SILVICULTURE AND THE LONG-TERM DYNAMICS OF SINGLE-TREE SELECTION ON PIONEER FOREST

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Abstract—The uneven-aged silvicultural prescriptions being applied to oak-hickory stands on the Pioneer Forest contain elements of both art and science. The scientific element is found in the quantitative analysis of long-term inventory information to guide marking decisions, as stands currently receive their third and, in some cases, fourth cutting cycle harvest. The artistic element is borne of experience, as newly hired foresters and technicians serve the equivalent of an apprenticeship under the watchful guidance of the senior forest management staff. Contrary to popular belief, quantitative evidence and practical observation suggest that the uneven-aged methods being applied in Pioneer Forest are both sustainable and productive over time.

INTRODUCTION

What silvicultural approach do Pioneer Forest managers use (is it classical single-tree selection), and how has this approach affected the forest structure over the last 50 years on this 154,000+ acre, privately owned, oak-dominated forest? Answering these two simple questions might seem straightforward. However, I have been wrestling with the answer to these questions for over a decade. This has been a good exercise because it finally dawned on me why it is so hard to describe what they do on the Pioneer Forest. It all goes back to the basics of silviculture.

Silviculture has been defined as the art and science of producing and tending a forest stand to meet a landowner's objectives on a sustainable basis (Smith 1986). It seems that foresters on the Pioneer tend toward the artistic side of silviculture. Newly hired foresters at the Pioneer Forest essentially serve an apprenticeship; the new forester follows an experienced one around the woods observing and asking questions for about 6 months before they're allowed to mark their first stand for harvest. Even then, they work only under the watchful eye of their mentor until they have shown they understand and can properly apply the system. All the Pioneer foresters are educated professionals with a good background in the science of forestry. The trouble is that a textbook on scientific application of selection silviculture in oak-dominated ecosystems has not yet been written, so the only way to learn the system is from someone who already knows how to apply it. In other words, their practice is quintessentially an art and a science, passed down from master to apprentice.

Several years ago, when asked about their approach to marking stands, Pioneer Forest Manager Clint Trammel stated that their goal upon entry into a stand is to create or maintain a three-tiered canopy composed of an overstory, a midstory, and a sapling/reproduction layer. Assuming that the three canopy tiers represent three broad age classes, the textbook definition of an uneven-aged stand is attained. However, that still says little about how individual trees are selected for harvest. What are the marking rules? Are trees marked from across the entire range of diameter classes with each entry? Is the stand marked to a target diameter distribution? The answers to these questions would help to determine whether the Pioneer Forest managers were practicing classical selection silviculture. Over time, through a series of discussions, the answers provided by the Pioneer Forest staff indicate an empirical rather than an academic approach. Four general rules are followed on the Pioneer Forest:

1. Cut on a 20-year cycle by section (1 square mile; this is the operational unit on the forest). The harvest is scheduled when basal area reaches 95 to 100 square feet per acre rather than by strict adherence to the cutting cycle.

2. Only merchantable trees are harvested.

3. Culls are felled if suppressing crop trees. Snags are left.

4. Removal is based on vigor, canopy position, site/species relationships, and potential for increase in value.

Typically, there are four issues raised that suggest single-tree selection is an inappropriate silvicultural system for regenerating shade-intolerant tree species, in general, or oaks, in particular. First is the concern that oaks will not develop under the shade of a continuous canopy (Sander 1980). Therefore, with single-tree selection it is not possible to develop the age structure necessary for an uneven-aged stand (e.g., three separate age classes). Second, it is thought that an oak-dominated stand cannot develop or maintain the reverse J-shaped diameter structure indicative of a balanced uneven-aged stand (Sander 1980). Third, when single-tree selection is applied in an oak-dominated stand, the result in other situations has been a shift in species composition toward more shade-tolerant tree species (Trimble 1970, Della-Bianca and Beck 1985, Schlesinger 1976). This is related to the first argument. Oak cannot become established beneath the shade of a continuous canopy and so will be replaced by more tolerant species such as red maple (*Acer rubrum* L.) or hickory (*Carya* sp.) that can tolerate these conditions. Fourth, if the data show an age structure, diameter structure, or species composition indicative of a sustainable silvicultural system, then there must be an alternative explanation. Either the long-term results of the current management practices are not yet apparent or the data were collected over too large an area. The response to these concerns by the staff of the Pioneer Forest has always been to invite skeptics out to the forest to see what they are doing, and to witness the results of their management.

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Unfortunately, not everyone is able to make the trip to south central Missouri, nor is seeing necessarily believing. Objective scientific data were required. The purpose of this paper is to quantitatively explore four questions relative to silviculture on the Pioneer Forest. Has the Pioneer Forest staff been able to create uneven-aged stands in an oak-dominated system? Has the species composition of the stands continued to be oak-dominated? Finally, were Pioneer foresters able to create the stand diameter structure necessary to sustain an uneven-aged stand? Only if the answers to these three questions were yes would it make sense to address the final issue. Is the silvicultural system in practice on the Pioneer Forest single-tree selection or is regeneration occurring in distinct even-aged groups better described as group-selection or patch clearcutting? Answering each of these questions required a definition of the uneven-aged state that was much more rigorous than that which is currently in use by the forestry profession. However, it also required an evaluation of the Pioneer system in a manner to which accepted successful applications of a single-tree system had never been subjected.

The Pioneer Forest offers a unique opportunity to see the long-term results of a silvicultural system rarely attempted in an oak-dominated ecosystem. This is possible because a continuous forest inventory (CFI) has been maintained on the forest since the 1950's. The CFI plot network consists of two, 1/5-acre fixed-radius plots per square mile on the forest. These are permanent plots, and all trees larger than 5 inches in d.b.h. are uniquely identified and remeasured at 5-year intervals. This dataset makes it possible to track change through time so that the effect of the Pioneer system on stand diameter structure and species composition can be examined relative to a known starting point. The examination of spatial scale was made with only the most recent inventory (1992), and the dataset used to examine forest age structure was collected apart from the CFI plot network (Loewenstein 1996, Loewenstein and others 2000).

AGE STRUCTURE

In order to determine whether the Pioneer management system created an uneven-aged stand structure, a statistically testable definition of age structure had to be developed. By definition, an uneven-aged stand is one that contains at least three age classes either intimately intermixed or occurring in small groups (Helms 1998). To conduct a statistical test, age class was defined within the context of an even-aged stand where the range of ages is expected to be within 20 percent of the rotation length. One assumption had to be made because the concept of rotation does not apply to uneven-aged silviculture (Meyer 1943); an uneven-aged stand is managed by diameter structure, and tree age is of little or no importance. For purposes of the test, however, a rotation length of 90 years was assumed. This gave an age-class range of 18 years. Based on these assumptions, the test of a binomial proportion was then used to categorize sampled stands as either even-aged, two-aged, or uneven-aged.

Ten 1-acre plots were sampled across one section (1 square mile) on the Pioneer Forest. The section was chosen at random from all Pioneer holdings that had been entered for treatment at least three times since the property was acquired by the forest in the 1950's. This restriction ensured that the observed age structure was influenced as little as possible by management practices applied prior to acquisition by Pioneer Forest. Sample plots were limited to an acre in size to ensure, to the extent possible, that silvicultural treatments were applied in a fairly uniform manner across each plot. Age was determined for 60 oaks on each plot. Our interest was in determining whether the Pioneer system can sustain an uneven-aged oak-dominated forest with oaks maintained in all age classes. If the oak component is unable to establish and periodically recruit additional age-classes into the stand, it is not sustainable in the long-term.

Seven of ten 1-acre plots were classified as uneven-aged, two as two-aged, and a single plot was determined to be even-aged. However, in order to adequately interpret these data, some additional information is required. First, the test used was very conservative. Had an alternative definition of an age class been used (e.g., Schnur (1937) defined an age class as spanning not more than 8 years) or a less conservative statistical test, at least 9 of the 10 samples would have been classified as uneven-aged. It must also be noted that although the Pioneer Forest has been under the current management strategy since the 1950s, trees are very long lived and many of the trees currently standing in the forest were established prior to commencement of the current silvicultural system. The total range in age of the trees sampled was from 12 years to 233 years; but, 87 percent of the sampled trees germinated prior to the creation of Pioneer Forest. Even so, on eight of the ten 1-acre plots, a new age class has been recruited under the current management regime. Given that the Pioneer silvicultural system is recruiting oak into the stand and that on at least 70 percent of the forest sampled the age structure was found to be uneven-aged, it appears that the three age classes required for the uneven-aged state can be developed in this oak-dominated system and that the Pioneer Forest silvicultural system is able to create/maintain this age structure.

DIAMETER STRUCTURE

A reverse J-shaped diameter distribution is considered indicative of an uneven-aged stand because it allows for ingrowth, natural mortality, crop tree selection, and harvest while maintaining a stable diameter structure (Schlesinger 1976). However, it has been suggested that oaks and other shade intolerant species are unable to maintain this reverse J-shaped distribution because they are unable to successfully reproduce or recruit into successively larger size classes under the shade of a continuous canopy (Sander 1980). From the time active management started on the Pioneer Forest in the early 1950s, the composite diameter structure on the forest has maintained a reverse-J shape (fig. 1). However, the forest has been steadily changing. With each succeeding CFI inventory, the stocking percent increased markedly, and the number of stems in each diameter

class increased as evidenced by the increased height of each subsequent distribution (fig. 1). On average, the forest has changed from an open woodland structure (32 percent stocking) to a closed canopy forest.

A sustainable forest structure is expected to be stable over an extended period of time. Forest stocking levels have steadily increased on the Pioneer Forest, so, in a strict sense, forest structure has changed. However, examining the Pioneer Forest diameter distributions on a relative scale rather than an absolute scale produces a somewhat different picture (fig. 2). Even with a marked increase in stocking levels, the relative diameter structure on the Pioneer Forest has remained remarkably stable over time. The forestwide q-value, defined as the proportion of trees in one diameter class relative to the number of trees in the next smaller diameter class, has not varied by more than 0.02 over the 40-year period illustrated. Whether this diameter structure will remain constant as stocking levels on the forest continue to rise is subject to ongoing discussion. However, its stability across the first 40 years of management under the Pioneer system is a matter of record.

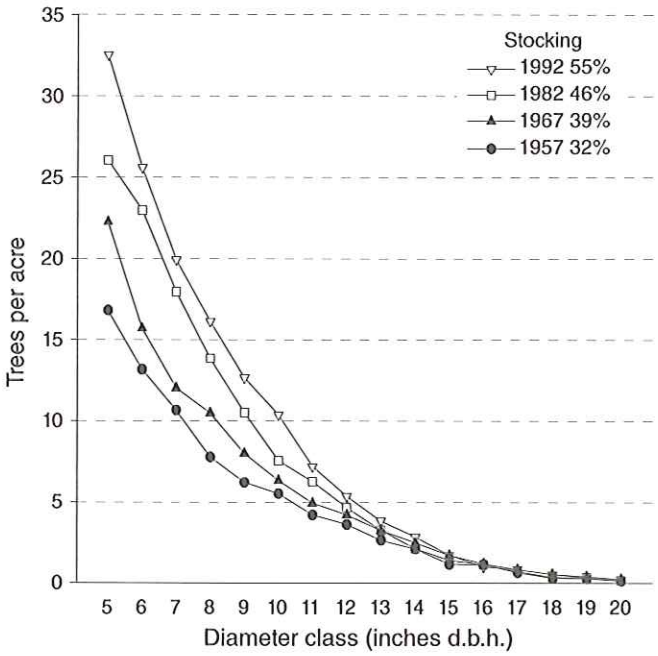

Figure 1—Diameter distributions of all trees inventoried on the Pioneer Forest in 1957, 1967, 1982, and 1992.

SPECIES COMPOSITION

The single-tree selection method has been successfully used to manage shade-tolerant species, which are able to establish and develop in the shade cast by a continuous cover of overstory trees. However, oaks tend to be intolerant to moderately tolerant of shade, and it has been suggested that they cannot be regenerated using the single-tree selection system (Sander and Clark 1971, Sander and Graney 1993). The common perception among foresters is that when selection silviculture is practiced in an oak-dominated ecosystem, a shift in species composition occurs toward more shade-tolerant species that are often of lesser commercial value (Johnson 1977, Niese and Strong 1992). Further, such shifts in composition have been shown in numerous studies (e.g., Trimble 1970, Della-Bianca and Beck 1985, Schlesinger 1976). It should be noted, however, that these studies were conducted in highly productive forests that tend to receive adequate rainfall during the growing season. In those mesic forests, regeneration of oak species can be difficult. Shade-tolerant competitors often overwhelm and out-compete oak reproduction regardless of the silvicultural method employed. However, the Pioneer Forest is located in the Ozark Highlands of Missouri where moisture is limited, and the drought-tolerant oaks are easily regenerated.

In the early 1950s when selection silviculture was first applied on the Pioneer Forest, seven principal species (or species groups) comprised over 90 percent of both the standing basal area and tree density (number of trees per acre). These species were white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), northern red oak (*Q. rubra* L.), post oak (*Q. stellata* Wangenh.), the hickories (*Carya* sp.), and shortleaf pine (*Pinus echinata* Mill.). By the early 1990s, the average basal area on the Pioneer Forest had increased by approximately 50 percent, and the number of trees per acre (all stems > 5 inches in d.b.h.) had increased by over 70 percent.

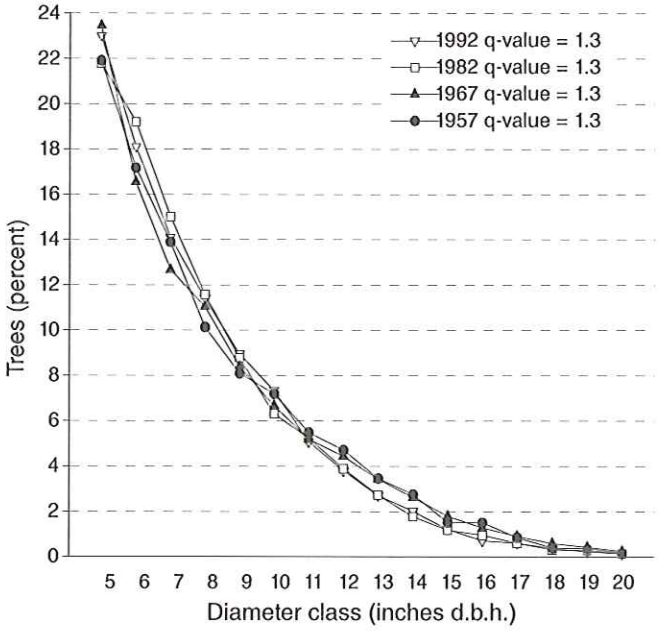

Figure 2—Relative diameter frequency distributions of all trees inventoried on the Pioneer Forest in years 1957, 1967, 1982, and 1992.

Even with this marked increase in both volume and density, the seven species that dominated the forest in the 1950s still accounted for over 90 percent of both basal area and trees per acre (Loewenstein and others 1995). It is true that the proportion of trees among these species has shifted somewhat with white oak increasing in prominence at the expense of the others. However, even this small change in the relative proportions of the oak species only serves to bring the current species mix closer in line with that which is thought to have occurred historically across the region.

Although there were no large shifts in the overstory species composition (trees > 5 inches in d.b.h.), demonstrating that the species composition is sustainable also requires an examination of trees in the understory. Based on a 1992 inventory of subcanopy trees (1.6 to 4.9 inches in d.b.h.), six of the seven principal overstory species were among the 10 most abundant subcanopy species. Only northern red oak was not; it ranked 16th in understory tree abundance (Loewenstein 1996). White oak was the most abundant subcanopy tree, accounting for over 75 stems per acre. Flowering dogwood (*Cornus florida* L.), a shade tolerant, was the second most abundant subcanopy tree. Flowering dogwood, however, rarely reaches the overstory; stems greater than 4.6 inches in d.b.h. were found on less than 7 percent of all CFI plots. The only other subcanopy shade tolerant species of significance were black gum (*Nyssa sylvatica* Marsh.) and maples (*Acer* sp.). Combined with dogwood, these three species groups comprised 98 percent of the subcanopy shade-tolerant species and accounted for 87 percent of the total density of overstory shade-tolerant species. Approximately two-thirds of all shade-tolerant species inventoried in 1992 were in the 2-inch d.b.h. class, and more than 90 percent were less than 4.6 inches in d.b.h. (fig. 3). In general, there is little or no evidence that shade-tolerant species have increased in importance in the overstory. Moreover, and more importantly, the accumulation of shade-tolerant trees in the smallest diameter classes does not appear to have suppressed the establishment and growth of intolerant species including the oaks. In the 2-inch diameter class, which included the greatest proportion of shade-tolerant species, the combined oaks and other intolerants outnumbered the shade-tolerant species nearly two to one.

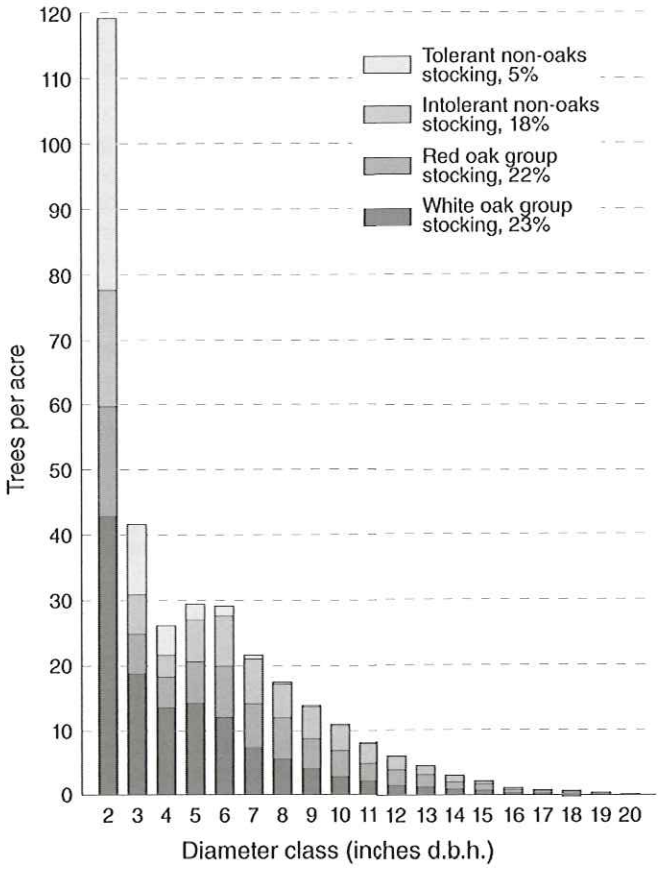

Figure 3—Diameter distributions by species group of all trees in 1992 (stocking, 67 percent).

SPATIAL SCALE

Finally, the issue of spatial scale must be addressed to determine whether or not single-tree selection, as opposed to group selection, can sustain oak recruitment on the Pioneer Forest. Oaks are intolerant to moderately tolerant of shade. Therefore, successful oak reproduction may require small even-aged groups or patches that are larger than those provided by the single-tree selection system.

Beginning with the accepted definition of an uneven-aged stand as one with at least three age classes either intimately intermixed or occurring in small groups (Helms 1998), an attempt was made to develop a test of spatial scale for uneven-agedness. Unfortunately, this definition is unsatisfactory from both a scientific and a statistical perspective. It is too ambiguous to be tested directly for two reasons: first, the maximum size of a single stand is undefined, and, second, the size at which a group opening becomes large enough to be considered a small clearcut (and by definition, a separate stand), is debatable as well. These two issues become problematic only because without spatial limits, it is possible to define group and stand in such a way that three age classes are always included within an arbitrary boundary, thus meeting a 'minimal' definition of an uneven-aged stand.

With any of the even-aged silvicultural reproduction methods (i.e., clearcutting, seed-tree, or shelterwood), regeneration occurs across the entire stand at the start of the rotation. Thus, age and size structure are consistent across the entire area. In group selection, regeneration occurs in small even-aged patches that are periodically created at each cutting cycle. The age structure and diameter structure of a group-selection stand combine measurements from each group into a single distribution. Individually, trees in each group are fairly uniform in both age and diameter. Only when combined across the stand does a recognizable uneven-aged structure appear (a reverse J-shaped distribution is typical). In single-tree

selection, however, regeneration is distributed much more uniformly across the stand. The age (size) classes are intimately intermixed. For this reason, under single-tree selection the diameter structure of the stand should be more uniform and occur at a smaller spatial scale than might be expected with either group selection or by combining separate even-aged stands.

By examining the spatial scale at which a stable reverse J-shaped diameter distribution occurs, it should be possible to place the silvicultural method employed by Pioneer Forest managers along the continuum from single-tree selection, through group selection or into any of the even-aged systems. If this spatial scale is relatively small (1 acre or less, for instance) there could be little question that the diameter structure was stable, sustainable, and occurring in a pattern suggestive of the single-tree selection system. If, however, the spatial scale at which the forest wide diameter distribution reoccurs were fairly large (several acres or more), then the likelihood that this distribution consists of accumulated even-aged groups of trees increases dramatically. On the Pioneer Forest, it was found that the forestwide, reverse J-shaped diameter distribution reoccurred on average at a spatial scale of only 0.6 acres (Loewenstein 1996). Given that the most intensively managed even-aged plantations cover at least 1 acre (Smith 1986) and extensively managed forest stands may be several hundred acres in size (the operational unit or stand size on the Pioneer Forest is one section, 640 acres), this is strong evidence that single-tree selection is indeed the silvicultural system employed on the Pioneer Forest, and it is maintaining a stable diameter structure at a very small spatial scale.

SUMMARY

Despite a widely held belief that oaks regenerate most easily using clearcutting or shelterwood methods, this knowledge leads many to discount the use of uneven-aged methods to manage oaks. However, the data in this paper show that the staff of the Pioneer Forest has successfully used single-tree selection over the past 50 years. The efficacy of the Pioneer system was evaluated in four ways:

1. The age structure of the oak component was found to be uneven-aged across 70 percent of the area sampled.

2. The diameter structure was found to exhibit a stable, reverse J-shaped distribution that has not changed over time. Such a distribution is considered indicative of a balanced, uneven-aged stand.

3. The species composition on the forest has changed little over the past 50 years and shows no evidence of a compositional shift toward shade-tolerant species. The oak component has been maintained in the overstory and understory, and the white oaks are increasing in prominence.

4. Finally, the forestwide diameter structure appears stable at a spatial scale of 0.6 acres. This scale strongly suggests that the entire range of size/age classes is well distributed across the landscape and not occurring in distinct even-aged groups.

The evidence from these studies collectively indicates that the single-tree selection system can be used to sustain an uneven-aged oak-dominated forest in this Ozark ecosystem, and that single-tree selection is indeed the system applied on the Pioneer Forest.

ACKNOWLEDGMENTS

The author would like to express sincere appreciation to Leo Drey, Clint Trammel, and all of the Pioneer Forest staff for their assistance during the conducting of this ongoing research and for making their CFI database available for analysis. He would also like to thank U.S. Forest Service scientists, Steve Shifley and Jim Guldin, for their review of this manuscript.

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