Large Area Comparisons of Forest Management Practices in West Virginia (1951-Present)[1]

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Introduction

Changes in species composition and possible associated changes in forest productivity after timber harvesting have important implications with respect to forest management options for landowners and for regional wood using industries. To better understand partial harvesting and its impacts, a study employing three different partial cutting practices, with monitoring of unmanaged reference stands, was initiated in 1951 and continues to date on the Fernow Experimental Forest in West Virginia.

Using portions of the experimental design, numerous forest management concerns have been addressed. Topics have included residual tree quality following harvesting operations (Trimble and Smith 1970, Smith et al. 1994), composition of natural regeneration (Smith and Miller 1987, Miller et al. 1995), forest economics (Miller 1993), growth and yield (Trimble 1970), and water yield following forest management activities (Troendle 1979). Using the original study design, Schuler (2004) recently completed an assessment of long-term trends in productivity. Hundreds of tours have been given to natural resource professionals, educational groups, policy makers, and others using the various treatment units to demonstrate the effects of different forest management practices and to discuss relevant issues.

New issues continue to emerge that are relevant to forest management today that were not part of the original study design. For example, changing species composition is affecting future mast supplies for wildlife. Also, much has been learned concerning the effects of forest management activities on the sustainability of the federally endangered running buffalo clover (*Trifolium stoloniferum*) (Madarish and Schuler 2002) and the preferences of the endangered Indiana bat (*Myotis sodalis*) for different stand structural characteristics (Ford et al. 2002).

Methods

This study is located on the Fernow Experimental Forest (39.030 N, 79.670 W) within the Monongahela National Forest. Elevations on the Fernow range from about 1700 to 3,600 ft asl. The average growing season is 145 days (May to October); mean annual precipitation is about 56 inches, which is distributed evenly throughout the year (Pan et al. 1997). The ecological landtype of the Fernow is referred to as the Allegheny Mountains of the Central Appalachian Broadleaf Forest (McNab and Avers 1994). This study encompasses 21 physical research units, or compartments, on 690 acres (Table 1).

Field inventories were conducted for all trees more than 5 inches in diameter at breast height (dbh) by 2 inch classes and species before the first cut and usually just prior to each management intervention cycle (e.g., 10, 15, or 20 years thereafter). Table 2 briefly summarizes the silvicultural treatments and compartments used on the Fernow Experimental Forest. Each treatment was adjusted for the range of site qualities present, and to approximate what cutting methods would have been used operationally. For example, diameter-limit harvests in the Central Appalachians routinely occur about every 15 years on good to excellent growing sites, but may require a slightly longer period on fair sites. Patch cutting in our study resulted in a mosaic of even-aged patches of different ages throughout the stand and is area controlled (Table 2). The single-tree selection silvicultural treatment was designed to favor the development of large sawtimber-size trees. In addition to the field inventories, permanent camera points also capture the changes brought about through time and by management activities (Fig. 1).

Shannon-Weiner's diversity index (H') (Whittaker 1972) and Pielou's evenness index (J') (Pielou 1969) were calculated based on species relative density (species stem density/total stem density for dbh >/= 5 inches) for all periods and management scenarios. Because communities can change without affecting measures of diversity, i.e., one species replaces another, species composition through time also was assessed using an ordination technique (McCune and Mefford 1999). Univariate analysis of variance was used to discern differences in mean periodic annual increment (PAI) related to treatments and site index (SI). Because management/measurement cycles differed somewhat among treatments (Table 2), the effects of time on PAI were evaluated separately for each treatment. To achieve adequate replication for a repeated measures analysis, data from SI categories 70 and 80 were combined after preliminary analysis indicated no significant differences in overall productivity, similar species composition, and equal cutting cycles (SI 60 cutting cycles were longer).

	Site index			
Treatment	80	70	60	**Total**
Diameter-limit	2/109	2/86	2/40	6/234
Single-tree selection	2/104	2/54	2/22	6/180
Patch	2/59	2/64	2/57	6/180
Reference (unmanaged)	1/69	1/12	1/12	3/94
Total	7/340	7/217	7/131	21/690

Table 1. Number and area (acres) of research compartments used to assess alternative silvicultural systems, by treatment and northern red oak site index (compartments/acres).

Single-tree selection					
SI	Cutting cycle	RBA[a]	LDT[b]	Q	Compartment
	(years)	($ft^2 ac^{-1}$)	(inches)		
80	10	65	32	1.3	WS5A, 20A
70	10	50	26	1.3	7C, 16B
60	15	35	20	1.3	WS5B, 19B
Diameter-limit					
SI	Cutting cycle (years)	Harvest DBH[c] (inches)			Compartment
80	15	17			WS2A, 9B
70	15	17			27A, 9A
60	20	17			WS2B, 20C
Patch cutting					
SI	Cutting cycle (years)	Rotation age			Compartment
80	10	65			18A, 17A
70	10	75			30, 18B
60	15	85			17C, 18C
Unmanaged					
SI					Compartment
80					WS4A
70					WS4B
60					WS4C

[a]Desired residual basal area of trees with dbh ≥ 11 inches.
[b]Largest diameter-class tree to retain in the residual stand structure (e.g., 32 represents center of 2 inches dbh class).
[c]Trees with dbh of 17 inches or greater are harvested at each cutting cycle.

Table 2. Characteristics of silvicultural treatments and compartments used on the Fernow Experimental Forest (see Table 1 for area of compartments).

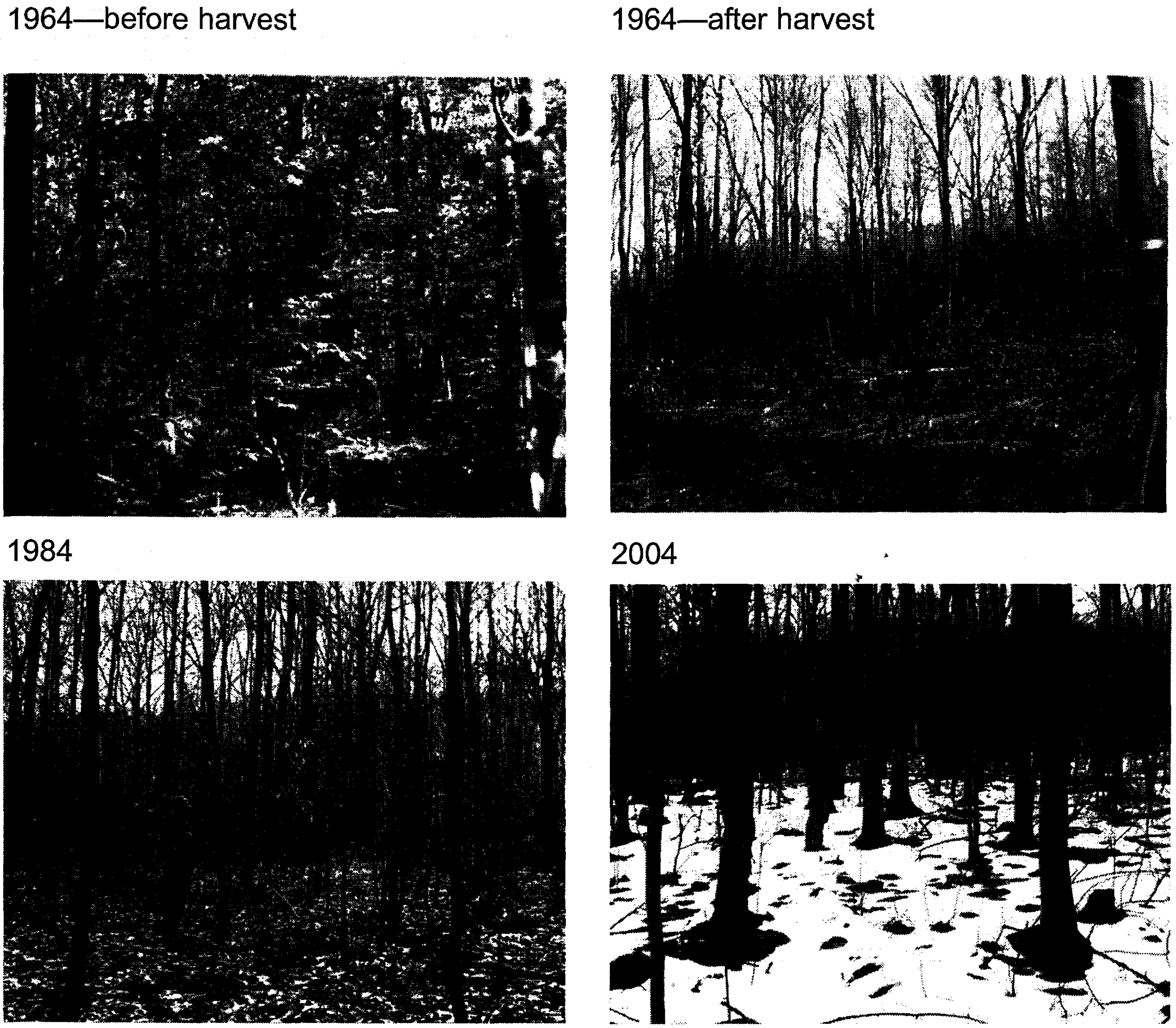

Figure 1. The sequence above captures 40 years of change from a permanent camera (CP 03 in Compartment 18A). The sequence depicts pre- and post-harvest stand development following a 0.4 acre patch cut. The technician in the photographs is standing by the same tree in 1984 and 2004.

Results

Thirty-two species of trees were identified during inventory dates ranging from 1951 through 2001 within the study area. During the most recent inventories, sugar maple (*Acer saccharum*) and red maple (*A. rubrum*) were the two most abundant species as measured by relative density. This was a notable change from the initial inventories when the most abundant species were northern red oak (*Quercus rubra*) and chestnut oak (*Q. prinus*). Over the period, northern red oak and chestnut oak declined to the third and eighth most abundant species, respectively. Apart from the maples, only American beech (*Fagus grandifolia*) and black birch (*Betula lenta*) increased in importance and represented at least 5% of overall relative density at the most recent inventory dates. All other species declined or were minor components of species composition.

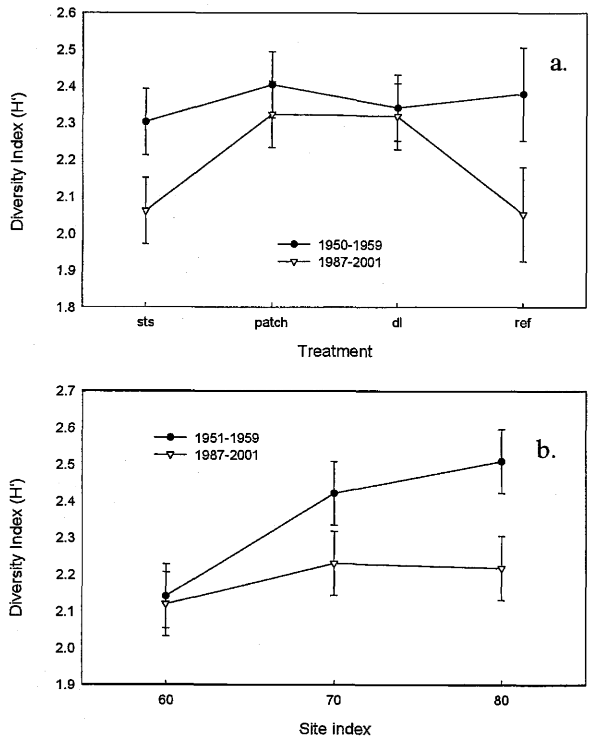

Figure 2. Mean Shannon-Weiner diversity index (H') stratified by treatment (a) and site index (SI) category (b) (sts = single-tree selection, patch = patch cutting, dl = diameter-limit, and ref = unmanaged reference stands). Vertical lines represent ± 1 standard error.

Treatment and SI category	Mean PAI ($ft^3ac^{-1}yr^{-1}$)	N
Single-tree selection	65 A	6
Diameter-limit	61 A	6
Patch cutting	57 A	6
Reference (unmanaged)	36 B	3
SI 80	64 A	7
SI 70	57 AB	7
SI 60	52 B	7

Table 3. Cubic volume net periodic annual increment (PAI) of merchantable trees (DBH >/= 5.0 in.). Treatment means from about 1951 to 2001 for each treatment and SI category. Means separated (*a* = 0.05) using the Duncan mean comparison procedure.

Unmanaged reference and single-tree selection compartments displayed statistically significant declines in diversity (Fig. 2a). When the study was initiated SI categories 70 and 80 were more diverse than SI 60 compartments. However, through time, these categories (SI 70 and 80) have declined in diversity, while SI 60 has not (Fig. 2b).

The model predicting overall PAI (mean PAI during study duration) from site and treatment was highly significant ($P < 0.001$). PAI was related to both SI ($P = 0.034$) and silvicultural treatment ($P < 0.001$). The unmanaged reference compartments had the lowest productivity and were significantly different from the managed compartments (Table 3). The type of treatment was not significant in terms of productivity given the variation within treatments. However, overall PAI was about 80% greater in stands managed with single-tree selection than in the unmanaged areas for all SI combined. PAI was significantly different ($a = 0.05$) for SI 80 and 60 but neither differed from SI 70 (Table 3).

Changes in PAI through time were evaluated by combining the data from SI 70 and 80 to achieve adequate replication. A change in PAI was significant with respect to time for the diameter-limit treatment only ($P = 0.047$). There was not a significant quadratic term, indicating a linear response through time (Fig. 3). Mean periodic increment for the diameter-limit compartments increased from 61 ft^3 per acre per year during the first 15-year period to 69 ft^3 per acre per year during the third 15-year period. In contrast, declining trends for the other treatments are suggested graphically, but were not significant in the repeated measures analysis ($P_{[sts]} = 0.602$, $P_{[patch]} = 0.143$, $P_{[ref]} = 0.149$).

Contrary to expectations, the increase in PAI in the diameter-limit compartments (red oak SI 70 and 80) is not totally understood but may be related to the inadvertent effect of the diameter-limit treatment on residual stocking. Early in the study, in two of the three compartments used for the diameter-limit repeated measures analysis, residual stocking levels were less than full after the initial harvests according to even-aged guidelines (Gingrich 1967). Stands that are not fully stocked are expected to be less productive because the residual trees cannot fully utilize the growing space. Residual stocking following subsequent harvests in the diameter-limit compartments happened to meet full stocking criteria and subsequent productivity estimates were similar to the single-tree selection treated compartments.

Discussion

Commercial Species

The uneven-age management and partial harvesting practices evaluated in this study are not sustaining shade intolerant or mid-tolerant species. The greatest declines in diversity have occurred in the unmanaged and the single tree selection stands (Fig. 4), on the best sites (SI 70 and 80). All hard mast species are in decline with the oaks being the most important component. Based on the probability of no new oak recruitment and the expected diameter growth rate of about 2 inches per decade (Lamson and Smith 1991), all of the remaining oak will be harvested in about 50 to 60 years using the 17 inch diameter-limit protocol. Smaller minimum diameters (e.g., 12 inches), often used in commercial logging operations, would shorten this period to about 30 years.

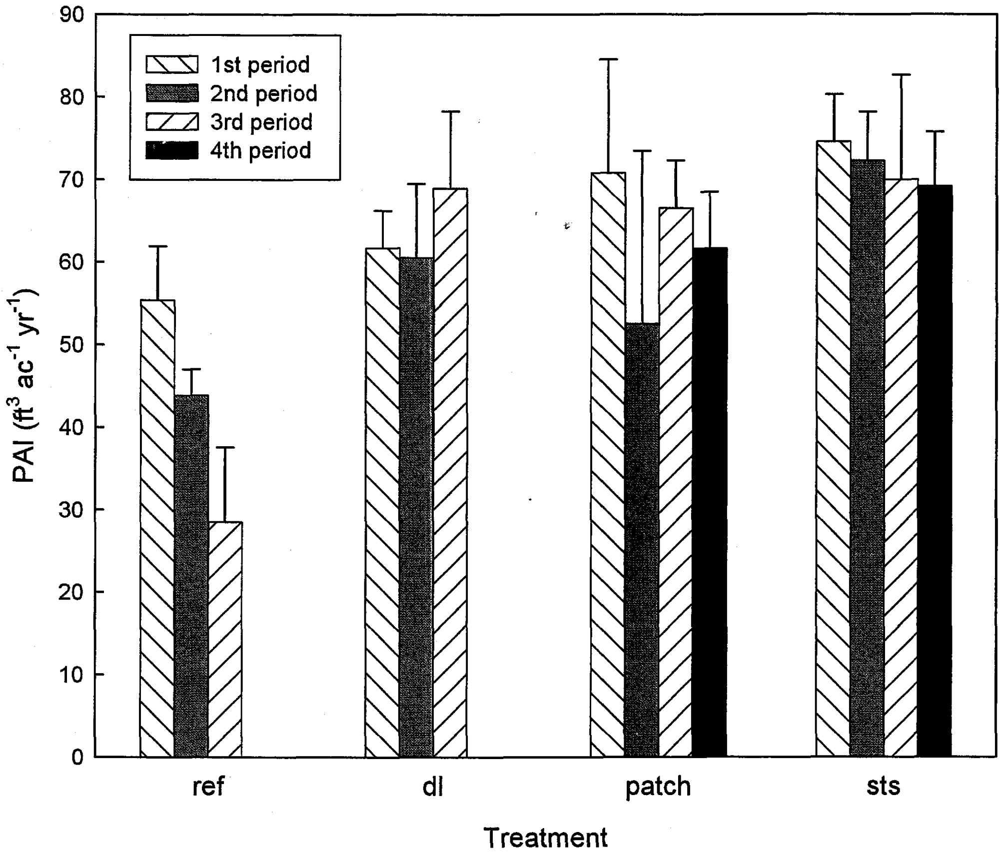

Figure 3. Mean cubic volume net periodic annual increment (PAI) of merchantable trees (DBH >/= 5.0 in.) (vertical lines = 1 standard error) by measurement cycle and treatment category (northern red oak site index 50 of 70 and 80): diameter-limit (dl); single-tree selection (sts); unmanaged reference areas (ref); patch cutting (patch). Measurement cycles differed by treatment and were as follows: 10 years for sts and patch, 15 years for dl, and 10, 20 and 40 years after the initial inventories for the reference compartments.

Likely Future Loss of Mast Production

Future overstory composition of the unmanaged, single-tree selection, and diameter-limit areas will increasingly resemble the beech-maple-basswood type (Tyrrell et al. 1998), which is generally located in the northern third of the eastern United States and southern regions of eastern Canada. Beech bark disease is beginning to cause overstory mortality of American beech in the immediate vicinity of the Fernow Experimental Forest. Thus, the future beech-maple-basswood forest probably will lack overstory beech and associated production of hard mast. The expected future composition represents a significant change from the previous mixed mesophytic forest type that included hard oaks, hickories, beech, and at one time American chestnut (*Castanea dentata*). Of course, mast-producing species are a critical food source for many wildlife species and the loss of most hard mast production could affect both game and non-game species alike.

Economic Implications

The loss of oaks and the commercially valuable and shade-intolerant black cherry (*Prunus serotina*) in the single-tree selection and diameter-limit compartments will significantly reduce the future monetary value of these stands. These valuable species also are not regenerating in the unmanaged reference compartments. Species regenerating within the small openings of the patch cut compartments contain a mixture of both shade-intolerant and shade-tolerant species. However, the oaks have not been regenerated within these openings (Miller et al. 1995).

Maintaining oak in eastern hardwood forests has been the focus of much research and likely involves the over abundance of white-tailed deer and lack of disturbance to the understory and forest floor. Prior to the 1920s, research has shown that mixed-oak forests experienced understory fires about every 5 to 15 years (Shumway et al. 2001, Schuler and McClain 2003). Understory fires would have greatly reduced the development of shade-tolerant understories. The combination of low light levels brought about by a dense understory and browsing of slow-growing oak seedlings by deer is detrimental to the development of larger oak seedlings and sprouts. Without larger oak seedlings in the understory, oak cannot respond competitively following any form of canopy disturbance. The effects of prescribed fire combined with the shelterwood regeneration method are currently being evaluated as a silvicultural prescription to regenerate oak on the Fernow Experimental Forest.

Running Buffalo Clover

Although the silvicultural practices evaluated in this study have had undesirable effects on maintaining desirable commercial species, the effects on the endangered running buffalo clover (*Trifolium stoloniferum*) appear to be positive. The Experimental Forest is the site of the second largest known population of this species (RBC). Most large subpopulations on the Fernow coincide with actively managed compartments used in this study. In 1999, a comparison of lighting conditions was made between 35 RBC locations and 35 random points within Compartment 9A/B, treated with a diameter-limit cut every 15 years. A Li-Cor® LAI Plant Canopy Analyzer was used to measure the leaf area index (LAI) and gap area. Sites with RBC consistently had less LAI than randomly selected sites (Madarish and Schuler 2002). Research has shown RBC is associated with periodic ground disturbance and limestone soils. Ground disturbance from skidder activity and increased partial sunlight may help sustain RBC over the long run, since on the Fernow most RBC can be found growing in skid roads that are used every 10 to 15 years. Partial cutting and skid roads appear to provide canopy gaps for increased sunlight and scarification of the soil that may facilitate stoloniferous expansion. Only small subpopulations of RBC exist in unmanaged areas on the Fernow.

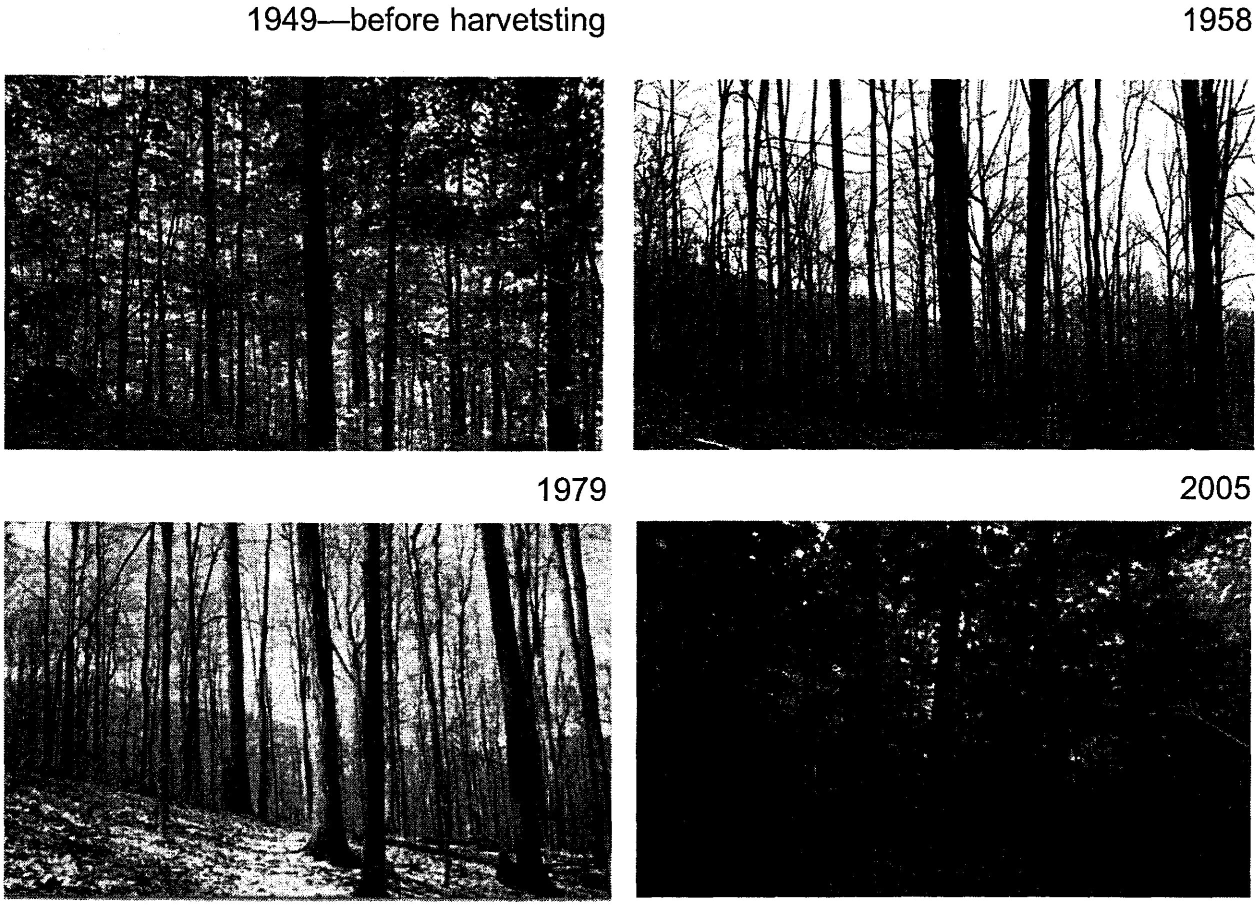

Figure 4. The sequence above captures over 50 years of change from a single camera point (CP 04) in Compartment 8C (SI 80) managed using single-tree selection and the criteria described in Table 2. There have been six harvests totaling about 22,000 board feet/acre from this compartment during the past half-century.

Bats

Study and monitoring of bat activity also have become part of the activities related to all silvicultural studies on the Fernow (Ford et al. 2002). Because of the presence of Big Springs Cave, a hibernaculum for the endangered Indiana bat (*Myotis sodalis*) in the center of the Fernow Experimental Forest, bat monitoring and research has been an ongoing part of the lab's activities for the past decade. Species with relatively large body sizes and high-wing loadings or low echolocation such as the eastern red bat (*Lasiurus borealis*) tend to forage in more open habitats where silvicultural manipulations have resulted in patch openings. Species such as the northern bat (*Myotis septentrionalis*) that are small and highly maneuverable, with low-wing loading and high echolocation characteristics, tend to forage in more closed, interior forest conditions. Acoustical sampling has been an excellent tool for documenting the beginning of the winter hibernation period and the beginning of spring activity for Indiana bats and other species that roost in Big Springs Cave (Fig. 5). The Fernow has been a focus for the study of summer and fall day-roosting ecology of both the Indiana bat and the northern bat.

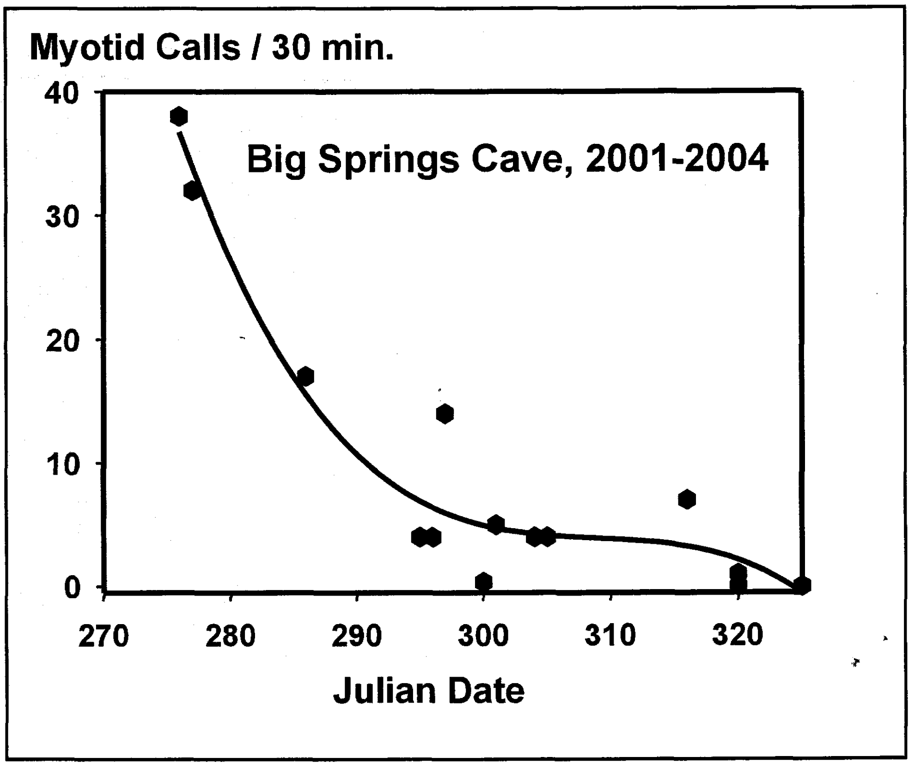

Figure 5. Fall Indiana bat echolocation activity on the Fernow Experimental Forest near Big Springs Cave.

Summary

Three generations of scientists have contributed to the establishment and continuation of this long-term silvicultural study. Extension of this study will require incorporating the requirements of the National Environmental Policy Act (NEPA) and other environmental legislation, endangered species consultations and restrictions, National Forest Plan guidelines for stream side management zones, in addition to the logistical and scientific concerns of the past. In recent years we have completed two Environmental Impact Statements and four Biological Assessments to keep this study active. We consult with the United States Fish and Wildlife Service regarding the endangered species that may be affected by our experimental manipulations. We have written one Forest Stewardship plan to retain some of the revenue generated by the planned timber harvests to pay for stewardship activities and are working on another stewardship plan. These complexities illustrate that long-term silvicultural research is no longer the domain of silviculturists alone, but requires a multi-disciplinary staff to plan and evaluate the effects of the treatments and the proposed treatments on both designed response variables and secondary effects on non-target resources (e.g., forest hydrology, wildlife and herbaceous species, and non-native invasive plants). Our multi-disciplinary approach to silvicultural research reflects the complexities of forest management in the 21st century. This long-term research project, then, is far more than an academic inquiry into the response variables envisioned 50 years ago. It also provides an irreplaceable platform for scientific study of emerging new issues and management concerns. Confronting the complexity of the present ensures that we as researchers are well-grounded in the challenges that forest managers face each day.

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