. However, on the thin-till site red oak and some red maple is prominently represented in the mid-story and could be represented in the canopy by age 50 as suggested by Hibbs (1983).

Although, the two sites seem to be different, there are some similarities but the thin-till site is lagging 10 years behind. The diameter distributions were similar for the thin-till site in 1995 and the swale-till site in 1986, and there were few significant difference between years in the mean diameter or height of the tallest trees for any species. The black and yellow birch grew better on the more mesic swale-till site and the red oak grew better on the more xeric thin-till site. Although, there was a higher density of trees and a larger basal area on the thin-till site in 1995 compared to the swale-till site in 1986, the ratio of the basal area to density was remarkably similar. This indicates that even though the thin-till site had more trees, they were of the same size as those on the swale-till site.

The pattern of stand development described here demonstrates the dependence on the type of disturbance, variations in soil type, and small scale variations within the sites. Since virtually all the advanced regeneration was removed, faster growing intolerant species have dominated the stand since cutting for a much longer time period than what previous studies have reported (Oliver, 1978; Hibbs, 1983). Even though the two sites are located 30 m apart, they have developed quite differently, especially the mid-tolerant species. There is greater stratification of tree crowns, fewer stems, and fewer species on the swale-till site at age 28. Certain more mesic-loving species, such as pin cherry, black birch, yellow birch, and beech, have competed better on the swale-till whereas gray birch and red oak grew better on the drier thin-till site.

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