REGENERATING MIXED OAK STANDS IN PENNSYLVANIA: A QUARTER-CENTURY RETROSPECTIVE

P.J. Gould, K.C. Steiner, J.C. Finley, and M.E. McDill[1]

ABSTRACT.—The outcomes of regeneration treatments in 90 oak-dominated stands in Pennsylvania are examined 20 to 33 years after treatment. Approximately one-quarter of the stands failed to reach 50 percent stocking after at least 20 years, but most stands regenerated successfully. Red maple is the most frequently observed species in the regenerated stands, followed by oak species and sweet birch. The relative basal area of oak decreased from pre-harvest levels while the relative basal area of sweet birch and red maple increased substantially. Oaks and red maple regenerated from both seeds and sprouts, while sweet birch regenerated primarily from seeds. Oaks were generally larger than their competitors and may become an increasingly important component of the regenerated stands.

Regeneration treatments in oak-dominated stands in the eastern United States often result in stands where oaks play a diminished role (Lorimer 1992). Since the mid 1960s, Pennsylvania State Forest managers have been regenerating mixed-oak stands using even-aged silvicultural prescriptions. To date, a comprehensive evaluation of regeneration outcomes has not been conducted. The objectives of this study are:

1) to document the outcomes of regeneration harvests conducted between 1968 and 1978 in 90 oak-dominated stands on Pennsylvania State Forest lands,
2) to determine whether the relative importance of oaks and other species in the regenerated stands differs from the pre-harvest condition,
3) to asses whether oaks may become dominant in the stands where they occur, and
4) to measure the relative importance of seed-origin and sprout-origin oak and non-oak stems in the regenerated stands.

METHODS

Data were collected on a set of 90 oak-dominated stands at two points in time—before regeneration treatment and 20 to 33 years after treatment. Pre-harvest data for each stand were amassed through an extensive search of operational records collected by the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry (and precursor agencies) as part of the state's timber management program. Stands were entered into the analysis if three conditions were met:

1) the results of a pre-harvest stand exam could be found,
2) the pre-harvest stand exam indicated that oak species accounted for at least 50 percent of the pre-harvest basal area, and
3) the regeneration harvest occurred at least 20 years prior to 2001.

Pre-harvest stand exams were used to assess the composition of each stand prior to harvest. A prism plot sample (n = 10) of basal area, tallied by species, was included in each pre-harvest exam. The samples were used to calculate the number of stands in which each recorded species appeared and the frequency of appearance within the set of stands (number of appearances/total number of stands x 100 percent). Pre-harvest relative basal area (species basal area/total stand basal area x 100 percent) was calculated by species for each stand. General descriptions of stand condition were frequently included in the pre-harvest exams and were used as qualitative data.

Follow-up stand exams were used to assess the composition of each stand 20 to 33 years after

[1] Research Assistant (PJG), Professor of Forest Biology (KCS), Associate Professor of Forest Resources (JCF), and Assistant Professor of Forest Management (MEM), School of Forest Resources, Pennsylvania State University, Ferguson Building, University Park, PA 16802. PJG is corresponding author: to contact, call (814) 865-1441 or e-mail at pjg169@psu.edu.

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stand initiation. In stands of 30 or more acres, approximately 30 prism plots were taken along five or six equally spaced parallel lines. In smaller stands, at least one prism plot was taken for each acre of stand area, with a minimum of 10 plots. The species, crown class (dominant, codominant, intermediate, or suppressed) and dbh (diameter at breast height –4.5 ft) of each "in" tree was recorded (Smith and others 1997).

The stocking level of each stand was calculated for all observed species and for only oak species (Gingrich 1967). The frequency and relative basal area of each species in the regenerated stand was calculated in the same way as in the pre-harvest stands. The quadratic mean diameter (QMD) and basal area of dominant and codominant trees was calculated by species for each stand. Oak species were considered individually and as a group.

Differences between the pre-harvest and post-harvest relative basal area of oaks and other species were compared using paired t-tests, with each stand serving as the pairing variable. The dominance of oaks in the regenerated stands was evaluated by comparing the basal area and QMD of dominant and codominant oaks to those of common competitors. Analysis of variance (alpha < 0.05) was used for the comparisons with each stand serving as a block to account for variation between stands. Consequently, comparisons between oaks and competitors were restricted to regenerated stands in which the species co-occurred.

The contribution of stump sprouts and seedlings to the dominant and codominant basal area of common species was evaluated using a subset of 25 follow-up exams. The exams, completed in 2000 and 2001, were conducted in the same way as described above, except each "in" tree was recorded as either a seed-origin or sprout-origin stem. Origin determinations were based on clumping of stems, stump remnants, and the shape of the root collar. If there was not any evidence that a single stem originated as a stump sprout, it was classified as a seed-origin stem. Stems classified as seed-origin likely include stems that established before the regeneration treatments and re-sprouted after treatment (i.e., seedling sprouts).

Relative basal areas were calculated as the percentage of each species' total basal area originating from sprouts or seeds. Seed and sprout-origin relative basal areas and QMDs were compared for each species using paired t-tests, with stand as the pairing variable.

RESULTS

The distribution of stocking levels in the regenerated stands is bimodal, with almost one-quarter of stands failing to reach a stocking level of 25 percent and most of the other stands reaching stocking levels in excess of 75 percent (table 1). Heavy pre-harvest mortality, usually due to defoliation by the oak leaf roller (*Archips semiferana*), was noted as having occurred in most poorly stocked stands, but some well-stocked stands also had heavy pre-harvest mortality. Stocking of oak species is heavily weighted towards the < 25 percent class, but 10 percent of stands have an oak stocking level in excess of 75 percent. Stocking was not found to be correlated with stand age (p = 0.481). Because of the bimodal distribution of stocking levels, further analysis was limited to stands that reached at least 50 percent stocking. The sample size was reduced from 90 to 65 stands after poorly stocked stands were excluded.

Forty-eight tree species were observed in the regenerated stands. The pre-harvest and post-harvest frequencies and relative basal areas of the most common species are listed in table 2. Red maple (*Acer rubrum* L.) is the most common species, occurring in all stands. Oak species

Table 1.—*Percentage of 90 formerly oak-dominated stands in central Pennsylvania that reached each stocking level 20 to 33 years after stand initiation*

	Stocking Intervals (percent)[1]			
Species	< 25	25 - 50	50 - 75	> 75
All species	22.2	5.6	3.3	68.9
Oak species	61.1	24.4	4.4	10.0

[1]Calculated from Gingrich (1967)

Table 2.—*Frequency and mean relative basal area of common species before and after regeneration treatments in 65 formerly oak-dominated stands in Pennsylvania. Stands were sampled before treatment and 20 to 33 years after treatment. Differences are based on individual paired t-tests.*

	Frequency		Relative Basal Area		
Species	Before	After	Before	After	P (Difference)
Red maple	93.8	100.0	11.5	37.1	<0.001
All oaks	100.0	98.5	77.7	30.2	<0.001
Chestnut oak	89.2	83.1	31.6	15.4	<0.001
Sweet birch	29.2	80.0	0.9	11.3	<0.001
N. red oak	89.2	75.4	13.5	5.2	<0.001
Black oak	87.7	64.6	3.2	9.9	<0.001
Scarlet oak	67.7	63.1	7.9	3.5	0.004
Black cherry	6.2	60.0	0.2	4.7	<0.001
white oak	89.2	58.3	14.6	2.7	<0.001
Hickories	44.6	52.3	1.0	2.1	0.004
Black gum	30.8	50.8	0.9	1.2	0.275

occur in all but one stand (98.5 percent of stands), and chestnut oak (*Quercus prinus* L.) is the second most common tree species (83.1 percent), followed by sweet birch (*Betula lenta* L.) (80.0 percent). Northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.), white oak (*Quercus alba* L.), and black cherry (*Prunus serotina* Ehrh.) all occur in at least 60 percent of the stands. Hickory species (*Carya* spp.) and black gum (*Nyssa sylvatica* Marsh.) both occur in about one-half of the stands. Yellow-poplar (*Liriodendron tulipifera* L.), a ubiquitous competitor in some parts of the eastern United States, appears in only 26.2 percent of the regenerated stands.

The frequencies observed in the regenerated stands were similar to those observed in the pre-harvest stands with some notable exceptions (table 2). Sweet birch, which occurred in only 29.2 percent of stands before harvest is now present in 80.0 percent of stands and black cherry increased from 6.2 percent to 60.0 percent. The frequency of white oak decreased from 89.2 percent of stands before harvest to 58.3 percent of regenerated stands.

The mean relative basal area of each species in the regenerated stands follows its frequency rank in most cases (table 2). Red maple contributes an average of 37.1 percent to total basal area, while the oaks contribute an average of 30.2 percent. Only red maple, chestnut oak, and sweet birch have mean relative basal areas of 10 percent or more.

The mean relative basal areas of most species in the regenerated stands are significantly different from their pre-harvest levels (table 2). The mean relative basal areas of red maple, sweet birch, and black cherry increased ($p < 0.001$ in all cases). The mean relative basal area of the combined oak species and of each individual oak species decreased, with the exception of black oak, which experienced an increase ($p \leq 0.004$, in all cases).

The QMD and mean basal area of dominant and codominant red maple, sweet birch, and oaks were compared across 47 regenerated stands where the species co-occur (table 3). Oaks have a significantly larger mean QMD (5.4 inches) than red maple and sweet birch (4.4 and 4.8 inches, respectively). The mean QMDs of red maple and sweet birch are not significantly different from one another. Oaks have significantly more basal area than sweet birch

Table 3.—*Quadratic mean diameter and mean basal area of oak species, red maple, and sweet birch in 47 formerly oak-dominated stands in Pennsylvania, USA, where the species co-occur. Means not sharing letters in each column are significantly different at P < 0.05.*

Species	Diameter[1]	Basal Area[2]
Oaks	5.4 a	21.6 a
Red maple	4.4 b	17.7 ab
Sweet birch	4.8 b	7.5 b

[1]Qudatric mean diameter (inches).
[2] in ft^2 $acre^{-1}$

(21.6 ft^2 ac^{-1} versus 7.5 ft^2 ac^{-1}) while the basal area of red maple (17.7 ft^2 ac^{-1}) does not significantly differ from either oak or sweet birch.

Sprouting played an important role in regenerating the oaks and red maple, but a minor role in regenerating sweet birch (table 4). Sprouts contribute an average of 67.9 percent of the oak basal area in the regenerated stands, a value near the observation made by McIntyre (1936) that 75 percent of second-growth oaks in Pennsylvania were of sprout origin. Sixty percent of the red maple basal area and 2.5 percent of the sweet birch basal area is of sprout-origin.

The relative basal area of sprout-origin oaks is significantly greater than that of seed-origin oaks ($p = 0.006$) while the opposite is true for sweet birch ($p < 0.001$) (table 4). A significant difference was not found between sprout-origin and seed-origin red maple basal area ($p = 0.116$). In most stands, both sprout and seed-origin oaks and red maples were found. Sprout-origin sweet birch stems were found in five stands, always with seed-origin stems. The mean QMDs of sprouts do not differ from the mean QMDs of seedlings for any of the three species.

DISCUSSION

Regeneration treatments in oak-dominated stands resulted in a range of outcomes. On one hand, a sizable percentage of stands failed to reach 50 percent stocking of any tree species. Regeneration failures tended to occur after heavy mortality in the pre-harvest stand, but apparently healthy stands also failed to regenerate. On the other hand, most stands regenerated well and 14.4 percent of stands are already 50 percent or more stocked with oak. In general, an oak component was maintained in most successfully regenerated stands.

Although an oak component was maintained in most stands, oak relative basal decreased from pre-harvest levels. Red maple and sweet birch became more prominent after the regeneration harvests and the two species account for almost 50 percent of the basal area in the regenerated stands, compared to 13.4 percent in the pre-harvest stands. Red maple was present in most of the pre-harvest stands and the regeneration harvests likely released advanced red maple regeneration, as well as stimulating stump sprouting (Lorimer 1984). Both regeneration strategies are reflected in the regenerated stands.

In contrast to red maple, sweet birch invaded stands after the regeneration harvests. Most sweet birch stems are seed-origin and the frequency of occurrence rose from 29.2 percent in the pre-harvest stands to 80.0 percent in the post-harvest stands.

Oaks exhibit signs of dominance in the regenerated stands where they occur. In stands where oaks, red maple, and sweet birch coexist, oaks have significantly larger QMDs. Oak basal area exceeds sweet birch basal area and is not significantly different from red maple basal area. Although stump-sprouts are the most important source of oak basal area in the regenerated stands, the QMDs of sprout and seed-origin stems do not indicate that one source of regeneration is growing faster than the other.

Although oaks appear to play a diminished role in the regenerated stands, the dominance of oak may increase as the stands develop. Oliver (1978) argued for a deterministic pattern of increasing oak dominance with a similar combination of species. Unlike southern Appalachian stands, where yellow-poplar may overtop oaks later in stand development, it seems plausible to expect oak to increase in dominance, especially over red maple (Beck and Hooper 1986). Assuming established oak are out-growing

Table 4.—*Relative basal area and quadratic mean diameter of seed-origin and sprout-origin stems sampled in 25 stands in central Pennsylvania. Differences are based on individual t-tests of samples paired by stand.*

	Relative Basal Area[1]				Quadratic Mean Diameter (in)			
Species	#	Seedlings	Sprouts	P(Difference)	#	Seedlings	Sprout	P (Difference)
Oaks	24	32.1	67.9	0.006	21	7.3	7.0	0.422
Red maple	25	40.0	60.0	0.116	24	5.6	5.2	0.193
Sweet birch	20	97.5	2.5	<0.001	5	5.0	4.8	0.882

[1]Percentage of species basal area from each origin.

potential competitors, the relative basal area of oaks will increase as the stand develops.

CONCLUSIONS

- The regeneration of mixed-oak stands in central Pennsylvania meets with a range of outcomes, from excellent oak regeneration to complete regeneration failure. Most stands that successfully regenerate contain some oak.

- The importance of oak decreased after regeneration harvests, while the importance of sweet birch and red maple increased. Red maple was present in most stands before harvest and regenerated through stump sprouting and seed. Sweet birch was relatively rare in the pre-harvest stands and invaded through the establishment of seedlings.

- Oaks show signs of being superior competitors in the regenerated stands. The relative basal area of oaks may increase as the stands develop.

- Stump sprouting and seedling establishment are both important mechanisms for regenerating oak. Sprout-origin stems are not larger than seed-origin stems after 20 years.

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