Influence of Crown Class, Diameter, and Sprout Rank on Red Maple (*Acer rubrum* L.) Development During Forest Succession in Connecticut

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Abstract: Crown class, stem diameter, and sprout rank of 2067 red maples on medium quality sites were measured at 10-yr intervals between 1927-1987. Nominal stand age was 25 yrs in 1927. There was a progressive increase in the probability of an individual red maple ascending into the upper canopy and persisting in the upper canopy from suppressed through dominant crown classes between ages 25-85. While 41% of dominant red maples remained in the upper canopy for any 30-yr period, less than 10% of intermediate red maples ascended into dominant or codominant crown classes. Mortality rates were highest for the lower crown classes between ages 25-85. Mortality rates between ages 25-55 ranged from 18% for dominant trees to 75% for suppressed trees. Within several diameter classes at age 25, survival through age 55, and the proportion found in upper canopy at age 55 was greater for the higher crown classes. Mortality increased by approximately 10% with each decrease in crown class for similarly-sized red maples. Mortality rates between ages 25- 55 were lower for the largest red maple in a sprout clump than for lesser sprouts and single stem red maples. Ingrowth was an important component of the lower crown classes, accounting for two-thirds of suppressed red maple at stand age 85. Red maple mortality rates decreased, and the rate of ascension into superior crown classes increased, following gypsy moth defoliations between 1961-64 and subsequent upper canopy oak mortality.

INTRODUCTION

Red Maple (*Acer rubrum* L.) accounts for over 8% of net hardwood growing stock volume in the United States and nearly 21% of the pole size class in the northeastern states (Waddell et. al 1989). Red maple is becoming an increasingly important component of the Connecticut forest. In 1985, red maple was the predominant species on 221,000 acres of sawtimber and 95,000 acres of poles and saplings, a 10% increase since 1972 (Dickson and McAfee 1988).

Red maple is a common understory species in many eastern oak forests (Walters and Yawney 1990), and is often a major component of young stands following final harvest of mature trees (Parker and Swank 1982, Beck and Hooper 1986, Ward and Heiligmann 1990). Red maple has the potential to eventually replace upper canopy oaks in unmanaged stands (Christensen 1977, Oliver and Stephens 1977, Abrams and Downs 1990, Nowacki et al. 1990, Stephens and Ward 1992). Some management practices have increased the proportion of red maple (Rudolph and Lemmien 1976, Heiligmann et al. 1985, Hill and Dickmann 1988, Kittredge and Ashton 1990, Abrams and Nowacki 1992). Gypsy moth outbreaks have accelerated red maple population increases in some locations by increasing overstory oak mortality (Collins 1961, Stephens 1981, Hix et. al 1991, Stephens and Ward 1992).

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Managing red maple has long been an anathema for foresters because of the high proportion of low quality trees (Walters and Yawney 1990). Consequently, research focusing on red maple has been minimal (Collins 1961, Wilson 1968, Lorimer 1984). Because red maple is a major competitor of more valuable hardwoods, e.g. northern red oak, it is imperative that we fully understand those factors which strongly influence red maple during stand development.

The objective of this research was to examine the influence of initial crown class, diameter, and sprout rank on 30-yr crown class transition rates for red maple in 25 and 55-yr-old stands; i.e. the probability of surviving and moving among crown classes, or dying between stand ages 25-55 and 55-85. Specifically, we proposed these hypotheses: (1) red maple crown class transition rates are independent of crown class, (2) red maple crown class transition rates are independent of diameter class, and (3) red maple crown class transition rates are independent of sprout rank.

STUDY AREA

The study areas are located in the Cabin (40 ac), Cox (50 ac), and Reeves Tracts (40 ac) of the Meshomasic State Forest, and in the Turkey Hill Tract (80 ac) of the Cockaponset State Forest. Elevations range from 300 to 550 ft m.s.l. Mean site index was 67 ft (reference age 50 yrs) on moderately well drained soils (Guinane 1985). We limited this study to the moderately well drained soils, excluding areas in excessively well drained or poorly drained soils. Soils are very stony to extremely stony fine sandy loams derived from gneiss and schist glacial tills and are acidic to strongly acidic (pH 4.5-6.0).

Plots are located in forests typical of many second-growth forests in southern New England. Most of the land was cleared for pasture or cultivation by the mid-1800's. The remaining woodlots were repeatedly cut for fuelwood and wood products, and burned by accident or to improve pasture for livestock grazing until the 1920's. The forests on these tracts originated around 1900 (Hicock et al. 1931). Upper canopy oaks were 80-yr-old in 1983 (Guinane 1985).

Upland oaks have dominated the upper canopy on medium quality sites throughout this study, accounting for over 50% of the upper canopy trees and 60% of upper canopy basal area since 1937 (Stephens and Ward 1992). Upper canopy density has steadily declined from 265 trees/ac in 1927 to 118 trees/ac in 1957 to 69 trees/ac in 1987 (Stephens and Ward 1992). Mean upper canopy dbh (diameter at 4.5 ft aboveground) increased from 5.1 inches in 1927 to 10.0 inches in 1957, and then increased to 13.6 inches in 1987. Red maple (*Acer rubrum*) and birch (*Betula lenta* and *B. alleghaniensis*) accounted for two-thirds of lower canopy trees in 1987 (Stephens and Ward 1992).

METHODS

The study was begun in 1926 in the Turkey Hill Tract. Cox, Reeves, and Cabin Tracts were added in 1927. Trees were mapped to the 0.66 ft (1 link) on transect segments 16.5 ft wide by 66 ft long (0.25 chain x 1 chain). Each transect had from 10 to 20 segments. Transects were spaced 264 ft (4 chains) apart on all tracts except Turkey Hill where transects were 330 ft (5 chains) apart. The centerline of each transect was permanently located by a stake and rock cairn at 132-ft (2 chain) intervals. This study used the 253 transect segments (6.3 ac) on medium quality sites which have not been disturbed since 1927. Segments which have been disturbed by partial cutting, road and trail construction, or fire were excluded.

The species, diameter, crown class, and sprout rank of each tree were recorded. Minimum dbh was 0.6 in prior to 1957; since 1957 the minimum dbh has been 0.5 in. Transect maps were used to relocate trees in the subsequent inventories of 1937 and 1957. Trees have been relocated since 1967 using the distance along the centerline together with the tree's position right or left of centerline. Sprout ranks within a clump were assigned by diameter, i.e. the tree with the largest diameter was assigned sprout rank 1, next largest was assigned sprout rank 2, etc. Sprout rank 0 was assigned to red maples which were not part of a sprout clump.

Crown class designations in 1927 and 1937 were likely based on Fernow (1917), which are nearly identical to those used in later surveys (Smith 1962). Crown class is a qualitative measure of relative canopy position (Smith 1962). Dominant trees have crowns extending above the general canopy level. Codominant trees form the larger part of the upper canopy and receive direct sunlight from above and on at least one side. Although intermediate trees extend into the upper canopy, they only receive direct sunlight from above. Suppressed trees do not reach into the upper canopy and receive no direct sunlight.

Crown class was not recorded for trees on the Turkey Hill Tract in 1926. Therefore, the crown class in 1926 was assumed to be the same as the crown class in 1937 for those trees on the Turkey Hill Tract which were first measured in 1926 and survived into 1937. Trees on the Turkey Hill Tract which died before 1937 were excluded from this study.

We define antecedent crown class as the crown class at the beginning of either 30-yr period. Resultant crown class is defined as the crown class at the end of either 30-yr period. Mortality during either 30-yr period was also considered a distinct resultant crown class. The distribution of stems (%) among resultant crown classes is synonymous with crown class transition rates and the two terms are used interchangeably throughout this paper.

Chi-square statistics (Neter et al. 1982) were used to determine whether the distribution of stems among crown classes in 1957 or 1987 (resultant crown classes) was independent of crown class in 1927 or 1957 (antecedent crown classes). Chi-square statistics were calculated using CC_i x CC_j contingency tables for the 30-yr periods between 1927-57 and 1957-87. CC_i were the antecedent crown classes in 1927 or 1957 with $i=1,2,3,4$ (dominant, codominant, intermediate, suppressed). CC_j were the resultant crown classes in 1957 or 1987 with $j=1,2,3,4,5$ (dominant, codominant, intermediate, suppressed, mortality). Contingency table cell values were the observed number of trees which had been in CC_i at the beginning of a 30-yr period and were in CC_j at the end of the 30-yr period. Differences in resultant crown class distributions in 1957 or 1987 were considered significant at $p \leq 0.01$.

The influence of sprout rank on red maple survival and development is not well understood. Sprout rank and antecedent crown class interactions were examined through 30-yr mortality rates. Because few sprout clumps had more than three sprouts, all sprout ranks ≥4 red maples were combined with sprout rank 3 trees for analysis. Differences in mortality rates for the 1927-57 and 1957-87 periods among crown classes and sprout ranks were tested using procedures in Neter et al. (1982, p325-329). Differences were considered significant at $p \leq 0.01$.

Diameter is correlated with crown class within a stand (Marquis 1991). To assess the influence of crown class independently of diameter, trees measured in 1927 were assigned to 5 diameter classes: 0.6-1.5, 1.6-2.5, 2.6-3.5, 3.6-4.5, and 4.6-5.5 inches dbh. Most red maples > 5.5 in dbh, and all > 7.5 in dbh, were in the dominant crown class. Differences in mortality rates between 1927-57 among crown and diameter classes were tested using procedures in Neter et al. (1982). Differences were considered significant at $p \leq 0.01$. We were unable to perform a similar analysis for the period between 1957-87 because diameters in 1957 were highly segregated by crown class; i.e. most trees in any 2-in or 4-in dbh class were confined to a single crown class.

RESULTS

Red maple density in each crown class at 30-yr intervals is shown in Table 1. There was a sharp drop in the densities of all crown classes between 1927-57. However, the relative density of red maple increased in the intermediate and suppressed crown classes. Mean diameter of red maple in all crown classes increased between 1927-57 (Table 2).

Table 1.—Absolute and relative density of red maple on medium sites by crown class and year

Crown class	Stems/acre			Percent of all stems		
	1927	1957	1987	1927	1957	1987
Dominant	7.0	1.3	1.4	7.7	2.1	4.2
Codominant	17.9	7.4	5.7	15.1	13.1	16.1
Intermediate	50.9	16.1	27.7	23.2	24.4	35.4
Suppressed	182.9	114.8	139.8	29.1	35.1	31.1

Table 2.—Mean diameter (inches) of red maple on medium sites by crown class and year

Crown class	Diameter		
	1927	1957	1987
Dominant	5.3	10.5	11.5
Codominant	4.3	7.2	9.5
Intermediate	2.7	5.1	5.7
Suppressed	1.3	2.1	1.9

The increase in red maple density between 1957-87 (Table 1) has been attributed to an ingrowth pulse following the defoliations between 1961- 64 (Ward 1988). Red maple ingrowth between 1957-87 was twice the 1927- 57 level (Table 3). By 1987, ingrowth accounted for two-thirds of suppressed red maple, up from 40% in 1957. Relative density also increased between 1957-87, as did mean diameter of all crown classes (Table 2), except for the suppressed crown classes.

Table 3.—Ingrowth (stems/acre) of red maple on medium sites by crown class and period

Crown class at end of 30-yr period	Period	
	1927-1957	1957-1987
Dominant & codominant	0.3	0.3
Intermediate	1.7	4.0
Suppressed	44.4	93.7

Crown Class Transition Rates

Red maple crown class transition rates between 1927-57 (Table 4) were not independent of antecedent crown class in 1927 (Table 5). Further analysis indicated crown class transition rates between 1927-57 were significantly different among all antecedent crown classes in 1927 (Table 5). There was not a marked distinction in crown class transition rates between upper and lower canopy red maples. Rather, there was an intergradation of crown class transition rates among antecedent crown classes; i.e. the crown class transition rates for each antecedent crown class were intermediate between crown class transition rates of the proximate antecedent crown classes.

Table 4.—Thirty-year crown class transition rates (%) of red maple on medium quality sites by antecedent crown class

Period	Antecendent crown class	Resultant crown class (row percents) DOM[a]	COD	INT	SUP	MORT	Sample size
1927-57	Dominant	11.4	29.6	25.0	15.9	18.2	44
	Codominant	2.7	15.0	28.3	33.6	20.4	113
	Intermediate	.0	2.8	10.6	40.7	46.0	322
	Suppressed	.0	.5	1.2	23.3	75.0	1157
1957-87	DOM & COD[b]	12.7	30.9	20.0	12.7	23.6	55
	Intermediate	2.0	8.8	39.2	16.7	33.3	102
	Suppressed	.0	1.1	13.6	7.2	48.1	726

[a]DOM-dominant crown class, COD-codominant, INT-intermediate, SUP-suppressed, MORT-mortality.

[b]Dominant and codominant crown classes were combined because of insufficient trees (< 25) in the dominant crown class.

Between 1927-57 there was a 25% difference in mortality rates between codominant and intermediate trees, and a 29% difference in mortality rates between intermediate and suppressed trees (Table 4). Although mortality rates of dominant and codominant trees between 1927-57 were similar, there was a distinct difference in the proportion of red maple remaining in the upper canopy between 1927-57. Over 40% of dominant red maples, compared with 18% of codominant red maples, remained in the upper canopy through 1957. Few red maple in the intermediate and suppressed crown classes in 1927 were able to ascend into upper canopy positions by 1957.

Red maple crown class transition rates between 1957-87 (Table 4) were not independent of antecedent crown class in 1957 (Table 5). Further analysis indicated crown class transition rates between 1957-87 were significantly different among all antecedent crown classes in 1957 (Table 5). As in the 1927-57 period, crown class transition rates between 1957-87 demonstrated a pattern of intergradation among antecedent crown classes.

Mortality rates between 1957-87 were lower than for the preceeding 30- yr period, differing by approximately 10 percentage points among antecedent crown classes (Table 4). Transition rates into the upper canopy through 1987 for intermediate and suppressed crown classes remained below those for upper canopy red maples, but were 4x higher than for the 1927-57 period.

Table 5.—Pearson chi-square statistics for a comparison of red maple antecedent crown classes with resultant crown class distributions[a] for the periods 1927-57 and 1957-87. See Table 4 for actual distributions.

Period	Antecedent crown classes	Chi-square	DF	Probability
1927-57	All	599.0	9	< 0.001
	Dominant vs. codominant	10.7	3	< 0.013
	Codominant vs. intermediate	60.3	3	< 0.001
	Intermediate vs. suppressed	139.5	3	< 0.001
1957-87	All[b]	262.0	6	< 0.001
	Upper canopy vs. intermediate	22.8	3	< 0.001
	Intermediate vs. suppressed	86.5	3	< 0.001

[a]Resultant dominant and codominant crown classes were combined because of insufficient trees (< 25) in the dominant crown class.

[b]Antecedent dominant and codominant crown classes were combined because of insufficient trees (< 25) in the dominant crown class.

Canopy Position - Sprout Rank Interactions

Mortality rates between 1927-57 were not independent of sprout rank and crown class in 1927 (Table 6). Mortality was higher for the lower crown classes within a given sprout rank. Mortality nearly doubled with each decrease in crown class for sprout rank 1 (largest sprout in each clump) and sprout rank 0 (single stem) red maples. Interestingly, mortality between 1927-57 was significantly lower for sprout rank 1 than for sprout rank 0 red maples, especially in the suppressed crown class. Mortality was highest for red maples with a sprout rank ≥2. There was an interesting contrast between sprout rank 0 and 1 for those red maples in the upper canopy in 1927. Although mortality was higher for sprout rank 0 than for sprout rank 1, persistance in the upper canopy through 1957 was higher for sprout rank 0 trees, 36%, than for sprout rank 1 trees, 20%.

Similar patterns were noted for the 1957-87 period (Table 6). Within a given sprout rank, mortality was highest in the inferior crown classes. Mortality of sprout rank 1 red maples was not significantly lower than for sprout rank 0 between 1957-87. Mortality was highest for the lesser sprouts within a clump.

Crown Class - Diameter Class Interactions

As might be expected, diameter was not independent of crown class in 1927 ($F=712$, $d.f.=3$, $p<0.001$, $r^2=0.57$). Mortality rates between 1927-57 were not independent of crown class in 1927 for the diameter classes examined (Table 7). Within each diameter class 30-yr mortality rates were highest for those trees in lower crown classes. For example, mortality of upper canopy red maples in the 2.6-3.5 in dbh class was half the mortality of similarly sized trees in intermediate and suppressed crown classes. Although mortality was generally lower for trees with larger diameters within a given crown class, only for the suppressed crown class were these differences significant. Mortality was significantly different among most diameter classes when crown classes were combined.

Table 6.—Mortality (%) between 1927-57 and 1957-87 by crown class and sprout rank of red maple on medium quality sites. Only categories with a minimum of 25 trees are shown.

Period	Antecedent crown class	Sprout rank 0	1	2	>=3
1927-57	Upper canopy	23.2 a	11.5 a	-	-
	Intermediate	41.9 b	28.2 ab	60.9 c	70.5 c
	Suppressed	74.9 c	41.1 b	87.1 d	92.3 d
	Combined	66.1 b	31.0 a	75.7 c	85.9 d
1957-87	Upper canopy	30.3 ab	-	-	-
	Intermediate	25.0 a	24.2 a	-	-
	Suppressed	44.7 bc	40.6 abc	54.0 c	73.0 d
	Combined	41.7 a	36.2 a	54.0 b	73.0 c

[a]Mortality rates (%) for a given period followed by the same letter are not significantly different at $p \leq 0.01$. Significance levels for combined crown classes determined separately.

Table 7.—Mortality (%) between 1927-57 by crown class and diameter class in 1927 of red maple on medium quality sites. Only categories with a minimum of 25 trees are shown.

Crown class in 1927	Diameter class (in) in 1927: 0.6-1.5	1.6-2.5	2.6-3.5	3.6-4.5	4.6-5.5
Upper canopy	-	-	22.2 a	14.6 a	18.5 a
Intermediate	55.6 bc	53.7 b	44.4 b	28.1 ab	-
Suppressed	78.9 d	68.2 c	49.1 b	-	-
Combined	78.2 a	62.9 b	41.7 c	21.8 d	19.1 d

[a]Mortality rates followed by the same letter are not significantly different at $p \leq 0.01$. Significance levels for combined crown classes determined separately.

DISCUSSION

Survival and development of red maple in 25 to 85-yr-old stands on medium sites was not independent of antecedent crown class (Tables 4 and 5), sprout rank (Table 6), and diameter class (Table 7). The utility of crown class for predicting red maple development and survival has been demonstrated across a wide geographical range including New Hampshire (Marquis 1969), New York (Lorimer 1981), and Wisconsin (Hix and Lorimer 1990, Hix and Lorimer 1991).

The amount of red maple which can expected in future stands depends not only on the absolute number of red maple, but also on the distribution of red maple among the crown classes. For example, using the crown class transition rates in Table3, each red maple in the upper canopy in a 55-yr-old stand requires approximately 2.4 dominant, 6.4 codominant, or 35.7 intermediate red maples in a 25-yr-old stand.

A period of drought between 1961-66 and repeated episodes of defoliation during 1961-64, 1971-72, and 1981 confound analysis of changes in class crown transition rates, including mortality, after 1957 (stand age 55). The first defoliations coincided with the stage in stand development when upper canopy competition shifts from height growth towards lateral crown expansion. No known major defoliation occurred prior to 1961 (Stephens and Waggoner 1970). Basal area mortality between 1957-67 was over 25%, three-fourths was oak (Stephens and Ward 1992). The post-defoliation mortality of the 1960s was similar to a partial harvest.

The combination of defoliation and natural succession likely contributed to the dramatic decreases in red maple mortality in all crown classes for the 1957-87 period compared to the 1927-57 period (Tables 4 and 5). Concurrently, the proportion of red maple remaining in the same crown class for 30-yrs doubled or tripled, and the proportion ascending in crown class increased by at least 4-fold. The increase in red maple density and crown class ascension following the oak defoliation (Collins 1961, Stephens 1981, Hix et. al 1991), appears to be a natural analogue of red maple increasing following partial cuttings (Rudolph and Lemmien 1976, Hilt and Dale 1982, Hill and Dickmann 1988, Kittredge and Ashton 1990, Ward 1992, Heiligmann and Ward 1993).

Additional evidence that partial removal of the overstory benefits red maple can found by contrasting this study with stand development between ages 37-80 yrs on medium quality sites in Massachusetts (Lorimer 1984). The stands in Massachusetts had received cultural treatments ranging from light thinning and improvement cuts to several precommercial weedings and a series of hardwood thinnings. Mortality rates of upper canopy red maples in Massachusetts, approximately 21% per 30-yr period (Lorimer 1984), were similar to the 18-24% 30-yr mortality rates observed in this study (Tables 4 and 5). However, suppressed red maple mortality rates in the Massachusetts stands, 17-29% per 30-yr period, were much lower than the 48-75% mortality rates observed in our stands. The series of partial overstory removal appears to have decreased mortality of lower canopy red maple and increased persistence of red maple within the upper canopy.

This study concurs with earlier research that upper canopy dominance by red maple in sapling-pole stands should not be an automatic cause of concern (Oliver and Stephens 1977, Oliver 1978, Hibbs 1983). Only a small fraction of red maples in subdominant crown classes in 25-yr-old stands were found in the upper canopy 30 yrs later and less than half of dominant red maples in 1927 persisted in the upper canopy through 1957 (Table 4).

CONCLUSIONS

This research provides information on the proportion of red maples in unmanaged stands 25 and 55-yrs-old which can be anticipated to maintain or change crown class, or die in the subsequent 30-yr period. Crown class designation provides a practical field method of determining the future status (upper canopy, lower canopy, or mortality) of individual red maples. Should the anticipated amount of red maple in the upper canopy exceed management objectives, then removal should focus on red maples in the dominant crown class. Only a small proportion of other red maples will be found in future upper canopies. In stands where anticipated red maple densities are below management goals, high thinning of trees other than red maple will decrease red maple mortality. High thinning will also increase persistence of those red maples already in the upper canopy.

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