PRO-B SELECTION METHOD FOR UNEVEN-AGED MANAGEMENT OF LONGLEAF PINE FORESTS

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Abstract-- Interest in uneven-aged silviculture has increased since advent of ecosystem management programs, which place greater emphasis on ecological values and ecosystem services while also harvesting timber from the forest. However, traditional uneven-aged approaches (e.g., BDq) are often criticized as too complex, costly, and requiring highly-trained staff. The Proportional-B method (Pro-B) addresses these concerns, making uneven-aged silviculture a practical management option. In an operational-scale study, Pro-B was successfully used, by forest staff from a range of professional backgrounds, following less than 3 hours of training, to apply single-tree selection and group selection in longleaf pine (*Pinus palustris* Mill.) forests. Field crews achieved precision levels within 3 to 5 percent of the target residual basal area. By aggregating many diameter size-classes into only three size-class groups, Pro-B improves efficiency by requiring tree markers to remember only three fractions while making a single pass through the stand. Not being restricted by maximum-diameter rules also allows flexibility to retain larger trees for enhancing structural diversity. Trees of specific species and with good form, broad crowns and cavities can be retained, while adjusting spacing to release residuals. Systematic quantification of tree removal enables different individuals to obtain consistent results. A stable structure is maintained with characteristics of a mature forest, while regeneration is initiated and timber is removed through a periodic cutting cycle. With a focus on forest sustainability and flexibility to retain large trees and biological legacies by mimicking small-scale natural disturbances, Pro-B might be implemented to achieve the production objectives and stewardship goals of retention forestry.

INTRODUCTION

Ecosystem management policies emphasizing biodiversity and long-term sustainability have, in recent years, increased the interest in and practice of uneven-aged silviculture (O'Hara 1998). This is true nowhere more than in southern pine forests, where even-aged methods for timber production lead to adverse consequences for other ecosystem values (Guldin 2006). Protecting native plant communities, maintaining continuous forest canopy, and facilitating development of large old trees are among the desirable habitat features resulting when uneven-aged silviculture is applied in an adaptive management framework (Brockway and others 2006). Uneven-aged silviculture also affords a major advantage, in that natural regeneration is more or less continuous through time, as late-successional stand dynamics are emulated (Guldin 1996).

Despite an historical decline, longleaf pine (*Pinus palustris* Mill.) forests are highly valued for a variety of resources having ecological, economic and cultural importance and substantial interest has recently emerged in best management approaches for sustaining and restoring them (Brockway and others 2005a, Van Lear and others 2005). Although longleaf pine has been mostly managed with even-aged methods and was formerly thought to be too intolerant for uneven-aged silviculture (Croker and Boyer 1975), recent evidence suggests this to be a viable management alternative (Brockway and Outcalt 1998, Farrar 1996, Gagnon and others 2003, McGuire and others 2001, Palik and others 1997). Longleaf pine can grow in pure stands and also in association with numerous trees species across a wide range of ecosystem types, including slash pine (*P. elliottii* Engelm.) on flatwoods, loblolly pine (*P. taeda* L.) and shortleaf pine (*P. echinata* Mill.) on mesic uplands, and various hardwoods on xeric sandhills, mountains and other site types (Boyer 1990). This natural variety indicates that no single prescription is appropriate for sustaining longleaf pine everywhere. Prudent managers will select approaches suited for their specific environment, which lead to: (1) an overstory dominated by mature longleaf pine occurring as uneven-aged stands or even-aged patches across an uneven-aged landscape, with a lesser component of other tree species; (2) a midstory that is generally absent or mostly composed of ascending longleaf pine in scattered, modestly-sized canopy gaps; and (3) an understory with abundant longleaf pine seedlings and groundcover dominated by native grasses and

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forbs with lesser cover of shrubs and vines (Brockway and others 2005a). Research has fostered improved technology for the establishment, recovery, and maintenance of longleaf pine ecosystems (Jose and others 2006). Private sector interest and public sector direction now emphasize improved management of existing longleaf pine and, on suitable sites, eventual expansion of the area occupied by longleaf pine. To these ends, the principal goal of all sustainable forest management should be application of silvicultural methods that ensure maintenance of longleaf pine ecosystems in perpetuity. Such methods will incorporate natural regeneration and, to the degree possible, simulate disturbance events and other ecological processes (e.g., lightning strikes, periodic surface fire, windstorms) that contributed to maintaining longleaf pine ecosystems prior to settlement. However rather than relying upon random chance, management will deliberately manipulate the ecosystem to achieve specific stewardship objectives (Brockway and others 2006).

Uneven-aged silviculture is not new in the South and has been practiced in loblolly pine and shortleaf pine using the Volume Guiding Diameter Limit (VGDL) (Reynolds 1969, Reynolds and others 1984) and Basal Area-Maximum Diameter-q (BDq) procedures (Guldin 2006, Shelton and Cain 2000). Following field tests, guidance for uneven-aged silviculture in longleaf pine recommended the use of BDq, with B = 60 square feet per acre, D_{max} = 20 inches, and q = 1.44 for 2-inch size-classes (Farrar 1996). These parameters define a target structure with a “reverse-J” diameter distribution, against which stands are evaluated for cutting. In expert hands, BDq can be adeptly applied. However, the requirement to mark and tally trees by 2-inch size-classes may require multiple passes through a stand before the tally by size-class satisfies the cutting prescription. Such a challenge is often prohibitive in the field, thus limiting the applicability of BDq.

Frustration with the complexity of BDq and suspicion that such a procedure might constitute an unnecessary over-control of stand structure, led to efforts to expedite field application of selection silviculture. Recognition that basal area (B) is the most important of these variables, resulted in deletion of the requirements to identify a D_{max} and adhere to a specific q-value. Basal area is biologically linked to the cross-sectional area of sapwood, hence, leaf area index and total foliar display of the stand (O'Hara and Gersonde 2004, O'Hara and others 2001, O'Hara and Valappil 1999). Basal area may also be used for expressing stand condition relative to stocking, competition and prospects for regeneration success. Unless maximum timber production is desired, there is no need to set a tree-diameter size limit, since basal area occurring in a small number of trees in the larger size-classes can be compensated for through adjustments in the smaller size-classes. The q-value is informative concerning the relative balance among tree size-classes, but those near 1.4 or 1.5 may not be needed to support stand development, and values as low as 1.2 or 1.3 may be adequate. Thus, B was retained as the principal index for this method. Rather than tallying individual trees by numerous 2-inch size-classes, the many size-classes were combined into three size-class groups, each representing a stage in stand development and potential product [< 6, 6 to12, and > 12 inches at diameter breast height (d.b.h.)]. Tree marking was also changed to simply mark the fraction of trees that should be removed in each size-class-group. To attain the target stand structure, tree markers need to remember at most only three fractions that represent the rate of tree removal in each of the three size-class groups. This process systematically apportions residual basal area among size-class groups, thus the name arose as Proportional-B (for “proportional basal area”), or more simply Pro-B.

Extensive research performed with BDq has resulted in adaptations that improve its field application in a variety of forest types (Farrar 1996; Guldin 2011; Guldin and Baker 1998; Leak 1964; Leak and Filip 1975; Leak and others 1987; Nyland 1987, 1998, 2007). Pro-B is somewhat different, in that it was more recently developed to serve both timber production and biodiversity conservation purposes, while specifically retaining larger trees in the forest. The Pro-B stand structure is not rigidly defined by a q-value, recognizing that a diameter distribution may correspond to multiple q-values which can vary through time (Leak and Filip 1975). Tending an uneven-aged stand, so that its diameter distribution exactly matches a q-defined curve is an exercise of imposing arbitrary human values on the ecosystem (O’Hara 1998). Doing so ignores the wider range of structures that can be sustainable (O’Hara 1996, Seymour and Kenefic 1998). A substantial problem with q-based approaches is that reliance on them can create a false sense of stability, where imbalances in age structure may not become evident until well after they can be easily addressed (Seymour and Kenefic 1998). Alternatively, Pro-B stand structure is defined by the proportion of basal area distributed among size-class groups (typically 1:2:3, although other ratios may be valid). Also, the Excel-based Pro-B Calculator makes the complicated computation of marking guides much easier and provides an opportunity for the projected results to be assessed before field application. This study was undertaken to assess suitability of Pro-B for applying uneven-aged silviculture by: (1) ascertaining the consequences of applying single-tree selection and group selection in longleaf pine forests, including effects on stand structure, growth, and regeneration; (2) evaluating its effectiveness as a single-pass method; and (3) discerning the efficiency with which it can be learned and applied in the field by managers from a wide range of backgrounds.

MATERIALS AND METHODS

Study Sites and Management History

Goethe State Forest flatwoods are located 15 miles east of the Gulf of Mexico (29° 13' N, 82° 33' W), on the Lower Coastal Plain of the Florida peninsula. Temperatures in the humid subtropical climate range from a maximum of 91 °F in summer to a minimum of 41 °F in winter. Annual precipitation averages 57 inches, arriving mostly from April to September. At 50 feet above sea level, surface topography is nearly level and dominated by Smyrna fine sand, which is very deep, poorly-drained, low in organic matter and nutrients, and low in water holding capacity (Slabaugh and others 1996). The overstory was dominated by longleaf pine, with lesser amounts of slash pine and very few hardwoods. Tree seedlings were few and mostly comprised of slash pine and longleaf pine. Understory plants were dominated by shrubs, primarily saw-palmetto [*Serenoa repens* (W. Bartram) Small] and gallberry [*Ilex glabra* (L.) A. Gray]. Because of shrub dominance, the herbaceous layer was poorly developed, with wiregrass (*Aristida beyrichiana* Trin. & Rupr.) and broomsedge bluestem (*Andropogon virginicus* L.) the most prominent grasses and few herbs. The area was cutover about 100 years ago and then subjected to a 50-year period of fire exclusion, during which trees recovered and saw-palmetto expanded to now dominate the understory. Since 1992, active programs of prescribed burning and timber harvest have been implemented to foster multiple-use management and restore the ecosystem. Stands received improvement cuts between 1997 and 2004, and winter-season prescribed fire has been applied on a 3-year cycle. Mature pines were 48 through 74 years in age. Site index ranges from 70 through 80 feet at 50 years.

Blackwater River State Forest uplands are located 30 miles north of the Gulf of Mexico (30° 47' N, 86° 44' W), on the Middle Coastal Plain of the Florida panhandle. Average temperatures range from 80 °F in summer to 54 °F in winter. Annual precipitation averages 65 inches, with about half arriving from June to September. At 200 feet above sea level, topography is nearly level to gently inclined and occupied by Troup, Orangeburg, Lucy and Dothan sands, which are well-drained, low in organic matter and nutrients, and low to moderate in water holding capacity (Weeks and others 1980). The overstory was dominated by longleaf pine, with a smaller component of hardwoods and slash pine. Tree seedlings were abundant, with southern red oak (*Quercus falcata* Michx.), bluejack oak (*Q. incana* W. Bartram), post oak (*Q. stellata* Wangenh.), persimmon (*Diospyros virginiana* L.), and longleaf pine most common. Dangleberry [*Gaylussacia frondosa* (L.) Torr. & A. Gray], blueberries (*Vaccinium* spp.), and blackberries (*Rubus* spp.) were the most prominent shrubs. The herbaceous layer was well developed and species-rich, with wiregrass and broomsedge bluestem dominating the grasses and silverthread goldaster [*Pityopsis graminifolia* (Michx.) Nutt.] the most abundant herb. The area was occupied by second-growth longleaf pine that naturally regenerated after cutover of the original forest in the 1920s. This site has received numerous prescribed fires since 1970, on a 3-year cycle, initially during the dormant season and then changing to growing-season fire since 1995. Improvement cutting in 1981 and 1991 and hurricane-salvage in 2004 were followed by multiple waves of natural regeneration. Most of the mature pines were about 66 years, with the oldest being age 80. Site index is 80 feet at 50 years.

Experimental Design and Treatments

In summer 2004, a randomized complete block design was installed as three replications of the two silvicultural treatments, plus control, at each site. In spring 2005, treatments were assigned within the three replications that were grouped as blocks to topographically account for moisture gradient or spatial differences. The nine plots (stands) are each 22.2 acres (984- by 984-feet) and totaled 200 acres at each forest. Within each treatment plot, five 0.25-acre subplots were randomly located, each 66- by 164-feet with the long axis oriented in a north-south direction. The stand reproduction alternatives examined were the uneven-aged techniques of: (1) single-tree selection and (2) group selection, plus (3) no harvest to serve as the experimental control.

Single-tree selection has the advantage of maintaining a high level of canopy cover while periodically allowing removal of some trees from the forest. However, since longleaf pine is known to be intolerant of competition for light and soil resources, it is unclear whether it can regenerate and fully develop in the small space resulting from the death of a single overstory tree (Brockway and others 2005b). Most evidence indicates that several longleaf pine trees must fall from the canopy before sufficient space is available to allow longleaf pine juveniles to begin recruiting into the canopy (Brockway and others 2006). Hence, the importance of this comparative analysis experiment. Group selection simulates the natural gap-phase regeneration process of longleaf pine, by simultaneously tending the forest matrix and creating small canopy gaps (Brockway and Outcalt 1998). Although natural regeneration often occurs widely in the forest, young longleaf pine are usually more concentrated and better developed in canopy gaps ranging from 0.25- to 2-acres in size. Gaps may resemble very small clearings or contain scattered mature trees and typically regenerate as even-aged cohorts, in an uneven-aged matrix. Thus, the resulting forest eventually becomes an uneven-aged mosaic of even-aged patches. Patches with similar age cohorts need to be sufficiently dispersed to achieve the desired result (Brockway and others 2006). As long as herbaceous plants dominate the periodically-burned gaps, longleaf pine seed should germinate and seedlings will become established when good seed years are followed by favorable weather. Creating group openings at locations where regenerating seedlings already exist is an effective way to promote their release and eventual recruitment into the canopy. During treatment, the forest matrix was tended using Pro-B, and three 0.25- to 0.5-ha gaps were created in each 22-acre stand. Gap width ranged from 1.4 to 2 times the height of adjacent dominant trees.

Pro-B apportions the target residual basal area into a structure consistent with a ratio of 1:2:3 for small (< 6 inches), medium (6 to 12 inches), and large (> 12 inches) size-classes, respectively. This ratio was developed for forests having trees no > 24 inches, with most < 20 inches, at d.b.h. In BDq terms, this ratio would approximate a q-value of about 1.3. When Pro-B is applied in forests containing trees of larger diameter, a different ratio among and different boundaries for size-class groups may be more appropriate. These can be established only after a stable stand structure is defined. Alternative ratios and boundaries for size-class groups may also apply under circumstances where forest management seeks to maintain habitat conditions for at-risk species. For example, a residual basal area ratio of 1:3:6 for small (< 10 inches), medium (10 to 14 inches), and large (> 14 inches) size-classes is implied in the recovery plan for red-cockaded woodpeckers [*Picoides borealis* (Vieillot)] (U.S. Fish and Wildlife Service 2003). Developing new ratios and alternative size-class groupings suitable for differing forest conditions and management concerns will be areas of future study.

Measurements and Analysis

In winter 2005, tree data were collected on all subplots to establish pretreatment stand conditions. Species was recorded, and diameter of all trees >1 inch d.b.h. was measured to the nearest 0.05 inch. The total height of trees in a subsample representing the full range of size-classes was also measured to the nearest 4 inches to establish the height-diameter relationships for longleaf pine and slash pine. Repeated post-treatment measurements of trees were then completed following the 2006, 2007, and 2008 growing seasons. Following the 2005 and 2008 growing seasons, the number of slash pine seedlings and grass-stage (height < 6 inches) and bolt-stage (height 6 inches to 6 feet) longleaf pine seedlings were recorded on all subplots. Tree and seedling data were summarized as the mean for each plot and analyzed by treatment and change through time. Stand density and basal area were calculated from tree diameter data. Height-diameter relationships for pine were computed with regression analysis, using height and diameter data (Hintze 2007). Stand volumes (cubic feet per acre) were calculated for each species, by summing individual tree volumes to a 4-inch top outside bark on an area basis and using height and diameter data in regional equations (Saucier and others 1981). Means of dependent variables for each plot were used to estimate the means and variances for the treatment units. A repeated measures analysis of covariance (ANCOVA), using initial conditions as covariates, was used to evaluate time and treatment effects and interactions (Hintze 2007). Responses of treatments were compared using pairwise contrasts. The trend through time after treatment was analyzed using orthogonal polynomials. Significant differences were discerned at the 0.05 level.

RESULTS

Pro-B Application

Tree-marking guides were computed using the Pro-B Calculator, a Microsoft Excel-based tool with tabular fields for input of stand data and output of marking guides and graphic displays of pre-cutting and post-cutting structures. Pro-B apportioned the target of 50 square feet per acre into 8.3 square feet per acre for small (< 6 inches), 16.7 square feet per acre for medium (6 to 12 inches), and 25 square feet per acre for large (> 12 inches) size-class groups. During winter 2006, training workshops were held at the Goethe State Forest and Blackwater River State Forest, where less than 3 hours of instruction were presented about selection silviculture, the Pro-B method, and field considerations when applying the computed marking guides. In the field, newly-trained practitioners arrayed themselves 66 feet apart in a line along the edge of each stand and then made a single pass through, covering the width of their assigned lane, marking trees they identified for removal in accordance with the marking guides. These practitioners, ranging from administrators to field foresters, wildlife biologists, recreation specialists, and GIS specialists demonstrated remarkable skill in easily marking stands to a high level of precision (to within 3 to 5 percent error of the target residual basal area). Within the Pro-B numeric marking guides, they easily incorporated marking rules, such as: (1) take the worst and leave the best trees, (2) remove less desirable species, (3) adjust spacing to release residual trees, and (4) retain snags, live cavity trees, and large trees with broad crowns that can benefit wildlife. During November and December 2006, marked trees were removed by private logging contractors, and the resulting residual stands met prescription specifications.

Stand Structure

On the Goethe State Forest flatwoods, harvest reduced density from 126 to 74 trees per acre with single-tree selection and from 130 to 67 trees per acre with group selection. Declines in tree density were 41 percent following single-tree selection and 49 percent after group selection, with harvested stands significantly less dense than uncut controls. Harvest also reduced stand basal area from 70.9 to 50.9 square feet per acre with single-tree selection and from 72.6 to 44.8 square feet per acre with group selection. Declines in basal area were 28 percent following single-tree selection and 38 percent after group selection, again with lower residual basal areas than control stands. On the Blackwater River State Forest uplands, harvest reduced tree density from 137 to 107 trees per acre with single-tree selection and from 200 to 155 trees per acre with group selection. Declines in tree density were 22 percent following both single-tree and group selection, with harvested stands significantly less dense than controls. Harvest also reduced stand basal area from 60.9 to 47.8 square feet per acre with single-tree selection and from 73.5 to 48.7 square feet per acre with group selection. Declines in basal area were 22 percent after single-tree selection and 34 percent after group selection. An example of stand structural dynamics for group selection can be seen in figure 1.

Tree Volume and Growth

On Goethe State Forest flatwoods, total pine volume in treated stands prior to harvest averaged 1,959 cubic feet per acre, which was similar to the 1,933 cubic feet per acre in controls. Volumes were divided between longleaf pine and slash pine on an 80 to 20 percent basis in treated stands and a 59 to 41 percent basis in controls. Both selection methods reduced volume to levels significantly less than in controls (2,036 cubic feet per acre). Single-tree selection reduced volume by 26 percent to 1,438 cubic feet per acre, while group selection reduced volume by 36 percent to 1,257 cubic feet per acre. By the second post-treatment growing season, the annual volume growth rate was 2 to 4 percent. On Blackwater River State Forest uplands, total pine volume in treated stands prior to harvest averaged 1,409 cubic feet per acre, which was not significantly different from the 1,276 cubic feet per acre in controls. These volumes were mostly longleaf pine, with slash pine comprising only 4 percent

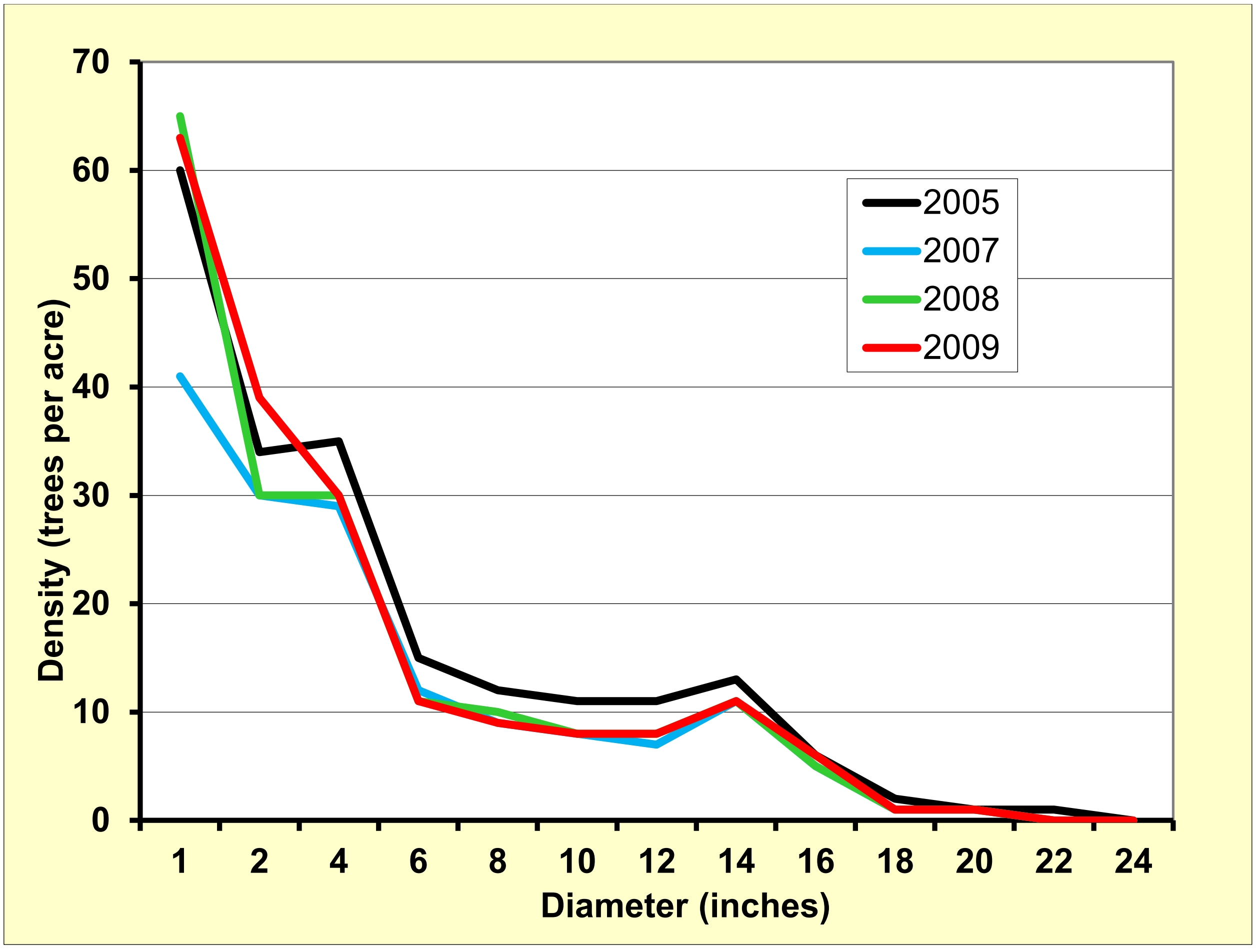

Figure 1--Changes in longleaf pine stand structure after application of group selection with the Pro-B method on uplands at the Blackwater River State Forest. Harvest in fall 2006 caused a decline in tree density by winter 2007, mostly in size-classes below 16 inches at d.b.h. Increased density was first noted for 1-inch trees in winter 2008, which translated into increased density for 2-inch trees by winter 2009. Tending across a broad range of diameters released a new wave of recruits for the canopy.

in single-tree selection stands and less than 1 percent in controls. Single-tree selection reduced volume by 28 percent to 1,035 cubic feet per acre, while group selection reduced volume by 25 percent to 1,040 cubic feet per acre, both significantly less than controls. By the second post-treatment growing season, the annual volume growth rate was 3 percent.

Pine Regeneration

On Goethe State Forest flatwoods, grass-stage longleaf pine prior to treatment averaged 20 seedlings per acre, with only those in the group selection stands significantly lower, at 9 seedlings per acre. Two years after treatment, grass-stage longleaf pine significantly increased (140 percent) to 48 seedlings per acre, overall. Without significant differences among stands, including controls, the increase in density could not be attributed to treatment, but was more likely the result of larger-scale factors, such as weather, seed dispersal, and fire cycles. Bolt-stage longleaf pines were present in as-yet very low densities (0 to 3 seedlings per acre). Conditions favoring a rising density in grass-stage longleaf pines have not yet facilitated bolting. Slash pine densities, initially 10 to 14 seedlings per acre, while rising in all stands, significantly increased only in group selection stands to 70 seedlings per acre. On Blackwater River State Forest uplands, grass-stage longleaf pine prior to treatment averaged 1,849 seedlings per acre. Two years after treatment, grass-stage longleaf pine significantly declined by 69 percent to an overall average of 597 seedlings per acre. With no significant differences among stands, the decrease in density could not be attributed to treatment. This decrease was perhaps related to mortality from drought stress, given the incidence of several dry years during that time period. Bolt-stage longleaf pines were initially present at 35 seedlings per acre, with significantly higher densities in group selection stands (73 seedlings per acre). Two years following treatment, bolt densities broadly improved so as to become comparable in all treatments (66 seedlings per acre overall). Increased bolt density likely resulted from the release of grass-stage seedlings already present. Slash pine densities initially ranged from 0 to 9 seedlings per acre and increased significantly only in single-tree selection stands to 52 seedlings per acre.

DISCUSSION

Goethe State Forest Flatwoods

Stand dynamics reflect ecosystem maintenance with prescribed fire and tree removal, causing reductions in density, basal area, and volume. Although treatment produced temporary disturbance, all stands soon stabilized and grew at normal rates. This finding fits the pattern of no growth loss for periodically-burned longleaf pine above sapling size (Boyer and Miller 1994). These stands were characteristic of seldom-burned forests, with low-density regeneration of less than 30 grass-stage and 5 bolt-stage seedlings per acre. Such low levels resulted from competition with saw-palmetto that creates a shrub-canopy with very few openings for seedling establishment. Burning and mechanical disturbance of tree harvest sufficiently diminished shrub cover, so that grass-stage seedling density more than doubled. This is encouraging, since regeneration is a key requirement for sustaining longleaf pine forests (Brockway and others 2006). A strong relationship exists between disturbances like fire and the composition of understory vegetation (Outcalt 2000), with frequently burned stands having fewer woody and more herbaceous plants (Glitzenstein and others 2003). Although fire can reduce shrubs like gallberry (Brockway and Lewis 1997), many burning cycles are needed to reduce shrubs like saw-palmetto, with its extensive rhizomes and capacity for rapid regrowth. Since longleaf pine ecosystems are prone to and highly resilient to disturbances like surface fire and partial canopy reduction (Outcalt 2008, Stanturf and others 2007), they are well suited for management using periodic prescribed burning and the regular cutting cycles of selection.

Blackwater River State Forest Uplands

Stand dynamics were dominated by tree removal during harvest, with reductions in density, basal area, and volume. Regardless of treatment, pine growth continued at normal rates. These stands were typical of forests that are regularly tended and burned with prescribed fire, having a well-developed longleaf pine overstory and a grass-dominated understory with abundant pine regeneration. With no significant difference among treatments, the decline of grass-stage longleaf pine could not be attributed to the reproduction methods. When considering the occurrence of several dry years during this time, the decline in grass-stage seedlings is most likely a result of drought-induced mortality. Although grass-stage longleaf pine seedlings may persist for many years beneath the canopy, the longer they remain unreleased, the greater the probability they will die by being weakened by competition, drought, and/or fire (Boyer 1990, Brockway and Outcalt 1998, Brockway and others 2006). Conversely, the rise in bolt-stage seedlings was encouraging but occurred across all stands and could not be attributed to the reproduction treatments. Conditions causing the grass-stage decline did not impair development of the bolt-stage seedlings. Under conditions of less stress, perhaps a greater number of grass-stage seedlings might have initiated height growth and moved into the bolt stage. Competition intensity can influence the number of seedlings emerging from the grass stage (Haywood 2000, Ramsey and others 2003). Continued management with prescribed fire and periodic selection cutting should maintain conditions favorable for regeneration (Glitzenstein and others 1995, Kush and others 2004, Outcalt and Brockway 2010) and ecosystem resiliency to a variety of disturbance agents (Stanturf and others 2007).

Comparing Selection Methods

Single-tree selection differs from group selection by foregoing deliberate creation of canopy gaps when tending the forest matrix. During each cutting cycle, the stand is reduced to a basal area low enough to initiate regeneration, by harvesting trees across a range of size-classes. Long-term application results in a forest with an irregular canopy, many very small gaps (< 0.25 acre) and a stable uneven-aged structure. While seedlings readily establish among overstory trees, they do not recruit to the canopy until released by disturbances that sufficiently reduce the inhibitory influence of nearby competitors.

Lightning and tree harvest are common disturbances that augment the size of such gaps, thus releasing suppressed seedlings (Moore 2001, Outcalt 2008). With repeated entries, removal of adjacent overstory trees can progressively enlarge very small gaps so they approach the dimensions of those created through group selection (Brockway and others 2006). In actual practice, these two selection methods may seamlessly blend together in the field through time. Ecological forestry provides a useful context for practicing selection silviculture (Franklin and others 2007). By using natural disturbance regimes as a template for management that creates and maintains complex structures, natural processes, biological legacies, and recovery intervals, selection can be used to address concerns about biodiversity, wildlife habitat, productivity, and ecosystem services (Palik and others 2002).

Group selection mimics natural gap-phase regeneration in longleaf pine ecosystems (Brockway and Outcalt 1998). This results in an uneven-aged mosaic of even-aged patches, where a continuous canopy is maintained, and seedlings regenerate in small gaps created by lightning and other local disturbances. Because competition from the overstory limits resource availability, seedling growth benefits most in 0.5-acre gaps at locations distal from overstory trees (Palik and others 2003). Pre-settlement longleaf pine forests were largely uneven-aged, where continuous tree recruitment occurred in areas of ≤ 3 acres (Pederson and others 2008). Group selection creates gaps ranging from 0.25 to 2 acres distributed throughout the forest to simulate the desired uneven-aged structure (Brockway and others 2006). Ideally, as the forest matrix is tended, gaps should be cut where advanced regeneration is already present, thereby decreasing the likelihood that they will become occupied by competing woody species. This method is compatible with prescribed fire on a 3-year cycle to control competing vegetation and maintain appropriate conditions for regeneration (Farrar 1996). Gap-based approaches, like group selection, can be used to sustain an uneven-aged forest structure that achieves a range of ecosystem stewardship objectives (Coates and Burton 1997).

The initial overall effect of applying single-tree and group selection with Pro-B was reduction in tree density, basal area and volume. On flatwoods, this was followed by an increase in grass-stage regeneration. Here, selection harvest had low impact on the shrub-dominated understory, with only small reductions (< 10 percent) in saw-palmetto cover that soon recovered. Logging did not diminish shrub cover sufficiently to stimulate expansion of herbaceous plants. Achieving regeneration success with selection is challenging on sites with severe competition, such as flatwoods dominated by saw-palmetto (Farrar 1996, Kush 2002). On uplands, tree density recovered in group selection stands within 2 years of treatment, and grass-stage seedlings declined while bolt-stage longleaf pine increased. Single-tree selection stands were less changed than group selection stands, since deliberately cutting gaps in the canopy alters the spatial pattern of overstory retention and creates a somewhat different understory environment.

Selection Silviculture with Pro-B

As Guldin (2006) noted, BDq can be more easily applied if the number of size-classes is reduced by basing them on five broad product-classes (i.e., small pulpwood, large pulpwood, small sawlogs, medium sawlogs, large sawlogs), and the tree tally is performed as a percent reduction within each product-class rather than as a numeric count of individual trees for each 2-inch size-class. Similar steps for improving BDq efficiency have also been suggested by Leak and others (1987) and Nyland (1987). For example, one long-used target structure for northern hardwoods, with a 20-year cutting cycle, consists of 10 square feet per acre for the 2- to 5-inch size-classes, 20 square feet per acre for 6- to 11-inch size-classes, 30 square feet per acre for 12- to 16-inch size-classes, and 10 square feet per acre for ≥ 17-inch size-classes, resulting in a basal area ratio of 1:2:3:1 among residuals (Nyland 2007). However, BDq, with its traditional focus on producing timber, tends to reduce important ecological structures, such as live trees for cavity-nesting species and snags, unless marking rules include retaining older trees and those with cavities (Kenefic and Nyland 2007). Since high vertical structural diversity and a range of cavity heights and sizes can be characteristic of uneven-aged forests, selection is best applied so as to conserve these ecological assets (Kenefic and Nyland 2000).

Pro-B represents a different approach, intended to simultaneously meet biodiversity goals and timber objectives. As a streamlined easy-to-apply method, Pro-B was developed for upland hardwoods in southern Missouri (Loewenstein 2005). However, recent application in riparian hardwoods, loblolly pine, and longleaf pine represented opportunities to try Pro-B in a wider variety of southern forests, and we encourage broader testing on this and other continents. Our application of Pro-B was a successful test for cutting longleaf pine stands to a target basal area, leaving a desirable diameter distribution. Pro-B was easily learned and adeptly applied by practitioners from a range of professional disciplines. The single-pass feature of Pro-B makes it a time-efficient method for practicing selection. With Pro-B, managers achieved the target basal area with a high level of precision. Basal area stabilized early after treatment and then steadily increased through time. Thus, Pro-B is an effective method for implementing selection silviculture. These tests highlighted the need to develop computational technology to quickly and accurately calculate marking guides for field use, following input of inventory data. Thus, the Pro-B Calculator was produced in an English series (with multiple versions from 40 to 100 square feet per acre in increments of 10 square feet per acre) and a metric series (with versions from 10 to 24 m^2 ha^{-1} in increments of 2 m^2 ha^{-1}). The Pro-B Calculator, Pro-B instructions, and selection silviculture literature will eventually be hosted on an internet website (http://www.Pro-B.auburn.edu) and made accessible on a 24/7 basis. Pro-B technology is in the public domain and offered to a wide audience, in hopes of encouraging broader use of selection silviculture and contributing to improved forest management.

CONCLUSIONS

Implementing selection silviculture through Pro-B can harvest high-quality timber, moderately reduce the overstory, and free growing space for the next wave of longleaf pine regeneration. As an easy-to-learn, accurate, efficient, effective, single-pass method, it can be used to improve stand structure by progressively adjusting the size-class distribution through time. With its focus on long-term sustainability through stability of structure, composition and function in residual stands, and flexibility to retain large trees and biological legacies by mimicking small-scale disturbances followed by adequate time intervals for recovery, the Pro-B method might be implemented to attain the timber production objectives and ecological stewardship goals of retention forestry (Gustafsson and others 2012).

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