RELATIONSHIPS BETWEEN FOREST CUTTING AND UNDERSTORY VEGETATION:

An Overview of Eastern Hardwood Stands

by Hewlette S. Crawford

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PLANT NAMES

To avoid repetition of long scientific names, only common names of plants are used in the text. The common and scientific names of the plants mentioned are:

COMMON NAME	SCIENTIFIC NAME
Angelica	*Angelica*
Aster	*Aster*
Blackgum	*Nyssa sylvatica* Marsh.
Blueberry	*Vaccinium*
Bramble	*Rubus*
Cinquefoil	*Potentilla*
Coralberry	*Symphoricarpos orbiculatus* Moench.
Dogwood, flowering	*Cornus florida* L.
Fern, bracken	*Pteridium aquilinum* L.
Galax	*Galax aphylla* L.
Goldenrod	*Solidago*
Grape	*Vitis*
Hawkweed	*Hieracium*
Hazelnut	*Corylus*
Hickory	*Carya*
Mountain laurel	*Kalmia latifolia* L.
New Jersey Tea	*Ceanothus*
Oak, bear	*Quercus ilicifolia* Wang.
Oak, black	*Q. velutina* Lam.
Oak, Northern red	*Q. rubra* L.
Oak, post	*Q. stellata* Wang.
Oak, scarlet	*Q. coccinea* Muench.
Oak, white	*Q. alba* L.
Panic grass	*Panicum*
Persimmon	*Diospyros virginiana* L.
Pipsissewa	*Chimaphila*
Plum, American	*Prunus americana* Marsh.
Poverty grass	*Danthonia spicata* L.
Pussytoes	*Antennaria*
Rose	*Rosa*
Sassafras	*Sassafras*
Sumac	*Rhus*
Teaberry	*Gaultheria procumbens* L.
Tickseed	*Coreopsis*
Tick-trefoil	*Desmodium*
Trailing arbutus	*Epigaea repens* L.
Virginia creeper	*Parthenocissus quinquefolia* L.
Wild lettuce	*Lactuca*

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ABSTRACT

The impacts of forest cutting upon understory vegetation were evaluated for Ozark oak-hickory and Appalachian oak-pine stands. These findings were related to similar information from other eastern forest types. Production of understory vegetation is related to stand type, stand structure, stand disturbance, and site. Stand type, structure, and site operate together to influence the understory of uncut stands. Cutting the stand increases the amount of understory vegetation, but this increase is regulated by site quality, stand type, and structure. Unless undetected changes are occurring in populations of endangered plant species, it seems that understory variety and production in managed even-age stands will not differ drastically from that in naturally occurring even-age stands.

AN EVEN-AGE SILVICAL SYSTEM for eastern hardwood stands has been applied on public land since the mid-1960s. On thousands of acres, the past practice of some form of selective cutting was replaced by clearcutting for regeneration and intermediate cutting for stand improvement. Controversy arose about the application of even-age management because of its impact upon several woodland resources, including understory vegetation. Will some of the less common plant species disappear under even-age management? Will a decrease in overstory variety cause a loss of variety in the understory? Will the initial flush of understory growth soon decrease, leaving a biological desert under dense coppice overstory?

I have searched the literature, reworked old studies, and analyzed new studies in an attempt to explain the impact of even-age management upon understory vegetation and to form a conceptual model of understory response to overstory change. I will present this information by comparing composition and production of understory vegetation in stands managed with an uneven-age system, stands subjected to intermediate cutting in an even-age management scheme, and stands that have been clearcut. Upland oak and oak-pine stands in the Ozarks and Appalachian Ridge-Valley Province will provide much of the new data for this analysis because of my experience in these areas. Information from published studies in other eastern hardwood stands will provide a base for comparison. Together, this information will be used to create a broad summary of understory and overstory relationships in eastern hardwood stands. This summary, in turn, will provide a base for detecting emerging patterns of plant change due to changing silvical systems.

Ozark Selective Cutting and Understory

I went back to the late 1950s and early 1960s to obtain data on understories in selectively cut stands. Murphy and Crawford *(1970)*, reported on understory that was within reach of deer—from ground level to a height of 5 feet—throughout the Missouri Ozarks. Their data are summarized here for comparison with data presented later.

Oak-pine/black oak/scarlet oak and white oak forest types had 150 to 200 pounds per acre of current annual understory growth less than 5 feet tall. More than two-thirds was woody vegetation, 10 percent was grasses and sedges, and the remainder was forbs. The greatest volumes of forbs were produced in seedling-sapling and sawtimber stands, the least in pole stands. Post oak/blackjack oak stands had approximately 225 pounds per acre of understory vegetation, 15 percent of the total in grass and about 20 percent in forbs. Mixed hardwood stands had approximately 160 pounds per acre of forbs and 160 pounds per acre of woody plants. Grasses and sedges yielded 50 pounds per acre.

Ozark Intermediate Cuttings

I studied the impact of intermediate cuttings upon dormant season understory (below 5 feet) vegetation in 20- and 40-year-old black oak/scarlet oak stands subjected to different intensities of cutting in the Missouri Ozarks. Stands were heavily, moderately, or lightly cut, which corresponded to leaving 30, 50, or between 70 and 90 percent stocking in the residual stands respectively. This spread in cutting intensities approached clearcutting at one extreme and light selective cutting at the other, providing opportunity to study understory response to different cutting intensities. Study sites were classified as good (site index for black oak 75 or greater) or fair (site index greater than 60 but less than 75). I reported the sampling method for this work elsewhere *(Crawford 1971)*.

Heavily cut stands had the greatest standing crop of dormant-season vegetation (table 1). Vegetation decreased as cutting was decreased except in 20-year-old stands on fair sites, where lightly cut stands had more vegetation than moderately cut stands. Twenty-year-old stands had more vegetation than 40-year-old stands having similar sites and cutting intensities. Herbaceous vegetation made up only a small part of the total standing crop: heavily cut 40-year-old stands on both sites yielded about 3 pounds per acre, but all other stands yielded less than 1 pound per acre. Mushrooms occurred sparingly (about ½ pound per acre) on almost all treatments. However, lightly cut 20-year-old stands on fair sites produced 3.3 pounds of mushrooms per acre.

Table 1.—Production of dormant-season vegetation below 5 feet in height 3 years after intermediate cutting at stand age 20 and 4 years after cutting at stand age 40

[In oven-dry pounds per acre]

Age and	Cutting intensity		
site	Heavy	Moderate	Light
AGE 20:			
Good (>75)	171	87	58
Fair (61-75)	99	68	82
AGE 40:			
Good (>75)	112	51	37
Fair (61-75)	59	24	5

After heavy cutting, the average number of plant species increased substantially in 40-year-old stands but only slightly in 20-year-old stands (table 2). Many species eliminated from the stands after 40 years of no cutting or only light cutting returned after heavy cutting. The response was greater on good sites than on fair sites. Twenty years without substantial cutting did not eliminate as many species as did 40 years without substantial cutting.

Table 2.—Average number of species per plot for stands thinned at age 20 and 40

Age and	Cutting intensity		
site	Heavy	Moderate	Light
AGE 20:			
Good	8.9	7.9	8.4
Fair	7.5	5.6	6.4
AGE 40:			
Good	10.1	6.9	6.6
Fair	6.1	5.4	2.8

The most abundant species by weight in stands of both ages were flowering dogwood, several species of oak, and species of hickory. Blackgum was abundant on good sites in 20-year-old stands and on fair sites in 40-year-old stands after light cutting. Grape was relatively common in the understory except on fair sites in older stands. Grape, blueberry, New Jersey tea, hazelnut, and rose were the most abundant nonarboreal genera. Succulent green plant material was sparse.

Some difference in species composition occurred between lightly and heavily cut stands. In 20-year-old stands, plants more abundant after light cutting than after heavy cutting were blackgum, mushrooms, blueberry, hawkweed, bramble, and Virginia creeper. In 40-year-old stands, red oak decreased after heavy cutting. These plants are all common in Ozark oak-hickory stands and in time will reappear naturally after heavy cutting.

In contrast, several species increased as cutting intensity increased: New Jersey tea, hazelnut, and American plum in 20-year-old

Table 3.—White, black, and scarlet oak sprouts 3 years after cutting at stand age 20 and 4 years after cutting at stand age 40

[Weights in pounds per acre]

Age and site	Heavy		Moderate		Light	
	Oven-dry weight	Plots stocked[a]	Oven-dry weight	Plots stocked[a]	Oven-dry weight	Plots stocked[a]
	Lbs.	*Pct.*	*Lbs.*	*Pct.*	*Lbs.*	*Pct.*
AGE 20:						
Good	69	94	19	89	3	78
Fair	42	94	21	78	13	78
AGE 40:						
Good	32	94	26	78	11	100
Fair	20	75	5	56	1	67

[a] Plot area is 115.32 square feet.

stands; and rose, cinquefoil, goldenrod, aster, coralberry, persimmon, New Jersey tea, panic grass, and poverty grass in 40-year-old stands. The common woodland poverty grass has often been reported as decreasing in abundance with decreasing overstory. I found that it increased less with heavy cutting on good sites than on fair sites, probably because of less competition on fair sites.

The sprout growth of commercial species in the understory of 20-year-old stands was compared with that in 40-year-old stands (table 3). In 20-year-old stands, light cutting gave fair distribution of oak sprouts but little weight. Heavier cutting substantially increased the weight on good and fair sites, but more on good sites. Light thinning on good sites in 40-year-old stands gave best distribution of sprouting, and additional thinning increased the weight. This suggests that, on good sites, it may not be necessary to substantially open 40-year-old stands to get reproduction started. Initial cutting to 70- and 90-percent stocking, followed by later cutting to release the oak reproduction, may provide adequate early regeneration.

Ozark Clearcutting

All stems greater than 0.5 inch dbh were cut from an oak-hickory stand that had a range in black oak site index from 50 to over 70. The dormant-season standing crop of vegetation produced during the third growing season after cutting was reported by Crawford and Harrison *(1971)* and is shown tabularly in comparisons with other data later in this paper. Most production was in woody stems. Grasses, sedges, and forbs amounted to 2.3 percent, 1.1 percent, and 1.8 percent by weight of the production on low (SI=50–60), medium (SI=61–70), and high (SI=>70) sites, respectively. The unreported compositional aspects of this study follow.

Sassafras yielded more than any other species on poor and good sites, 28 and 19 percent of the total weight, respectively (table 4). White oak attained the greatest weight of any species, 36 percent of the total, on sites between site index 61 and 70, and was also prominent on good sites, amounting to 18 percent of the total.

The weight of sprouts of commercial oak species (white, scarlet, and black) was greatest on the medium site, although distribution was the same on all sites, 92 percent of the plots being stocked with at least one of the three species. Black oak decreased with increasing site quality; scarlet oak, though scarce, increased with site quality; and white oak reached its maximum on medium sites and was more abundant on good sites than on poor sites. Growth competition with oak coppice on good sites came mainly from sassafras and grape. Blackgum was the primary competitor

Table 4.—Plant weight (in oven-dry pounds per acre) and percentage of plots[a] occupied, by species, 3 years after clearcutting

Species	Black oak site index					
	50-60		61-70		71+	
	Lbs.	*Pct.*	*Lbs.*	*Pct.*	*Lbs.*	*Pct.*
Carya Nutt spp.	9	42	25	67	22	58
Ceanothus L. spp.	3	25	1	33	3	50
Cornus florida L.	59	50	8	50	50	42
Corylus L. spp.	(t)[b]	17	5	33	16	67
Nyssa sylvatica Marsh.	23	33	76	67	43	33
Parthenocissus Planch. spp.	0	0	(t)	17	8	33
Quercus alba L.	56	67	145	67	99	83
Q. coccinea Muench.	2	17	12	25	25	42
Q. velutina Lam.	30	75	18	75	4	42
Rhus L. spp.	3	17	0	0	8	8
Rosa L. spp.	(t)	33	(t)	33	3	33
Rubus L. spp.	(t)	33	8	67	48	83
Sassafras Nees. sp.	110	100	58	92	102	92
Vaccinium L. spp.	24	75	6	83	5	67
Vitis L. spp.	47	58	33	92	94	83

[a] Plot area is 115.32 square feet.
[b]t = trace.

on moderate sites, followed by sassafras. Sassafras was by far the major competitor on poor sites, followed by dogwood and grape. On medium and good sites hickory production exceeded that of black oak.

Nontree species of importance in addition to grape were hazelnut, Virginia creeper, sumac, and rose spp. on good sites. Bramble increased with site quality. Blueberry reversed the trend. New Jersey tea produced more on low and high sites than on medium sites.

With the exception of grape, sprouting tree species made up most of the dormant-season aspect of clearcut stands. It may be this dormant-season view of an expanse of woody sprouts that causes the concern about a loss in variety of plant species after heavy cutting. This concern is not supported by the Ozark growing-season studies reported previously here.

Selective and Clearcutting in Appalachian Oak-Pine Stands

In southwestern Virginia, the summer understory production of vegetation was sampled with a modified double-sampling technique 6 years after a cutting that removed all stems larger than 2 inches dbh. An adjacent area comparable in stand and site conditions (site index 55 for upland oaks) was partially cut 5 years before sampling, and approximately 20 percent of the stand or 30 square feet basal area was removed. These stands had been managed under an uneven-aged system.

This work was reported by Crawford and others *(1975)*, and production data by vegetation class are included later in this paper for comparison with other work. Previously unreported details of species abundance are reported here for comparison with other stands.

Table 5.—Production of summer understory vegetation on southwestern Virginia clearcut and partial cuts

Vegetation	Clearcut		Partial cut	
	Lbs. per acre	*Percent of total weight*	*Lbs. per acre*	*Percent of total weight*
Ferns	55.6	2.2	0.3	< 0.1
Mushrooms	.4	<.1	3.4	.4
Grasses	5.1	.1	3.8	.5
Forbs	144.2	5.7	69.2	9.2
Shrubs	1,033.6	40.6	476.7	63.6
Trees	1,308.3	51.4	196.2	26.2
Miscellaneous	1.1	—	2.9	—
Totals	2,548 ± 237	—	753 ± 109	—

Plants that were more abundant in lightly cut than in clearcut stands included mushrooms, dogwood, aster, tick-trefoil, red oak, New Jersey tea, hickory, angelica, grape, and pipsissewa. Again, as in Ozark stands, these plants are common and will reappear in time in heavily cut stands.

In heavily cut stands several species were more abundant: bracken fern, scarlet oak, bear oak, blackgum, mountain laurel, tickseed, galax, and wild lettuce.

Woody plants made up approximately the same proportion of weight in both clearcut and partially cut areas (table 5). Shrub species were proportionately greater in the partial cut than in the clearcut. Forb production in the clearcut was more than twice that in the partial cut. Grass production was approximately equal in both areas.

As part of a larger study at another location in southwestern Virginia, we sampled understory vegetation during winter in a 7-year-old clearcut and in a mature stand formerly managed under uneven-age management and uncut for at least 7 years *(Harlow and others 1975)*. Both stands were in the oak-pine type.

The differences in understory plant composition between heavily and lightly cut stands were small in comparison with the differences found in Ozark stands. The lightly cut stand had twice the standing crops of dormant-season herbaceous vegetation, but composition was almost the same as in the clearcut; galax was the major contributor to herbaceous yield. Leaves of mountain laurel, teaberry, and trailing arbutus were common, as were fungi. Woody twigs of blueberry and oaks were more abundant in the clearcut than in the lightly cut stand, as were twigs and leaves of pine.

Comparisons of Understory Production

Thus far I have concentrated primarily upon previously unreported compositional aspects of several studies. Now let's compare understory production data reported in several studies throughout the eastern forest types.

In stands uncut for 40 years or more, understory production measured during summer was, in pounds per acre:

Forest type, location, and reference	*Woody plants*	*Herbaceous plants*
Oak-pine Long Island *(Whittaker and Woodwell 1969)*	543[a]	20
Pine-oak Smoky Mountains *(Whittaker and Woodwell 1969)*	418	70
Cove forest Smoky Mountains *(Whittaker and Woodwell 1969)*	13	338
Birch-beech-maple Hubbard Brook NH *(Siccama and others 1970)*	78[b]	65
Mixed oak Pennsylvania *(Wood 1971)*	34	5

In stands that had been selectively cut, understory production measured during summer was, in pounds per acre:

Forest type, location, and reference	*Woody plants*	*Herbaceous plants*
Oak-pine Southwestern Virginia *(Crawford and others 1975)*	674[c]	77
Oak-pine Ozarks *(Murphy and Crawford 1970)*	125	62
Black/scarlet oak Ozarks *(Murphy and Crawford 1970)*	110	45
White oak Ozarks *(Murphy and Crawford 1970)*	115	60
Post/blackjack oak Ozarks *(Murphy and Crawford 1970)*	155	75
Mixed hardwood Ozarks *(Murphy and Crawford 1970)*	160	210

[a] Weights include contribution from radial wood in addition to twig and leaf growth.
[b] Leaves and current twigs of woody plants less than 2 cm dbh.
[c] Weights include contribution from evergreen leaves older than 1 year.

In selectively cut stands, understory vegetation production measured during winter was, in pounds per acre:

Forest type, location, and reference	*Woody plants*	*Herbaceous plants*
Oak-pine Southwestern Virginia *(Harlow and others 1975)*	45[c]	20
Mixed hardwood Southwestern Virginia *(Harlow and others 1975)*	42[c]	9
Cove hardwood North Carolina *(Harlow and Downing 1966)*	39[c]	17

For comparison with intermediate cutting in even-age management, see table 1.

In clearcut stands, understory vegetation production measured during summer was, in pounds per acre:

Forest type, location, and reference	*Woody plants*	*Herbaceous plants*
Oak-pine 6 years after cutting Southwestern Virginia *(Crawford and others 1975)*	2,346	206

In clearcut stands, understory vegetation measured during the winter was, in pounds per acre:

Forest type, location, and reference	*Woody plants*	*Herbaceous plants*
Cove forest 3 years after cutting North Carolina *(Harlow and Downing 1969)*	310	53
Oak-pine 7 years after cutting Southwestern Virginia *(Harlow and others 1975)*	197[c]	11
Oak-hickory 3 years after cutting Ozarks *(Crawford 1971)*		
SI 50–60	386	9
61–70	402	4
70+	504	10

Discussion

Taking some intuitive license, I hypothesized the following conceptual model to explain how forest understory is affected by overstory change.

Production of understory vegetation is related to forest type, stand structure, stand disturbance, and site. In stands that have not been disturbed by cutting for approximately 40 years, type, structure, and site operate together to influence the understory. Site influences forest type and—along with age—affects stand structure. The three factors to a large degree determine the amount and composition of the understory.

Cove forests are found on mesic rich sites with site-index values between 100 to 150. Tree canopies are deep and well developed and permit little light to reach the forest floor. However, abundant moisture and adequate nutrients allow a relatively luxurious growth of shade-adapted forbs. Deer populations are low in extensive acreages of old-growth forests and do not severely influence growth of understory vegetation.

Pine-oak and oak-pine stands are usually found on more xeric and somewhat infertile sites with site-index values from 45 to 70 feet per 50 years with occasional stands over site index 70. More light penetrates the more open canopies and encourages growth of substantial volumes of woody plants, often ericaceous species adapted to dry infertile soils. Herbaceous species biomass and diversity are often related inversely to the woody understory and are related directly to site quality. In extensive areas of undisturbed forest, deer populations are likely to be in balance with the vegetation.

Other stands fall between the xeric pine-oak and mesic cove hardwood types. As the hardwood component increases in the overstory, woody understory usually decreases. Herbaceous plants are influenced by site quality and may become more abundant as site quality improves.

Stand disturbance through cutting increases the amount of understory vegetation. Stimulated by increased light, freshly cut stumps of many hardwood species produce new sprouts, fed by an extensive root system. Root and stool sprouts and seedlings may be abundant. The number of sprouts is influenced by the composition of the forest type and the size of stems at the time of cutting (stand structure).

Woody growth increases as cutting intensity increases. On better sites, herbaceous growth is better able to compete initially with woody vegetation, although on the better sites the released woody growth soon forms a complete canopy and reduces the growth of herbaceous material, leaving only those species that are more shade-tolerant or capable of photosynthesizing when the overstory is leafless. Production of understory vegetation decreases as stands close after cutting and develop deeper canopies. When stands mature into sawtimber size, production of understory vegetation increases slightly as natural mortality thins the canopy, permitting increased light filtration to the understory.

Distribution and presence or absence of plant species also influences production of understory vegetation. Stands of similar forest type, structure, and site subjected to equal cutting are likely to have greater amounts of understory vegetation if there is an abundance of understory species that are more shade-tolerant and remain green over winter.

Galax is an example of such a plant. It maintains evergreen leaves and its low growing habit enables it to take advantage of a more favorable climate near the ground and to photosynthesize during warm spells throughout the winter. Galax is abundant in several types in the Appalachians but is absent from the Ozarks. Its nearest functional cognate in the Ozarks is antennaria, which does not grow as vigorously or in as dense a group as does Galax.

Many low-growing evergreen woody species present in Appalachian stands during winter are absent or scarce in Ozark stands. Species such as teaberry, trailing arbutus, and mountain laurel are common in the Appalachians. These nonarboreal evergreen plants are important wildlife foods. The differences in amounts of herbaceous and low-growing evergreen woody plants available for winter food help explain the ability of many Appalachian stands to support more deer and turkeys than Ozark stands.

Substantial disturbance of many stands results in a surge of new vegetation growth and may trigger an irruption in the deer herd. Generally, deer reach peak numbers after the stand has started to close and the peak of understory vegetation growth is past. An increasing herd on a decreasing range results in overuse and decline of many plant species. We found in Ozark stands that a recovering range may include a preponderance of plants that are not utilized by deer and lack formerly abundant plants that were favored deer foods *(Halls and Crawford 1960)*. This was also substantiated in an Appalachian study by Wood *(1971)*, who found that continually abused ranges may have little understory vegetation.

Thus many interacting factors determine the volume and composition of understory vegetation. Light, water, nutrients, seed source, and plant and animal competition all interact. This mosaic of interacting factors still determines forest understory despite all of man's product-oriented managerial practices applied to date. Forest ecosystems are resilient. From evidence gathered thus far, it does not appear that understory composition or yields with even-age forest management will change drastically from conditions we now find in naturally occurring even-age stands. Understory yields will increase for a few years after cutting, but will decrease as the canopy closes. Species of plants appear, disappear, and reappear in subsequent stands after the forest regenerates.

However, focusing on endangered plant species may provide a more sensitive indicator of potential problems than does the broader understory-analysis approach I have taken here. Unfortunately most emphasis on endangered species has been focused upon animals. Significant changes in any land-use practice are likely to affect sensitive plants before they affect sensitive animals. A reordering of priorities may be needed in existing endangered-species programs.

Literature Cited

Crawford, H. S.
1971. Wildlife Habitat Changes After Intermediate Cutting for Even-Aged Oak Management, J. Wildl. Manage. 35:275-286.

Crawford, H. S., and W. M. Harrison.
1971. Wildlife Food on Three Ozark Hardwood Sites After Regeneration Cutting. J. Wildl. Manage. 35:533-537.

Crawford, H. S., J. B. Whelan, R. F. Harlow and J. E. Skeen.
1975. Deer Range Potential in Selective and Clearcut Oak-Pine Stands in Southwestern Virginia. USDA For. Serv. Res. Pap. SE-134. 12 p.

Halls, L. K., and H. S. Crawford.
1960. Deer-Forest Habitat Relationships in North Arkansas. J. Wildl. Manage. 24:387-395.

Harlow, R. F., and R. L. Downing.
1969. The Effects of Size and Intensity of Cut on Production and Utilization of Some Deer Foods in the Southern Applachians. Northeast. Fish and Wildl. Conf. Trans. 26:45-55.

Harlow, R. F., J. B. Whelan, H. S. Crawford, and J. E. Skeen.
1975. Deer Forage Analysis During Years of Oak Mast Abundance and Scarcity. J. Wildl. Manage. 39:330-336.

Murphy, D. A., and H. S. Crawford.
1970. Wildlife Foods and Understory Vegetation in Missouri's National Forests. Mo. Dep. Conserv. Tech. Bull. 4. 47 p.

Siccama, T. G., F. H. Bormann, and G. E. Likens.
1970. The Hubbard Brook Ecosystem Study: Productivity, Nutrients, and Phytosociology of the Herbaceous Layer. Ecol. Mongr. 40(4):389-402.

Whittaker, R. H., and G. M. Woodwell.
1969. Structure, Production and Diversity of the Oak-Pine Forest at Brookhaven, New York. J. Ecol. 57(1):155-174.

Wood, Gene W.
1971. Biomass, Production and Nutrient Distribution in Mixed-Oak Stands Following Clearcutting and Fire. Ph.D. thesis, Pa. State Univ. 157 p.

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