REGENERATION RESPONSES OF OAK-DOMINATED STANDS TO THINNING AND CLEARCUTTING IN NORTHWESTERN PENNSYLVANIA

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Abstract: Regenerating mature oak stands on better sites is difficult on the Allegheny Plateau because of abundant advance regeneration of faster growing competitors. We have observed that oak stands on the Allegheny National Forest (ANF) in northwestern Pennsylvania almost always regenerate to cherry-maple rather than to oak-hickory stands. Such conversion greatly concerns land managers and the general public. We surveyed 30 stands, varying in size from 8 to 42 acres, in a 786 acre compartment on the Sheffield Ranger District to document typical responses of oak-hickory stands on good sites to partial and complete overstory removal. These stands were 90 to 110 years-old when cut. Five stands were clearcuts that originated from previously uncut stands; 18 stands had been partially cut; and 7 stands remained uncut. The five clearcuts were 4 years old (1 stand), 7 years-old (1), and 15 years old (3) when examined. The 7 year old stand was fertilized 2 years after clearcutting. The 18 thinned stands were treated 6 years before we examined them. Trees to be cut were individually marked by ANF staff and commercially harvested. Advance reproduction in thinned stands varied from 0% to 75% of regeneration plots stocked with preferred species. Black cherry was more abundant in the advance reproduction than in the overstory. Advance reproduction of sapling size was present in 15 stands, occurring in up to 40% of plots in a stand. Most saplings were black cherry or red maple. Black cherry was the most numerous species in the clearcut stands and the only species consistently in the dominant position of the new age class. Isolated patches of dominant and co-dominant oak saplings were in the main canopy of the new age class on dry microsites and along skid trails. Oak seedlings were present in the new age class, but all were less than 1 ft tall. The unfertilized clearcut stands grew at essentially the same rate, or considerably faster than previously sampled cherry-maple stands. Response to fertilizer was of a magnitude similar to that in previously sampled cherry-maple stands.

INTRODUCTION

Regeneration greatly concerns forest managers throughout portions of the US with abundant amounts of oak community types (Clark and Watt 1971, Fosbroke and Carvel 1989, Holt and Fisher 1979, Loftis and McGee 1993, Weitzman and Trimble 1957). Oak regeneration is particularly difficult to obtain on better sites where advance regeneration of faster growing competitors is often abundant (Abrams and Downs 1990, Abrams and Nowacki 1992, Heiligmann and others 1985). Besides losing the high value red and white oak for commodity uses, the conversion of predominantly oak stands to other hardwood types concerns land managers because of the loss of biodiversity at the community level (McMinn 1991) and hard-mast for wildlife.

Oak stands on the Allegheny National Forest (ANF) in northwestern Pennsylvania are similar in many respects to stands throughout the Allegheny Plateau of New York, Pennsylvania, Ohio, and West Virginia. Regeneration of commercial species, including oaks, in the ANF is complicated by high populations of whitetail deer (Tilghman 1989). Aerial fertilization of recent clearcuts is common on the ANF, to overcome nitrogen and phosphorus deficiencies that lead to poor height development (Auchmoody 1982) that exposes the seedlings longer to deer browsing. This can result in a regeneration failure (Marquis 1974).

We have observed that oak stands on the ANF almost always regenerate to cherry-maple rather than to oak-hickory stands. Such conversion greatly concerns managers and the public (FEIS 1986). Deferring treatments until proven

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methods are available for regenerating stands to oaks is not a viable option in the face of gypsy moth and drought-induced mortality. We undertook this survey of one compartment typical of oak-hickory and transition hardwood stands on the Allegheny National Forest to document typical responses of these stands to partial and complete overstory removal. Although not a designed study, our approach illustrates the principle of adaptive management, where every management action can be viewed as an experiment.

METHODS

Study Area

All stands were in Compartment 4 of the Sheffield Ranger District, Allegheny National Forest (ANF). This compartment of 786 acres is within two miles of the Allegheny River. Climate is moderate, with cold, snowy winters and mild, warm summers. The average winter temperature is 28°F, and summer temperatures average 60°F. Total precipitation is 43 inches; about one-half falls as rain between April and December. Average seasonal snowfall is 74 inches. Dominant soils belong to the Hazleton (loamy-skeletal, mixed, mesic Typic Dystrochrepts), Cookport (fine loamy, mixed, mesic, Aquic Fragiudults), Cavode (clayey, mixed, mesic Aeric Ochraquults), and Gilpin (fine loamy, mixed, mesic Typic Hapludults) series which are productive for upland oaks, with northern red oak (*Quercus rubra* L.) site indices of 70 ft to 83 ft (Cerutti and others 1985).

Thirty stands, each covering 8 to 42 acres, were sampled: 5 clearcuts (Stands CC1-CC4, CCF5) that originated from previously uncut stands, 18 thinned stands, and 7 uncut stands. Of the five clearcuts, Stands CC1-CC3 were harvested in 1970; Stand CCF5 in 1978; and Stand CC4 in 1980. The stands were 15, 7, and 4 years old when examined. Only Stand CCF5 was fertilized in 1980 (2 years after cutting). The 4 year-old, Stand CC4, was approximately 100-110 years old at the time of overstory removal, based on stump ages of three dominant northern red oak.

The 18 thinned stands were treated in 1979, 6 years before we examined them. Trees to be cut were individually marked by ANF staff and stands were commercially harvested. Trees per acre varied widely following thinning (Table 1), from a low of 91 in Stand N5 (north aspect) to a high of 378 in Stand S2 (south aspect). Average stand diameters of 13.4 inches to 17.7 inches (approximately equal to median diameter; see Marquis and others 1992 for justification). The low correlation between basal area and relative density (r^2= .42) reflects the mixed species composition as well as differences due to thinning. In two-thirds of the stands, relative density was within the recommended 60% to 80% for sawtimber management (Marquis and others 1992). In the remainder of the thinned stands, relative density was 46% to 58%.

All but five of the thinned stands were classified as oak-hickory (Table 1), based on residual stand composition. The five northern hardwood stands all had an oak component that ranged from 8% to 24% of basal area (Table 2). Northern red oak and red maple (*Acer rubrum* L.) were the only species common to the overstory of all residual stands (Table 2). Black cherry (*Prunus serotina* Ehrh.) was a minor component in most stands. Other common associates included yellow-poplar (*Liriodendron tulipifera* L.) and cucumber tree (*Magnolia acuminata* L.).

The seven uncut stands resembled the thinned stands in most respects. Relative density ranged from a high of 93% to a low of 47% (Table 1). Average stand diameters ranged from 12.8 inches to 17.4 inches. One stand (N1) was predominantly red maple (60% of basal area) but had an oak component (7%). The other stands ranged from 34% to 79% oak basal area.

Measurements

Standard USDA Forest Service stand examination procedures were used in all stands except recent clearcuts (Marquis and others 1984). These included 10 baf prism plots for overstory trees (1.0 inch or larger dbh) with dbh tallied by 2-inch classes. Regeneration tallies were made on 20 or more 6-ft radius plots in each stand, including stems 5.50 inches or smaller dbh. Aspect was simplified into cardinal directions from compass readings: East=45° to 134°, South=135° to 224°, West=225° to 314°, and North=315° to 44°.

Table 1. Thinned and uncut stands in Compartment 4, Sheffield Ranger District, Allegheny National Forest in 1985 were mostly oak-hickory stands

Stand number	Aspect	Stand type[1]	Age[2]	Trees acre^{-1}	Stand diameter[3]	Basal area	Relative density	Sapling[4]	Oak sprout potential
Thinned					Inches	ft^2	--- Percent ---		Trees acre^{-1}
E1	E	O	95	173	17.4	76	46	40	7
E2	E	N	93	200	16.5	84	54	17	2
E3	E	O	99	138	16.3	78	60	20	5
E4	E	O	93	126	15.8	75	54	5	13
E7	E	N	76	334	13.4	120	78	0	18
N3	N	O	91	221	14.5	74	65	25	5
N4	N	O	88	254	15.1	91	67	25	8
N5	N	O	94	91	17.7	90	54	15	6
S1	S	N	89	362	14.8	96	70	20	7
S2	S	O	97	378	14.5	88	80	5	9
S3	S	O	93	148	16.5	82	58	17	7
S4	S	O	92	222	16.0	87	64	10	15
S5	S	O	87	163	15.7	84	55	0	9
W1	W	N	97	292	17.2	109	68	36	1
W2	W	N	93	147	16.9	106	60	5	1
W5	W	O	82	212	14.1	92	68	0	21
W7	W	O	89	279	14.0	89	75	36	12
W8	W	O	89	183	15.2	83	61	35	2
Uncut									
E5	E	O	74	403	13.0	113	76	20	31
E6	E	O	96	165	17.4	83	47	20	4
N1	N	N	97	430	17.0	102	65	29	1
N2	N	O	90	220	16.2	106	72	50	7
W3	W	O	87	358	13.9	118	93	14	35
W4	W	O	88	199	15.5	92	68	14	15
W6	W	O	87	380	12.8	83	74	27	36

[1] Stand type: O=Oak-Hickory, N=Northern Hardwoods.
[2] Effective age.
[3] Stand diameter is approxiamtely the media stand diameter.
[4] Saplings are the percentage of regeneration plots stocked with saplings of preferred species.

The SILVAH prescription software (Marquis and others 1992) was used to summarize these data and calculate stems per acre, basal area, volume, average stand diameter, and relative density. Relative stand density is the ratio of absolute stand density (taken as basal area) to a reference level of average maximum density of an undisturbed stand of similar species composition and diameter distribution (Marquis and others 1992). We also used SILVAH to determine regeneration adequacy from the understory data and stand type from overstory dominance calculated from basal areas of residual stands.

Table 2. Species composition of the overstory in thinned (residual) and uncut stands

Stand number	Basal area	Oak	Red oak[1]	White oak	Black oak[2]	Red maple	Black cherry
	ft²	- - - - - - -	- - - - - - -	- - - - - - -	Percent	- - - - - - -	- - - - - - -
Thinned							
E1	76	53	45	7	1	33	5
E2	84	24	16	8	0	40	9
E3	78	59	14	44	1	14	0
E4	75	74	23	39	12	12	3
E7	120	22	22	0	0	20	15
N3	74	63	7	55	1	26	3
N4	91	40	9	31	0	30	13
N5	90	40	31	8	1	41	0
S1	96	24	14	9	1	19	11
S2	88	73	7	60	6	22	2
S3	82	61	34	21	6	28	2
S4	87	73	43	23	7	21	1
S5	84	52	36	14	2	29	0
W1	109	12	8	4	0	59	3
W2	106	8	8	0	0	47	10
W5	92	79	40	26	10	19	2
W7	89	56	14	37	5	12	0
W8	83	36	5	28	3	40	5
Uncut							
E5	113	49	42	7	0	24	9
E6	83	34	33	1	0	41	5
N1	102	7	7	0	0	60	10
N2	106	36	11	25	0	38	17
W3	118	79	36	25	18	10	2
W4	92	65	38	15	12	26	0
W6	83	77	18	48	11	9	0

Regeneration adequacy was evaluated according to procedures detailed in Marquis and others (1984) and Sander and others (1976) for black cherry, northern hardwoods, large and small oak seedlings, and saplings. SILVAH was used to calculate oak sprouting potential using the procedure of Sander and others (1976) from overstory data on species and dbh. This estimate of sprouting potential was reduced to account for heavy deer pressure (Marquis and others 1984).

We examined the clearcuts using 0.01 acre circular plots. Three of the stands (CC1, CC2 CC3) were 15 years old when examined and we tallied the overstory by species and dominance class. We estimated annual height growth with a height pole on 20 dominant black cherry stems in each of three stands: a 15 year old clearcut (Stand CC2), a 7 year old fertilized clearcut (Stand CCF5), and a 4 year old unfertilized clearcut (Stand CC4).

Staff of the ANF surveyed stocking in Stands CC4 and CCF5 the summer after harvest and 2 years later. Seedling regeneration on 20 or more 6-ft radius plots was assessed in each stand. They differentiated seedlings into three height classes: taller than 5-ft, 3-ft to 5-ft, and under 3-ft. Preferred species (black cherry, red maple, white ash, oaks, yellow poplar, basswood (*Tillia americana* L.), cucumber tree, and hemlock) were tallied separately from non-preferred (beech (*Fagus grandifolia* L.) and the birches). The percentage of black cherry in the preferred class was estimated. The plots were evaluated for adequacy of stocking by preferred species according to the following criteria: Class I, 2 or more seedlings 5-ft or taller; Class II, 5 or more seedlings at least 3-ft tall; and Class III, 25 or more seedlings of any height. Any plot meeting one of these criteria was judged to be adequately stocked.

RESULTS

Regeneration in Partially Cut and Uncut Stands

From none to 75% of regeneration plots within the 18 thinned stands were stocked with preferred species (Figure 1). Black cherry was more prevalent in the new age class than in the overstory. Besides red maple, the other preferred regeneration was predominantly white ash and yellow-poplar. Oak regeneration was entirely small oak (less than 4.5 ft tall) in five of the six stands where it occurred (Figure 1). Species included northern red oak, white oak (*Q. alba* L.) and black oak (*Q. velutina* Lam.).

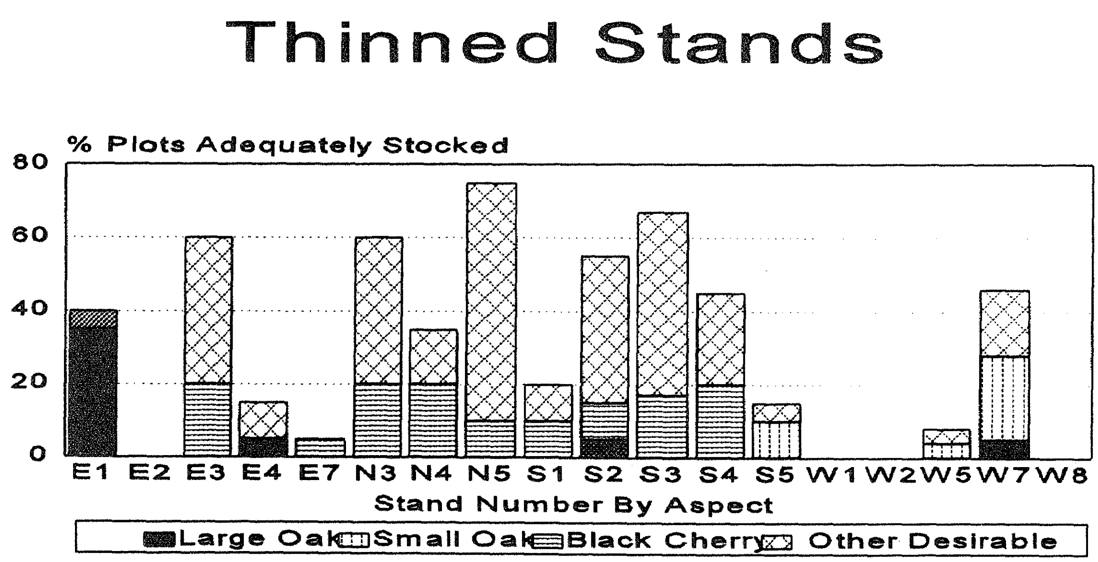

Figure 1. Percentage of the regeneration plots in thinned stands that were adequately stocked with oak (large or small), black cherry, or northern hardwoods (includes white ash, red or sugar maple, yellow-poplar, basswood, cucumber tree, or eastern hemlock).

Saplings were present in all but three stands, with up to 40% of plots having stems of this size (Table 1). Most saplings were black cherry or red maple. Other species were yellow birch (*Betula alleganiensis* Britton) and sweet birch (*Betula lenta* L.), hop-hornbeam (*Ostrya virginiana* (Mill.) K. Koch), blue beech (*Carpinus caroliniana* Walt.), red oak, white pine (*Pinus strobus* L.), cucumber tree and eastern hemlock (*Tsuga canadensis* L.). Sprouting potential (Sander and others 1976) was as high as 21 oak trees per acre, but most stands had fewer than 10 oak trees per acre likely to produce acceptable sprouts (Table 1). For the range of oak diameters in these stands, at least 46 trees per acre are needed to add 5% to regeneration stocking under heavy deer pressure (Marquis and others 1984).

From 5% to 50% of regeneration plots in the uncut stands were stocked with preferred species (Figure 2). Stand W3 had the highest relative density of any stand we examined (93%) and high regeneration stocking; 50% of the plots were adequately stocked. This uncut stand was also one of the few stands with oak regeneration.

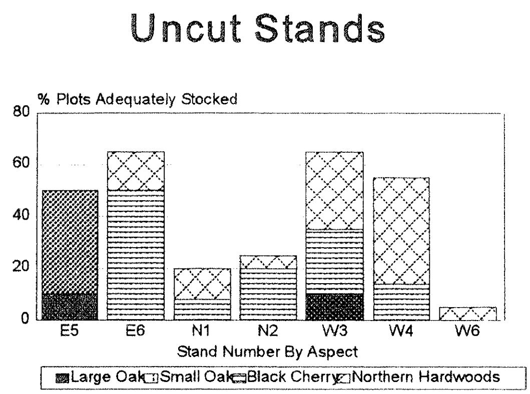

Figure 2. Percentage of the regeneration plots in uncut stands adequately stocked with oak, black cherry, or other desirable species (designations as in Figure 1).

Plots adequately stocked with oak regeneration occurred only in stands where more than 50% of basal area was oak (Table 3). This was true for both uncut and thinned stands. It was equally likely, however, that a stand with greater than a 50% oak basal area would have no oak regeneration. The thinned stands with oak regeneration ranged from 52% to 76% oak basal area, and the thinned stands greater than 50% oak basal area without oak regeneration ranged from 53% to 73% oak basal area. Thus, the probability of obtaining some oak component in the regeneration was 50% in thinned stands with greater than 50% oak basal area in the residual overstory.

Table 3. Relationship of oak advance regeneration to percentage of overstory basal area as oak species

	Some oak regeneration	No oak regeneration	Total
Oak BA> 50%	Thinned: 5 Uncut: 1	Thinned: 5 Uncut: 2	Thinned: 10 Uncut: 3
Oak BA< 50%	Thinned: 0 Uncut: 0	Thinned: 8 Uncut: 4	Thinned: 8 Uncut: 4
Total	Thinned: 5 Uncut: 1	Thinned: 13 Uncut: 6	Thinned: 18 Uncut: 7

Clearcut Stands

Stands CC1-CC3 show the range of species composition that results when previously uncut stands are clearcut (Table 4). Black cherry was the most numerous, and the only species in the dominant position of the new age class in all stands. Red and white oak and other hardwoods were, however, among the dominants and codominants in Stand CC3.

Table 4. Species composition by dominance class 15-years after clearcut harvest, stems per acre

	Dominant	Co-dominant	Intermediate	Overtopped
Stand CC1				
Black cherry	225	50	75	450
Red maple			25	325
White ash	25	50	25	333
Red oak				75
Hop-hornbeam		25	25	75
Sweet birch	50	225	50	125
Sugar maple	25			
Ironwood				100
Hamamelis virginiana (L.)				75
Stand CC2				
Black cherry	300	250	150	500
Red maple		50	25	650
White ash				50
Beech				50
Hamamelis virginiana (L.)				25
Stand CC3				
Black cherry	100	125	150	200
Red maple	75	300	50	850
Red oak	50	150	25	575
White oak		25		125
Populus tremuloides Michx.	25			75
Prunus pennsylvanica L.f.		25		
Amelanchier spp.				100
Aralia spp.		25		

None of the clearcut stands regenerated to oak. We did find isolated patches of dominant and codominant oak stems in the main canopy of the new age class on dry microsites, and adjacent to skid trails where competition from other species was absent around at least 50% of the crown circumference (data not presented). This edge effect favoring oak regeneration has been noted by others (Whitney and Runkle 1981, Crow 1988). Chestnut (*Castanea dentata* (Marsh.) Borkh.) persisted in openings for a number of years after logging. Oak seedlings were present in the new age class, but all were less than a foot tall. Understory plants typical of oak stands (e.g., *Rhododendron* spp., *Kalmia latifolia* (L.), *Sassafras albidum* (Nutt.) Nees, hop-hornbeam, *Vaccinium* spp., and *Cornus florida* (L.)) were reduced or absent in the 15-year-old stands (Table 4). Stocking surveys made in Stands CC4 and CCF5 the season following completion of cutting and again 2 years illustrate the early development of regeneration following clearcutting. Stand CC4 was well-stocked with regeneration at the time of the first post-harvest survey (Figure 3). Black cherry comprised 67% of the tallest seedlings (over 5-ft), 76% of the seedlings 3-ft to 5-ft tall, and fully 90% of the smaller seedlings. Two years later, 100% of the plots were stocked with seedlings taller than 5-ft. Stand CCF5 had lower initial stocking in the larger size classes and was fertilized to stimulate seedling growth. Height growth was accelerated such that the number of seedlings 3-ft and taller tripled. The percentage of black cherry stocking declined between the two surveys and red maple increased; overtopped oak seedlings were also present.

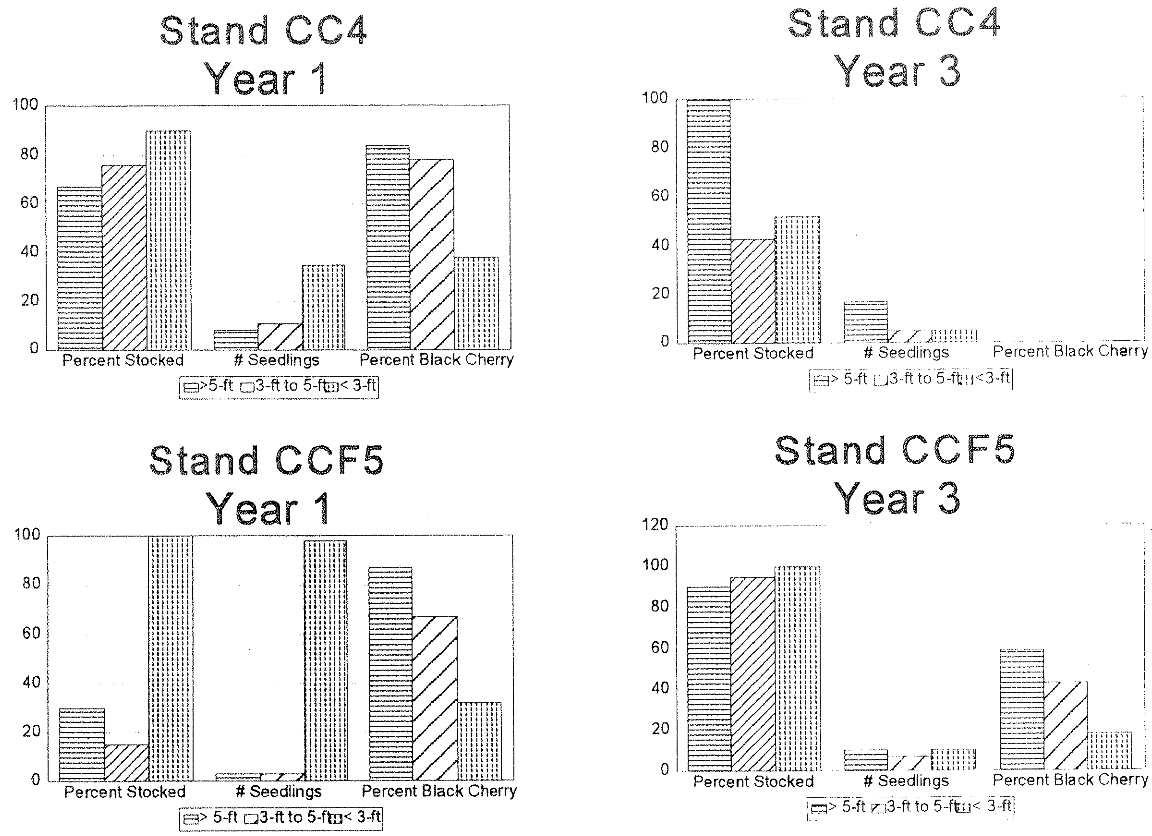

Figure 3. Regeneration stocking (percent of plots adequately stocked, number of seedlings per plot, and percentage black cherry stems) in Stand CC4 (unfertilized) and Stand CCF5 (fertilized) 1 and 3 years aftrer harvest. Seedlings were tallied in three height classes: > 5 ft, 3-ft to 5-ft, and < 3-ft.

The pattern of cumulative height of dominant black cherry in Stands CC2, CC4, and CCF5 (this study) is compared in Figure 4 to data from unfertilized (CM1) and fertilized (CM2) stands that developed after clearcutting cherry-maple stands. Black cherry in unfertilized Stands CC2 and CC4 grew at the same rate, or somewhat faster than in CM1, the unfertilized cherry-maple stand (Auchmoody 1982). Response to fertilizer in Stand CCF5 was of a magnitude similar to that in a previously reported cherry-maple stand, CM2 (Figure 4). We could not test the fertilizer response statistically as no true control existed.

DISCUSSION

The regeneration of valuable oak-hickory and cherry-maple forests in northwestern Pennsylvania has failed in the past due to myriad problems, including browsing by deer (Marquis 1974, Marquis and Brenneman 1981), interfering plants (Horsley and Marquis 1983), nutrient deficiencies (Auchmoody 1982), and insect predation (Galford and others 1991). All these factors contribute to insufficiency of advance regeneration at the time of overstory removal and a failure of surviving seedlings after release. Stands in the study area were typical of oak-hickory and transition hardwoods found on good growing sites. Red oak site index estimates for the predominant soils were all above the SI 70 threshold set by Sander and others (1976) as the upper limit for use of their regeneration guidelines. Aspect had no apparent influence on overstory or understory species composition, contrary to other studies (Auchmoody and Smith 1979, Trimble and Weitzman 1956). Evenly distributed and ample growing season precipitation, frequent cloud cover, and low summer temperatures resulting in general lack of soil moisture deficits probably counteracted effects of aspect noted elsewhere.

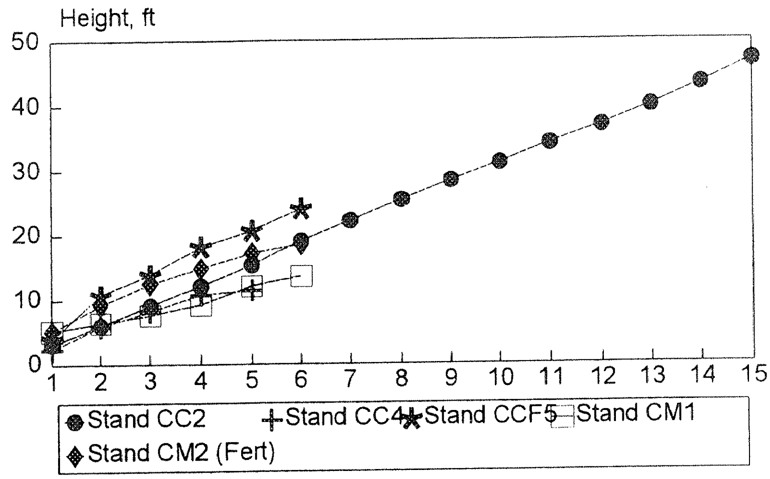

Figure 4. Cumulative height growth in clearcut stands regenerated from previously uncut oak-hickory (Stand CC2, CC4 and CCF5) or cherry-maple overstory (Stand CM1 CM2). Data for cherry-maple stands from Auchmoody (1982). Stands CCF5 and CM2 were fertilized 2 years after clearcutting.

The seven uncut stands represent the range of overstory and understory species composition found in the study area. Except for one stand classed as northern hardwoods (N1), these stands were dominated in the overstory by oaks or had a sizeable oak component. Red maple was the other dominant species. Black cherry occurred in the overstory, but was a minor component (0% to 10%). In the understory, however, oak seedlings occurred in only one stand (W4). We believe these uncut stands typify the conditions of the other stands in the compartment before thinning or clearcutting. Unfortunately, no records exist for pre-thinning regeneration tallies.

Thinning was the intent of the cuttings, however they can be viewed as establishment cuttings in a shelterwood sequence. Even stands dominated by oaks did not develop many oak seedlings consistently when thinned to the target 60% to 80% relative density. From these stands it appears, however, that at least 50% of residual stand basal area in oaks was a necessary, but not sufficient, condition for oak regeneration to develop. Abundant regeneration of other preferred species developed in most stands following thinning, although a third of the stands had less than 10% stocked plots.

The loss of oak types is cause for concern about loss of community diversity (McMinn 1991) and regulations require land managers to maintain an oak component on 20% of the Allegheny National Forest (FEIS 1986). Certainly the dominance of black cherry, at times in virtual single species stands, raises concerns about the risk of catastrophic pest or disease outbreaks. The prevalence of black cherry is due primarily to its prolific seeding and the preference for other species by deer (Hough 1965, Marquis 1975, Whitney 1984). The ability of black cherry to seed into stands with little or no presence in the overstory is well illustrated by these data.

When oak stands are mature but oak advance regeneration is lacking, conversion to cherry-maple stands is possible. While the fertilization results presented here are not conclusive, it appears that untreated black cherry on sites previously dominated by oak-hickory stands grow somewhat more vigorously than unfertilized black cherry growing on sites previously dominated by cherry-maple stands. The response to fertilization of Stand CCF5 shows, however, that these stands are somewhat deficient. It appears from these clearcuts that black cherry advance regeneration will grow beyond the reach of deer quickly enough to form a large proportion of the new age class. We doubt that mesic sites such as these can be naturally regenerated to oak, although a stronger foundation of research than these data is needed to be conclusive. Our data agree with other assessments, that oak will likely dominate only the poor sites after clearcutting (Abrams and Downs 1990, Hilt 1985). Further research is needed to develop effective methods of regenerating oak if biodiversity goals are to be met, probably relying on artificial regeneration. Continuing to regenerate these stands using conventional shelterwood cuttings will regenerate mostly black cherry and red maple, and occasionally some oaks.

LITERATURE CITED

Abrams, M.D. and J.A. Downs. 1990. Successional replacement of old-growth white oak by mixed-mesophytic hardwoods in southwest Pennsylvania. Can. J. For. Res. 20: 1864-1870.

Abrams, M.D. and G.J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. Bull. Torrey Bot. Club 119: 19-28.

Auchmoody, L.R. 1982. Response of young black cherry stands to fertilization. Can. J. For. Res. 12: 319-325.

Auchmoody, L.R. and H.C. Smith. 1979. Oak soil-site relationships in northwestern West Virginia. USDA Forest Service Res. Pap. NE-434.

Cerutti, J.R., M. Yaworski, N.J. Churchill, and A.R. Topalanchik. 1985. Soil survey of Warren and Forest Counties, Pennsylvania. USDA Soil Conservation Service.

Clark, F.B. and R.F. Watt. 1971. Silvicultural methods for regenerating oaks. In Oak Symposium Proceedings Northeastern For. Exp. Stn., Upper Darby, PA. p. 37-43.

Crow, T.R. 1988. Reproduction mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*) - a review. For. Sci. 34: 19-40.

FEIS. 1986. Final Environmental Impact Statement, Land and Resource Management Plan, Allegheny National Forest, Warren, PA. USDA Forest Service, Eastern Region, Milwaukee, WI.

Fosbroke, S. and K.L. Carvell. 1989. Managing Appalachian oaks: a literature review. Agric. For. Exp. Stn., West Virginia Univ. Circ. 149.

Galford, J, L.R. Auchmoody, H.C. Smith, and R.S. Walters. 1991. Insects affecting establishment of northern red oak seedlings in central Pennsylvania. In (L.H. McCormick and K.W. Gottschalk, eds.) Proceedings 8th Central hardwood forest conference, Pennsylvania State University, University Park, PA. p. 271-280.

Heiligmann, R.B., E.R. Norland and D.E. Hilt. 1985. 28-year-old reproduction on five cutting practices in upland oak. North. J. Appl. For. 2: 17-22.

Hilt, D.E. 1985. Species composition of young central hardwood stands that develop after clearcutting. In (J.O. Dawson and K.A. Majerus, eds.) Proceedings 5th Central hardwood forest conference, University of Illinois, Urbana-Champaign. p. 11-14.

Holt, H.A. and B.C. Fisher. 1979. Regenerating oaks in upland hardwood forests, Proc. of a conference held Feb. 22-23, 1979, Purdue University, West Lafayette, IN

Horsley, S.B. and D.A. Marquis. 1983. Interference by weeds and deer with Allegheny hardwood reproduction. Can. J. For. Res. 13: 61-69.

Hough, A. F. 1965. A twenty-year record of understory vegetation change in a virgin Pennsylvania forest. Ecology 46: 370-373.

Loftis, D.L. and C.E. McGee, eds. 1993. Oak regeneration: serious problems, practical solutions. Symposium Proceedings; 1992 Sept. 8-10; Knoxville, TN. USDA Forest Service Gen. Tech. Rep. SE-84. 319 p.

Marquis, D.A.1974. The impact of deer browsing on Allegheny hardwood regeneration. USDA Forest Service Res. Pap. NE-308.

Marquis, D.A. 1975. The Allegheny hardwood forests of Pennsylvania. USDA Forest Service Gen. Tech. Rep. NE-15.

Marquis, D.A. and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. USDA Forest Service Gen. Tech. Rep. NE-65.

Marquis, D.A., R.L. Ernst, and S.L. Stout. 1984. Prescribing silvicultural treatments in hardwood stands of the Alleghenies. USDA Forest Service Gen. Tech. Rep. NE-96.

Marquis, D.A., R.L. Ernst, and S.L. Stout. 1992. Prescribing silvicultural treatments in hardwood stands of the Alleghenies (revised). USDA Forest Service Gen. Tech. Rep. NE-96.

McMinn, J.W. 1991. Biological diversity research: An analysis. USDA Forest Research Gen. Tech. Rep. SE-71.

Sander, I.L., P.S. Johnson and R.F. Watt. 1976. A guide for evaluating the adequacy of oak advance reproduction. USDA Forest Service Gen. Tech. Rep. NC-23.

Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. J. Wildl. Manage. 53: 524-532.

Trimble, G.R., Jr. and S. Weitzman. 1956. Site index studies of upland oaks in the northern Appalachians. For. Sci. 1: 162-173.

Weitzman, S. and G.R. Trimble, Jr. 1957. Some natural factors that govern management of oaks. USDA Forest Service Stn. Pap. NE- 88.

Whitney, G.G. 1984. Fifty years of change in the arboreal vegetation of Heart's Content, an old-growth hemlock-white pine-northern hardwoods stand. Ecology 65: 403-408.

Whitney, G.G. and J.R. Runkle. 1981. Edge versus age effects in the development of a beech-maple forest. Oikos 37: 377-381.