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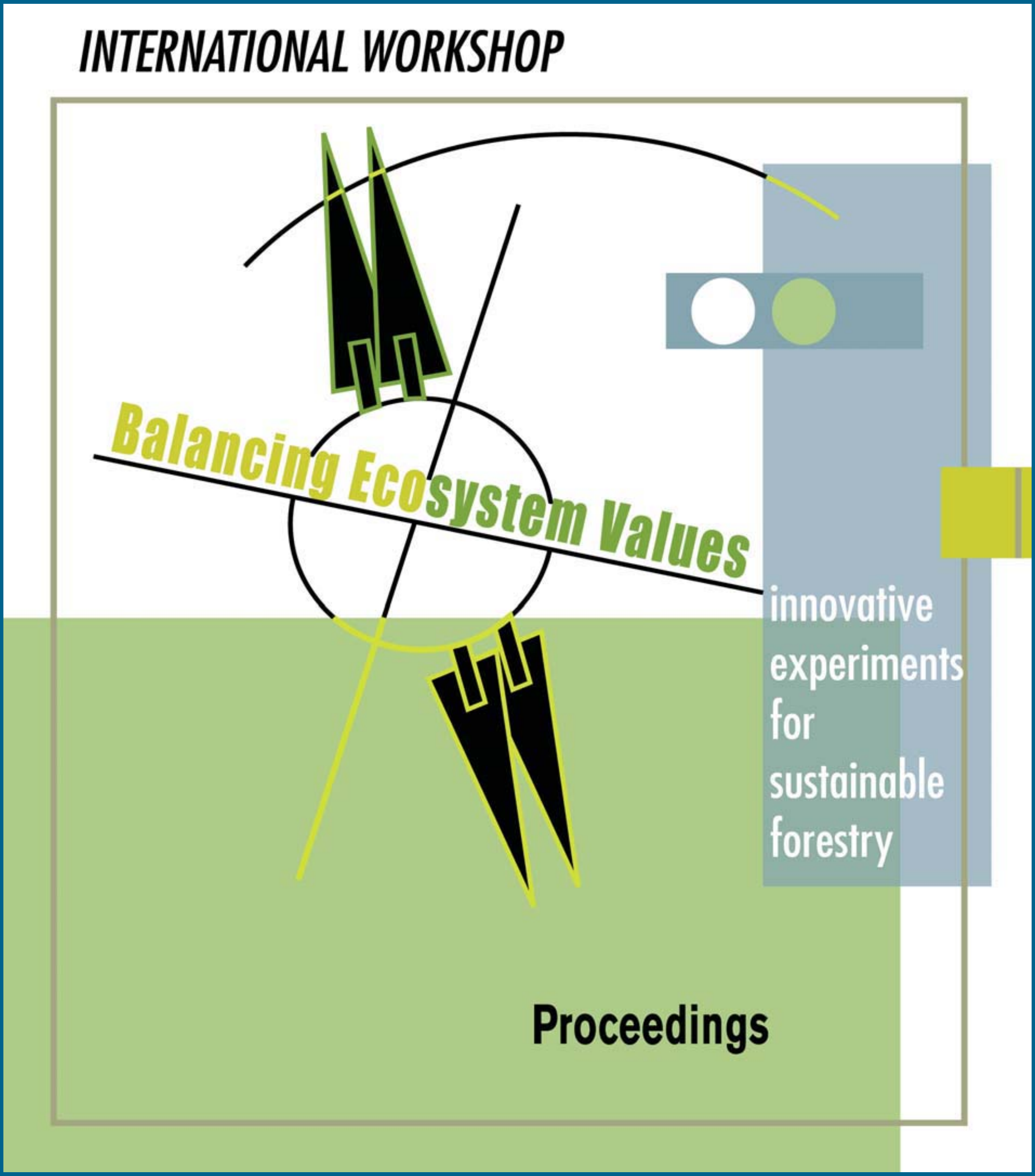
Balancing Ecosystem Values: Innovative Experiments for Sustainable Forestry

Charles E. Peterson and Douglas A. Maguire, Editors



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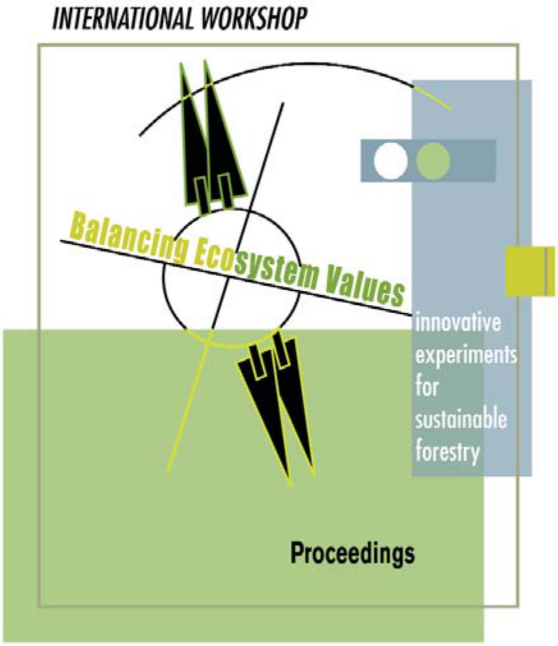

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Using Spatially Variable Overstory Retention to Restore Structural and Compositional Complexity in Pine Ecosystems

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ABSTRACT

Increasingly, forest managers incorporate overstory retention into silvicultural prescriptions for forests traditionally managed for single-cohort structure. The ecological benefits of retention may come at the cost of reduced growth of tree regeneration because of competition with residual trees. An important question in retention research, and its application, is how spatial pattern of retention (e.g., dispersed, aggregate) influences resource availability and heterogeneity, competitive environments, and regeneration dynamics. Recently, we initiated two operational-scale experiments in pine ecosystems (longleaf pine (*Pinus palustris* Miller) in southern Georgia, USA and red pine (*Pinus resinosa* Aiton) in northern Minnesota, USA) to address questions about the influence of retention pattern on resource availability and tree regeneration. These experiments address the hypothesis that resource availability at the stand scale will be highest with aggregate retention rather than dispersed retention because of nonlinear relationships between competitor abundance and target plant response. In both studies, our goal is to test approaches for restoring age diversity in single-cohort stands, while minimizing competitive inhibition of the new cohort. Our initial results show clearly that spatial pattern of retention has a significant effect on stand-scale resource availability and regeneration growth.

KEYWORDS: Structural complexity, biological legacies, overstory retention, longleaf pine, red pine, regeneration, plant competition, productivity.

INTRODUCTION

There is a fundamental truth that is apparent when contrasting forests that develop naturally (i.e., in response to natural disturbances and development processes) to those that develop in response to management: *nature generates complex forest stands, whereas management (for wood production) simplifies them*. The complexity inherent in natural stands is embodied in diverse (in a relative sense) age and size structures, diverse tree composition (again, in a relative sense), abundant large coarse woody debris, diverse understory, shrub, and ground layer plant communities, and spatially variable (horizontal and vertical) patterns in these attributes.

Complexity in natural stands is characteristic of all forests, including those that initiate following stand-replacement disturbances. Such forests rarely display the simplified structure that is characteristic of clearcuts, but rather include a rich legacy of biological (or biologically derived) structures that survive the disturbance and provide critical habitat, sustain important functions, and influence recovery processes in the post-disturbance ecosystem.

Incorporating biological legacies into regeneration harvest prescriptions has emerged as an important principle of ecological forestry and is being implemented in many regions (Franklin et al. 1997, Lindenmayer and Franklin 2002, Palik and Zasada 2002, Vanha-Majamaa and Jalonen

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2001). More specifically, retention of live, large overstory trees during regeneration harvest is one of the more obvious ways that foresters incorporate the legacy concept into management, particularly in forests that traditionally are managed for single-cohort structure.

Retention prescriptions for large trees (indeed, for all types of legacies) must address three questions: what species and sizes to retain, how many trees to retain, and what spatial pattern of retention to use—e.g., dispersed or spatially aggregated. It is the third question regarding spatial pattern of retention and influence on ecosystem responses that we are exploring. Spatial pattern of retention is receiving scrutiny (Franklin et al. 1997) because some ecological objectives may be sustained by dispersing retained trees whereas other objectives may be sustained by aggregating retained trees. Additionally, spatial pattern of retention may lead to profound differences in growth and productivity of trees (Palik et al. 1997, 2003). Our premise is that the ecological benefits of retention may come at the cost of reduced growth rates of tree regeneration because of competition with residual overstory trees. On the other hand, retention may provide a tool to better control the diversity of resource environments and the mixture of species regenerating in the stand.

Recently, we initiated two operational-scale experiments in pine ecosystems (longleaf pine (*Pinus palustris* Miller) and red pine (*Pinus resinosa* Aiton)) to address the influence of retention pattern on resource availability and tree regeneration. Similar experimental approaches were used in both study forests. In both studies, our goal was to test approaches for introducing structural complexity into simplified stands, while minimizing competitive inhibition of the new cohort of pines.

STUDY AREAS

The longleaf pine experiment was conducted in southern Georgia, USA, on the property of the Jones Ecological Research Center. The red pine study is being conducted in northern Minnesota, USA, on the Chippewa National Forest. Both study systems occur on deep, loamy sand soils. Historical age structures for the two systems are characterized by two to many cohorts of the dominant pine species. Longleaf pine forests are almost exclusively mono-dominant, whereas red pine forests historically contained admixtures of jack pine (*Pinus banksiana* Lamb.), eastern white pine (*Pinus strobus* L.), and several hardwood species.

EXPERIMENTS

The general experimental design is similar for both pine systems (fig. 1). Four retention treatments are assigned randomly within replicate blocks and include uncut control, dispersed retention, small-gap cutting, and large-gap cutting (the latter two treatments result in aggregate residual tree retention). The retention treatments are cut in similar residual basal areas (12 m^2/hectare (ha) for longleaf pine and 18 m^2/ha for red pine). Stand sizes are 2 to 3 ha for longleaf pine and 15 to 25 ha for red pine. The different residual basal areas in the two studies reflect natural differences in stocking for the two forest types; i.e., longleaf pine stands typically have low basal area, relative to red pine stands. Moreover, the differences in stand sizes correspond to the average patch sizes of management units on the two properties. Gap sizes are approximately 0.1 (small) and 0.3 (large) ha. Approximately 5 small and 2 large gaps were cut in each treatment stand for the longleaf pine study, while in the red pine experiment, gap numbers averaged around 28 (small) and 18 (large), respectively in each unit. Additionally, for the red pine experiment, the residual matrix between gaps was lightly thinned.

After harvest, nursery-grown seedlings were planted across the range of residual overstory basal areas in each treatment stand. For the longleaf pine experiment, only longleaf pine seedlings were planted, since these systems are typically mono-dominant. For the red pine experiment, equal mixtures of red pine, eastern white pine and jack pine were planted because all three pines can occur in these systems.

We are also examining the competitive interaction of understory vegetation and a new tree cohort. In both experiments, half of planted seedlings receive understory competition control (herbicides in longleaf pine; manual cutting in red pine), whereas the other half receive no understory control. We were unable to use herbicides to control the understory on the national forest study area. Here we report only on results from the understory control treatment.

Response variables measured include survival and growth (ground level diameter, biomass) of the planted pine seedlings and light (as a percentage of photosynthetically active radiation (PAR) in the open measured by using a LICOR LAI 2000 sensor), nitrogen (using resin exchange beads), and water availability (using time domain reflectometry (TDR)). Additional variables being measured in the red pine experiment include natural regeneration establishment and growth, biomass productivity of the residual

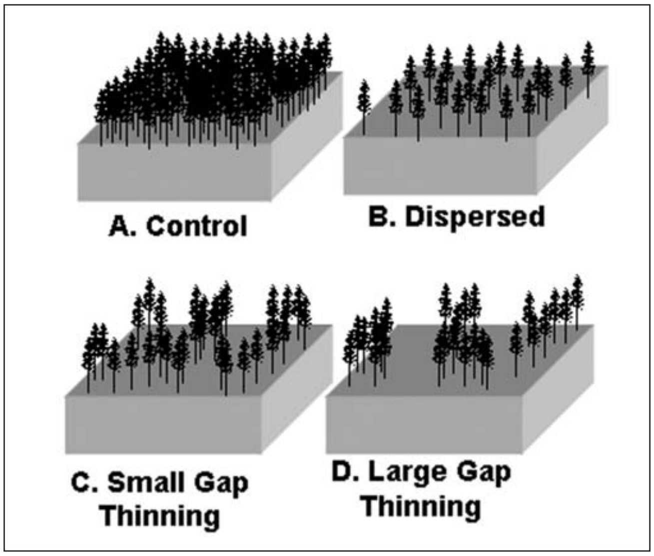

Figure 1—Conceptual representation of overstory retention treatments that differ in spatial pattern of residual trees. (A) undisturbed forest, (B) dispersed retention, (C) small gap thinning, (D) large gap thinning. Treatments B to D have the same residual overstory basal area. Note: in the red pine experiment only, some thinning also occurred in the residual matrix between the gaps.

cohort, shrub and herbaceous layer productivity, plant richness and community composition, tree pathogen responses, coarse woody debris dynamics, and songbird communities.

HYPOTHESES AND CONCEPTUAL BACKGROUND

Our experiments address the hypothesis that the availability of resources at the stand scale and heterogeneity will be higher with aggregate retention than dispersed retention because of a nonlinear (negative exponential) relationship between competitor abundance and target plant response (Palik et al. 1997). Research on plant competition has demonstrated the shape of this plant interaction relationship (fig. 2), in which target plant growth is low across a wide range of competitor abundance and only increases (exponentially) below threshold levels of low competitor abundance. It is hypothesized that the growth relationship reflects the pattern of availability of two or more limiting resources; e.g., it is only at low competitor abundance that light and nitrogen are both abundant (Palik et al. 2003).

We have used this neighborhood-scale relationship (i.e., the area immediately around the target plant) to generate stand-scale hypotheses about resource availability and growth of regeneration under different spatial patterns of retention (Palik et al. 1997, 2003). Specifically, given a fixed (and low) level of residual basal area in harvest stands, we predict that resource availability to a new cohort of trees will increase slowly from an uncut (control) stand, through dispersed retention, to small-gap aggregate retention, and will only increase exponentially where aggregate retention provides for many large openings in the stand (fig. 1). Similarly, we predict that new cohort (target plant) growth will follow a similar pattern, increasing exponentially only with aggregate retention that incorporates many large openings in the stand. The theoretical basis for these stand-level hypotheses is this: only when retention is aggregated, and large openings exist, will sufficient competitive neighborhoods be far enough away from overstory competitors to be free of extreme resource competition, i.e., they fall far to the left on the interaction curve (fig. 2).

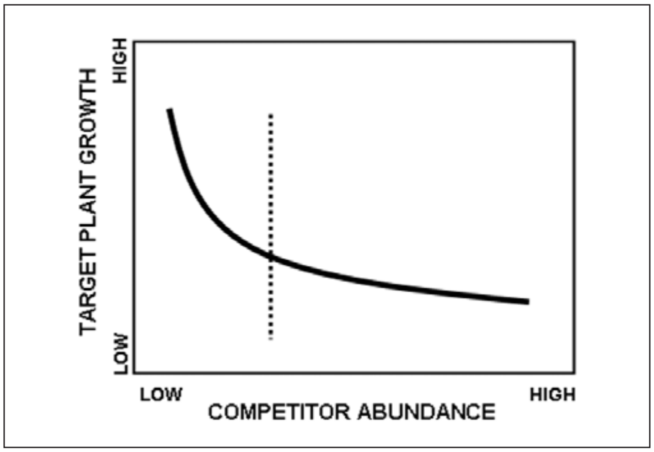

Figure 2—Conceptual relationship between competitor abundance and target plant growth.

RESULTS AND SUMMARY

Our research in the longleaf pine system is complete, and we have reported on this work elsewhere (Battaglia et al. 2002, 2003; Jones et al. 2003; Palik et al. 2003). In contrast, our experiment in red pine is ongoing; harvest treatments were installed in winter 2002-2003, and seedlings were planted in spring 2003. In the following sections, we summarize major findings of the completed longleaf pine experiment and highlight some of the features of the red pine experiment currently in progress.

Longleaf Pine Ecosystems

At the neighborhood-scale, resource availability and seedling growth of longleaf pine varied across the range of overstory abundance, expressed as overstory abundance index (a distance weighted measure of total basal area with 15 m of the seedling), according to the hypothesized negative exponential relationship (fig. 2). Nitrogen availability

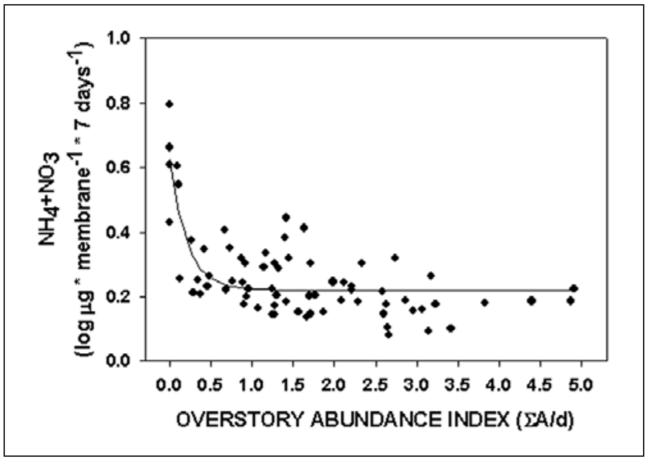

Figure 3—The response of nitrogen availability (expressed as NH_4+$N0_3$) to overstory abundance index (a distance weighted measure of total basal area with 15 m of the sample point) in a longleaf pine woodland (from Palik et al. 2003).

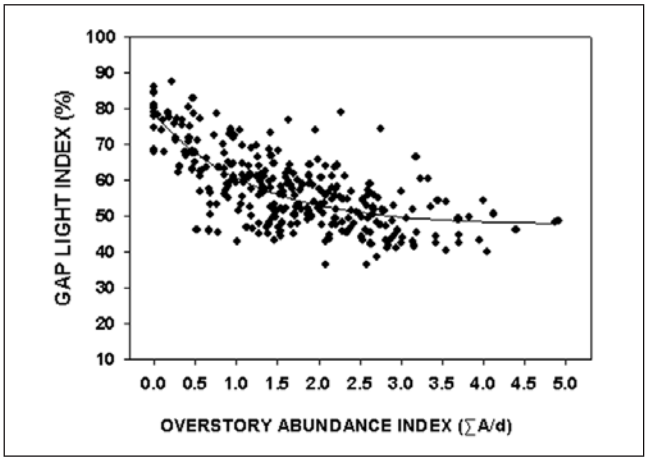

Figure 4—The response of gap light index (expressed as percentage of an open condition) to overstory abundance index (a distance weighted measure of total basal area with 15 m of the sample point) in a longleaf pine woodland (from Palik et al. 2003).

(fig. 3) increased only marginally across a wide range of overstory abundance, but increased more rapidly at low overstory abundance. Gap light index responded similarly, although the increase in light began at a higher overstory competitor abundance than with nitrogen (fig. 4). Above-ground seedling biomass growth responded similarly to nitrogen. Biomass increment was low and nearly constant across a wide range of overstory competitor abundance and increased exponentially at low overstory abundance (fig. 5). The response of below-ground biomass increment was similar to above-ground biomass increment (data not shown).

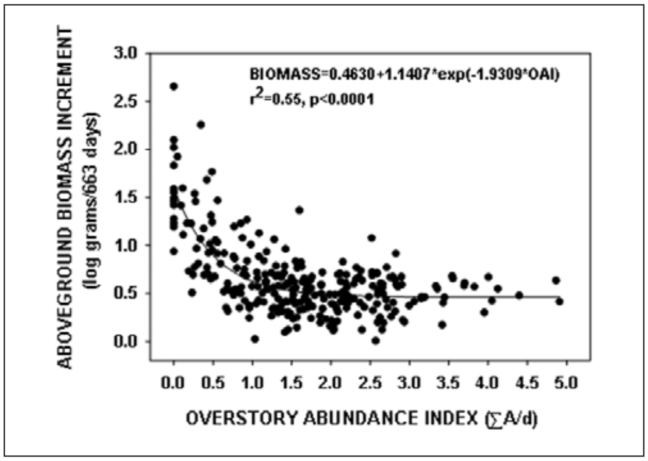

Figure 5—The response of above-ground longleaf pine seedling biomass increment to overstory abundance index (a distance weighted measure of total basal area with 15 m of the seedling) in a longleaf pine woodland (from Palik et al. 2003).

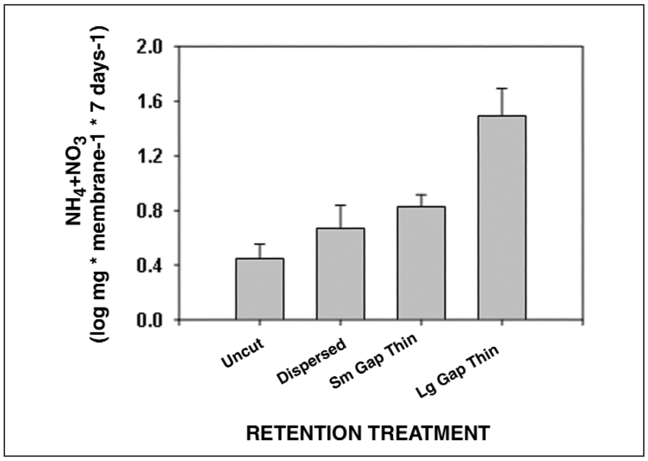

Figure 6—Soil nitrogen availability (expressed as NH_4+$N0_3$) in four retention treatments in a longleaf pine woodland. Values are means (±se) of three replicates (from Palik et al. 2003).

At the stand scale, resource availability and seedlings growth responses were as hypothesized. Nitrogen availability was lowest in the control stands, increased with dispersed retention and small-gap retention, and was greatest with large-gap retention (fig. 6). Similarly, gap light index increased across the same treatment array, although with more muted differences among treatments (fig. 7). Finally, the above-ground seedling biomass increment was similar among control, dispersed retention, and small gap thinning treatments, but increased substantially in the large gap thinning treatment (fig. 8). Our major findings, based on these results, are listed below:

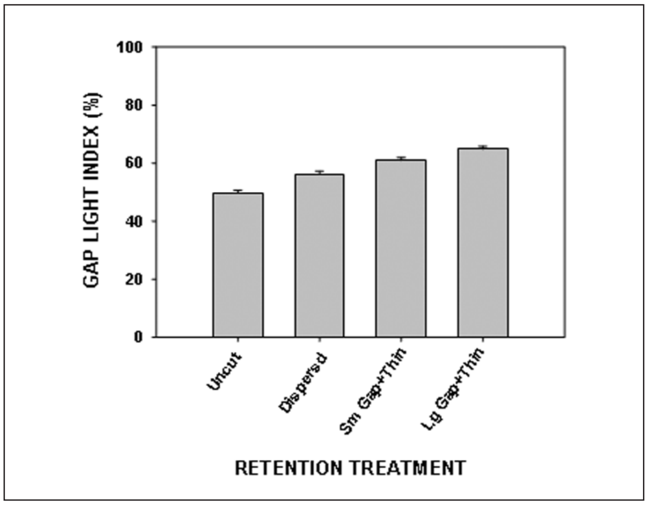

Figure 7—Gap light index (expressed as percentage of an open condition) in four retention treatments in a longleaf pine woodland. Values are means (±se) of three replicates (from Palik et al. 2003).

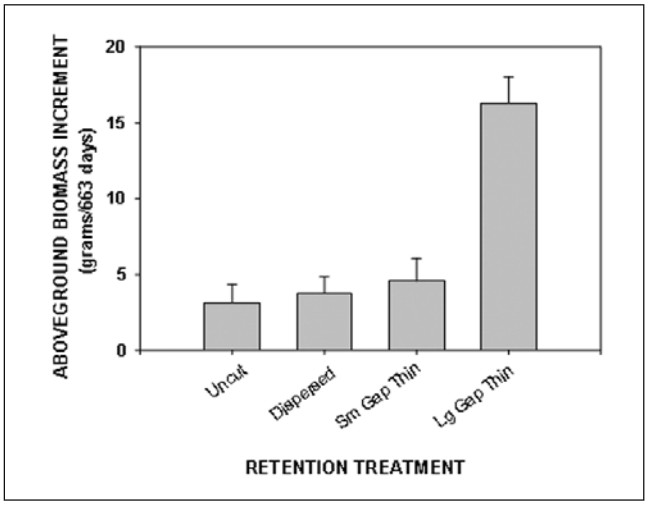

Figure 8—Above-ground longleaf pine seedling biomass increment in four retention treatments in a longleaf pine woodland. Values are means (±se) of three replicates (from Palik et al. 2003).

- All treatments retained significant structural complexity similar to mature overstory longleaf pine systems.

- Resource availability and competitive environments in the understory differed dramatically, depending on spatial arrangement of retained trees.

- Retaining trees in aggregates, through large-gap cutting, provided the most favorable resource environment for regenerating longleaf pine seedlings (in the absence of competing herbaceous and shrub competition).

- We expect similar (although muted responses) in resources and regeneration growth in the presence of competing herbaceous and shrub vegetation.

Red Pine Ecosystems

As with the longleaf pine experiment, we are examining resource availability in the red pine experiment and new cohort growth. Additional objectives, not included in the longleaf pine study, include an examination of

- Regeneration survival and growth of pine species differing in shade tolerance
- Development of natural regeneration
- Recruitment of large dead wood
- Productivity patterns and trade-offs between cohorts and among structural layers
- Responses of shrub and herbaceous plant communities to treatments
- Responses of red pine shoot pathogens to treatments
- Migratory songbird responses

We predict similar neighborhood and stand-scale responses in resource availability and seedling growth to retention treatments, and consequently, the same set of major summary points are likely to be true for the red pine system. Additionally, we have posed a set of stand-scale hypotheses for some of the other response variables listed below:

1) **Residual cohort production.** Among the three harvest treatments, productivity of the residual cohort will increase from large-gap retention to small-gap retention to dispersed retention because of decreasing inter-tree shading and greater ability to preempt soil resources.

2) **Shrub-herb preemption.** Among the three harvest treatments, resource capture and productivity of shrub and herb layers will be maximized with large-gap retention and minimized with dispersed retention because of decreased ability of the residual tree cohort to capture resources in the former treatment.

3) **Residual tree blowdown.** Among the three harvest treatments, blowdown of residual trees will be maximized with dispersed retention and minimized with gap-retention because of decreased mutual protection and support among neighboring trees with the former treatment.

4) **Ground layer plant communities.** Composition of ground layer plant communities will be less altered with aggregate (gap-based) retention relative to dispersed

retention because a greater percentage of the stand will be left in an unharvested (or minimally harvested) condition.

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