RESEARCH ARTICLE

Effect of Thinning and Clear-cuts on the Transmission of Fire in Slash Pine Plantations during Restoration to Longleaf Pine

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ABSTRACT

Restoration of the *Pinus palustris* (longleaf pine) bunch grass ecosystem that once dominated the southeastern coastal plain has become a goal for many managers on public lands. However, fire exclusion and conversion to *Pinus elliottii* (slash pine) plantations has provided the conditions for much of the forest to become susceptible to what Lindenmayer et al. (2011) call a "landscape trap," where ecological processes no longer function to maintain the ecosystem. For the longleaf pine-bunchgrass ecosystem, the trap occurs when fire-dependent herbaceous vegetation have been replaced with woody shrubs, and there are no fine fuels that will readily transmit frequent fire. Restoration of slash pine plantations to longleaf pine forest will require continued transmission of fire across the restoration areas. With the cooperation of the US Forest Service, we conducted an experiment to study the effectiveness of thinning and patch clear-cuts in slash pine plantations and compared the burnability of these treatments. Eighty percent of the thinned plots burned, but only 12% of the patch clear-cuts did. These differences resulted from reduced needle cast in the clear-cuts. Plots in which the ground cover was dominated by herbaceous vegetation were significantly more likely to burn (97%) than those dominated by woody vegetation (38%). Plots without fire for eight years prior to the experimental burn did not burn across the clearcut patches that had no recent needle cast from canopy trees. Maintenance of the canopy is important in fire transmittal because fire allows longleaf pine restoration without expensive site preparation and groundcover reintroduction.

Keywords: fire frequency, longleaf restoration, needle cast, *Pinus palustris*

Restoration Recap

- Practitioners attempting restoration in fire dependent ecosystems need to evaluate the contributions of the needle cast to fire transmission before using any canopy removal strategy.
- In the longleaf system both needle cast from the canopy, grasses, and other herbaceous vegetation supply the ground level fine fuels necessary for fire transmission across the landscape.
- In mesic flatwoods, woody groundcover vegetation does not promote transmission of frequent fire. Land managers who misapply restoration strategies may create systems that are susceptible to stand replacement fires or incur additional cost in site preparation and groundcover reintroduction.

The National Forest Management Act (1976) gave the US Forest Service the responsibility of maintaining biodiversity. To fulfill this responsibility, natural processes must be understood and incorporated into natural disturbance-based forest management because many species depend on forest conditions produced by various ecological processes for their survival. The longleaf pine-bunchgrass ecosystem of the Atlantic and Gulf Coastal Plains once covered an estimated 38 million ha (Frost 1993) of the Southeastern United States. This ecosystem is remarkable for the diversity of its plant species with counts of more than 40 species per m² in many *Pinus palustris* (longleaf pine) communities (Walker and Peet 1983, Peet and Allard 1993, Walker 1993). Over 900 species of plants and animals are endemic to the *P. palustris* ecosystem and

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numerous species have been recognized as endangered or threaten because of the loss of this forest type (Van Lear et al. 2005, USFWS 2009). Without fire, shrubs expand to cover up to 60% of the ground cover in 6–8 years (Miller et al 2003), reducing the local herbaceous diversity (Schmitz et al. 2002).

For over five decades, forest managers in the southeastern United States have replaced naturally regenerated *P. palustris* communities with slash pine and *Pinus taeda* (loblolly pine) plantations, initially because of low success rates when planting *P. palustris* seedlings. This practice has had advantages for commercial forestry and fiber production (Wear and Greis 2002). However, it also changed the disturbance regimes, reduced fire frequency, and created conditions for the ground cover of these forests to change from grasslands to shrublands.

In the longleaf pine-bunchgrass ecosystem, the long and highly flammable needles of *P. palustris* combine with the living and dead leaves of bunchgrasses and forbs to facilitate low-intensity burning (Abrahamson and Hartnett 1990, Landers 1991, Noss 1989, Platt et al. 1988, Varner et al. 2015). In even-aged plantations of *P. taeda* and *Pinus elliottii* (slash pine) across the South, this relationship has been severed, largely due to the impact that site preparation has on ground cover. "Site preparation" includes plowing, disking, or applying herbicide before planting seedlings to reduce competition between seedlings and ground cover species. Ground cover species are rarely completely lost during site preparation, but the relative abundance of some characteristic species, such as *Aristida stricta* (wiregrass) and *Gaylussacia dumosa* (dwarf huckleberry), are usually significantly reduced (Walker and Cohen 2009). The effect of site preparation varies depending partly on soil moisture with greater ground cover differences found between mesic plantations and undisturbed mesic flatwoods than between xeric plantations and undisturbed xeric sites (Smith et al. 2001). In wetter sites, a more intensive form of site preparation, "bedding", has a greater effect on the ground cover. Given the effect of intensive site preparation on ground cover (Walker and Cohen 2009), it may be more difficult to restore a functional bunch-grass ecosystem in the mesic flatwoods than in xeric sandhills.

The techniques used to establish slash pine plantations usually exclude fire as young slash pine seedlings are susceptible to fire mortality. In the groundcover, fire exclusion favors the expansion of more shade-tolerant species, such as *Serenoa repens* (saw palmetto), *Ilex glabra* (gallberry), *Myrica cerifera* (wax myrtle), and *Lyonia lucida* (fetterbush), which are all quite persistent once established. Brockway et al. (2005) suggested that in mesic plantations, burning every two years over a period of 10 to 20 years may be required to change the understory on wet sites and reduce the dominance of woody species.

Management strategies for the restoration of *P. palustris* usually involve clearcutting, mechanical or chemical site preparation, and planting *P. palustris* seedlings. An alternative strategy is to thin plantations, burn, and interplant, but does this strategy make a difference in whether the site can carry fire? Burning is a natural-disturbance-based method for forest management. Because the *P. palustris* system is a grassland ecosystem with trees, fire creates the conditions necessary for its development, and its restoration will require frequent fire. The effects of clearcutting on fire transmission are thus important. Partial retention of the *P. elliottii* stand during restoration could provide the needed canopy legacy that drives ecosystem processes (Kirkman et al. 2007). By providing needle cast on the forest floor, a retained canopy could contribute ecological attributes similar in function to a *P. palustris* canopy. It is expected that frequent fire will promote the recovery of the characteristic herbaceous ground cover, thereby reducing competition survival of *P. palustris* seedlings. *Pinus palustris* seedlings are more fire tolerant than any of the other southern pine species (Masters et al. 2005). Thus, restoration will require frequent fire as part of the management plans for groundcover recovery and exclusion of other pine species. This experiment tests the effectiveness of this natural disturbance-based concept for restoration of *P. palustris*, using the retention or removal of the current *P. elliottii* canopy to test the movement of ground fire through the stand.

Methods

All work was conducted in the Apalachicola National Forest (ANF), Florida, US. With 240,000 ha, the ANF contains 118,000 ha of managed pine and was established as part of the National Forest system in 1936. The ANF is southwest of Tallahassee, Florida, and includes a large part of four counties: Leon, Wakulla, Liberty, and Franklin. The ANF is south of the Cody Escarpment, an ancient Pleistocene shoreline with soils that are classified as poorly-drained spodosols: fine sands overlying limestone with little or no loam or clay subsoil (Peet 2006). The upland forest is dominated by mesic flatwoods that were often converted to slash pine plantations from 1960 to the early1990s. The forest is divided into 224 management compartments, or burn units, which are areas of 400 to 2000 ha of forest, each managed in a similar manner. To provide a continuous yield of timber stands, a single burn unit does not receive the same timber treatments by the Forest Service, but are exposed to the same burning treatments.

We designed a large-scale experiment that was implemented by the Forest Service. The experiment used 24 stands in eight burn units, all in mesic flatwoods. Within each burn unit, we randomly selected three slash pine plantations less than 50 years old and with suitable density for thinning (18–24 m^2/ha basal area) from the planted slash pine stands in that unit. In each of these three plantations, we randomly selected without replacement two of three timber treatments and implemented these treatments within half of the stand. In the eight burn units this process created 48 treatment units. The silvicultural treatments were: 1) reduction of the number of canopy trees by 33.3% (removing every third row); 2) reduction of the number of canopy trees by 50% (removing two rows then leaving two rows); and 3) reduction of the number of canopy trees by 33.3% and adding two different sizes of patch clear-cuts (0.1 hectare and 0.2 hectare). The 33% reduction cut (Treatment 1) acts as the control for this experiment because it is a typical silvicultural treatment for a first thinning in a stand of this age class. The 50% reduction treatment reduced the canopy more than a typical harvest and was expected to reveal how more extensive thinning would affect fire movement through an open *P. elliottii* plantation. This treatment allowed more light into the stand and is expected to facilitate the growth of interplanted *P. palustris* seedlings. The patch cuts provided 100% canopy removal and created a fuel gradient from the edge to the center for determining the importance of needle cast in fire transmission and estimating the fuel-establishment characteristics of needle cast into forest openings. The treatment units used in the experiment had a mean size of 13.7 ha and ranged from 6.8–24.6 hectares, which allowed ample space for implementation.

The treated compartments were burned according to normal forestry practices. No extra effort was made to achieve a complete burn in the experiment, allowing predictions about the impact of different canopy treatments on fire transmission to be made under standard management. We used burn rotations known to promote development of herbaceous ground cover. Four burn units were burned in the summer, 18 months after the previous burn, and two burn units were burned in the winter, two years after previous burn. The last two experimental units were intended to have the same two-year winter burn, but those two burn units were left unburned at the start of the experiment, and thus when they were burned there had been eight years without fire

Fire transmission was measured by establishing 3 randomly placed 0.04-ha plots along the removed rows in each treatment unit. Each plot contained 12 points established along the removed row with approximately 2-meter intervals between the points. In the randomly placed gap (square patch cut) treatments, similar 0.04-ha plots with again 12 points were established along a removed row located approximately at the central point in the gap. Stands were burned along with the rest of the burn unit with standard techniques, applying fire in strips and allowing it to move across the stand. Whether the measurement points did or did not burn provides an estimate of the fire's ability to move across the treatment landscape. Fires in the plots were often all or nothing, giving quite skewed distributions.

Estimates of groundcover composition were based on 50 sightings with an ocular tube from two 25-meter transects (James and Shugart 1970, James 1978). The two transects crossed at the plot center, one taken along the removed row of trees and the other across the rows, one reading every meter. All transects were made in early September after burning, which allowed estimates of vegetative responses to burning and harvest. The 10-cm ocular tube was constructed of a cardboard cylinder with a central fixed point on one end, held at arms-length for a sighting 2–4 feet from the observer (James and Shugart 1970, James 1978). The results were calculated as percentages of herbaceous or woody vegetation and bare ground. The plots were then classified as to their percentage of herbaceous cover by the results from the two transects at a standard elapsed time in post-fire groundcover development. Ground cover conditions were stratified into four groups based on the percentage of cover by herbaceous vegetation in the plots: 0–20%, 21–40%, 41–60%, and greater than 60%.

With the current design, there were effectively four canopy treatments, two thinning treatments, and two gap treatments. Estimates of the yearly accumulation of needle cast were made within randomly selected plots, representing randomly selected stands, in all four canopy treatments. All needles that fell onto the forest floor in 30 cm × 30 cm plots within one-year after the initial burn were collected, dried, and weighed. These needle-cast samples were gathered moving from the base of the nearest adjacent canopy tree towards the plot center. Samples were taken every 2 meters up to the midpoint to the next canopy tree on the opposite side of the clearing. This procedure allowed an estimation of the yearly accumulation of needle cast across the plot.

To test the ability of needle cast to carry fire, we spread one-year's accumulation of needles evenly across 1 × 2 m test plots on bare soil. Bare soil was used here as this would be the condition in which needle cast would function to allow the fire to bridge gaps. The plots were then lit with a strip fire across the middle of the plot. This test was repeated with two-year's accumulation of needles. Tests were replicated three times during periods of low humidity (40–50%) and high humidity (> 60%).

Results of the burns in the treatment units tended to be an all-or-nothing effect, which made it difficult to use ANOVA on the 4 factors involved in each test. Instead we used a non-parametric Kruskal-Wallis test for analysis which is effective when data do not meet the assumption of a normal distribution. ANOVA was used to compare the ground cover between the plots in the four timber treatments as those data are normally distributed. All statistical analyses were performed with Minitab 16 (Minitab Inc. State College Pennsylvania).

Results

Because plots were randomly placed in the stand, we estimated how fire moved at the plot level by what happened at the 12 established points and at the stand level by what happen in the plot. The extent of canopy reduction affected the ability of standard prescribed burns to move across the experimental stands (Figure 1). Only 26% of the plots in the large clear-cut gaps burn, significantly lower (Kruskal-Wallis test; $H = 46.45$, $df = 3$, $p < 0.000$) than the 80% burned in the 33% canopy reduction.

The percentage of the plot burned during the fire was affected by the groundcover conditions. While canopy treatments had no significant effect on the percentage of herbaceous ground cover (ANOVA; $F_{3,188} = 0.452$; $p = 0.716$), the herbaceous percentage of the ground cover affected the ability of fire to move across the plot. In the high-herbaceous plots, 97% of the plots burned, while in low-herbaceous areas only 38% burned (Kruskal-Wallis test; $H = 25.19$, $df = 3$, $p < 0.001$, Figure 2).

The effect of needle cast on the ability of the landscape to carry fire seemed to be a transitory effect of the canopy that only occurred in the presence of fresh needle cast. When plots with points established without prior burning were compared, they appeared to have the same response to fire as those established with prior burning even though they had an eight-year period to accumulate fuel. In these unburned plots, the movement of fire into large gaps was limited; less than 15% of the plots burned, while in plots with only 33% canopy reduction, 100% burned (Kruskal-Wallis test, effect of canopy; $H = 39.21$, $df = 3$, $p << 0.001$; Figure 3). Thus, in the *P. elliottii* shrubland, the lack of needle cast on the forest floor created large unburned patches in the forest landscape (Figure 4).

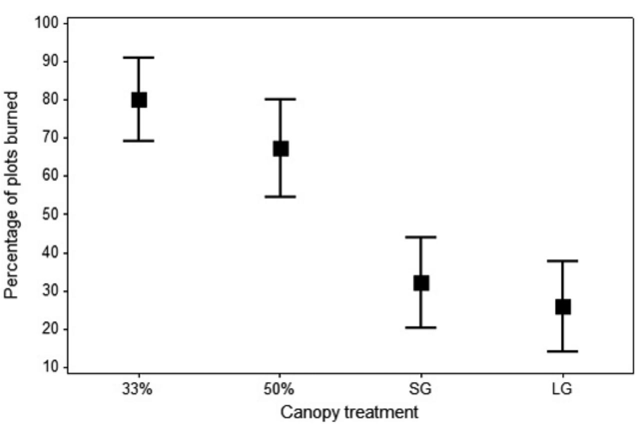

Figure 1. Percentage of plots burned, by canopy treatment, at the Apalachicola National Forest, Florida, US. The extent of canopy reduction affected the percentage of plots that burned. Those plots with low-needle-cast accumulations had the lowest percentage burned. Bars are 95% confidence intervals. The treatments are: 33% canopy reduction; 50% canopy reduction; small gap, SG = 0.1 ha; large gap, LG = 0.2 ha.

The relationship between herbaceous and woody vegetation in the ground cover was reciprocal: as the woody component increased, the herbaceous component decreased. However, the amount of bare ground in the plots increased with the percentage of woody vegetation, and this relationship continued until bare ground was replaced by the woody vegetation (Figure 5). The presence of bare ground indicates gaps in fuel that inhibit movement of fire across the stand.

The results of the needle-cast collections were consistent in both thinning treatments as trees from both side contributed to the accumulation; needle-cast

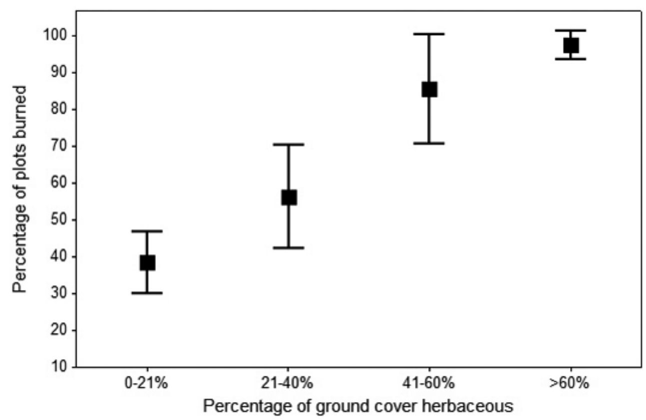

Figure 2. Percentage of plots burned, by ground cover condition, at the Apalachicola National Forest, Florida, US. The ability of fire to move across the landscape is related to the percentage of herbaceous vegetation in the ground cover. As the percentage of herbaceous vegetation increases, so does the percentage of plots burned. Bars are 95% confidence intervals.

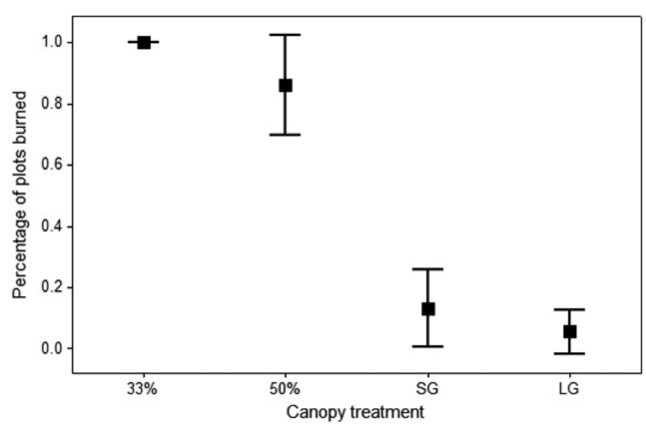

Figure 3. Percentage of plots burned after eight years with no fire by canopy treatment at the Apalachicola National Forest, Florida, US. Even without fire for eight years, the ground cover seems to depend on the needle cast to carry fire. Gaps in the canopy without fresh needle cast appeared immune to fire. Bars are 95% confidence intervals. The treatments are: 33% canopy reduction; 50% canopy reduction; small gap, SG = 0.1 ha; large gap, LG = 0.2 ha.

Figure 4. Limited fire movement into a canopy gap at the Apalachicola National Forest, Florida, US. In the absence of needles produced by the canopy, movement of fire across the landscape is restricted. In ANF burn unit 207 shown above, fire did not move across the canopy gap even with eight years of fuel accumulation. It did burn in the thinned areas surrounding the patch.

accumulations averaged approximately 100 grams/m^2 per year (Figure 6). In the clear-cut gaps, the needle accumulations quickly dropped off to become almost negligible in the center. Burn tests conducted on 100 and 200 grams/m^2 needle-cast accumulations found that at low humidity (40–50%), 100 grams of needles will support transmittal of a head fire across the landscape at a rate of 2.41 min/m (±0.81), but not a backing fire (fire moving against the direction of the wind). Under high humidity conditions, 100 grams of needles do not support fire movement, but 200 grams of needles allow fire to move effectively across the plot in both high- and low-humidity conditions. In the 200–gram test, the transmittal rate of the head fire was 1.24 min/m (±0.37) in low humidity as opposed to the 7.1 min/m (±1.77) for a backing fire in high humidity (> 60%). The importance of this test was that even at high humidity the fire continued to move across the plot in the 200 gram test.

Discussion

As shown by these experiments in *P. elliottii* plantations, tree harvest patterns affect the ability of the forest to carry fire, partly because the fine fuels supplied by needle cast are lost in some harvest patterns. The loss of herbaceous vegetation and the expansion of woody ground cover reduces fine fuels and creates bare spots that inhibit fire movement. Needle cast can partly compensate for this loss. Frost (1998) and Glitzenstein et al. (2012) recommend a three-year or less fire-return interval to maintain the *P. palustris* system, but as seen here that cannot be accomplished without needle cast in areas with reduced herbaceous vegetation.

Foresters now know how to plant *P. palustris* seedlings successfully, but as demonstrated, high levels of canopy removal in slash pine plantations can make them difficult to burn for years. Clearcutting a plantation with shrubby ground cover can put a stand into a "landscape trap" in which it has been "shifted into a state in which major functional and ecological attributes are compromised"

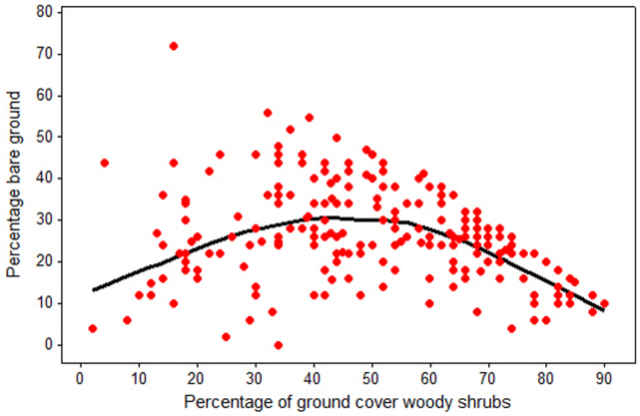

Figure 5. Relationship between woody ground cover and bare ground within the plots. Until it is displaced by woody ground cover, the percentage of bare ground goes up with the percentage of woody vegetation (LOWESS line 0.5).

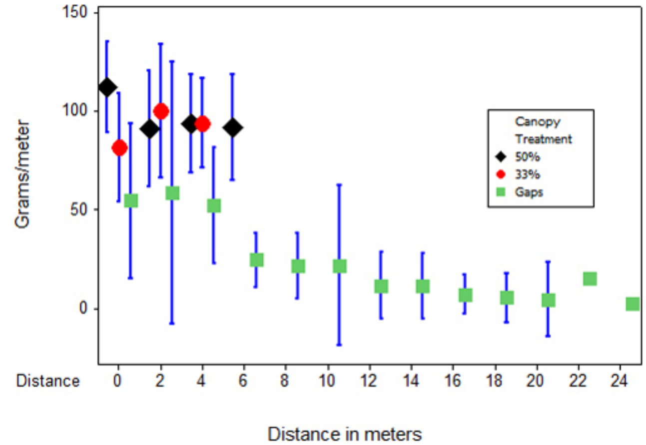

Figure 6. Annual needle-cast accumulation under canopy treatments taken one year after initial fire. Needle-cast weights were sampled every two meters across the plot. Measurements started at the base of the adjacent canopy tree and moved out into the plot until the midpoint to the next canopy tree. Bars are 95% CI for the mean. The treatments are: 33% canopy reduction; 50% canopy reduction; and gaps.

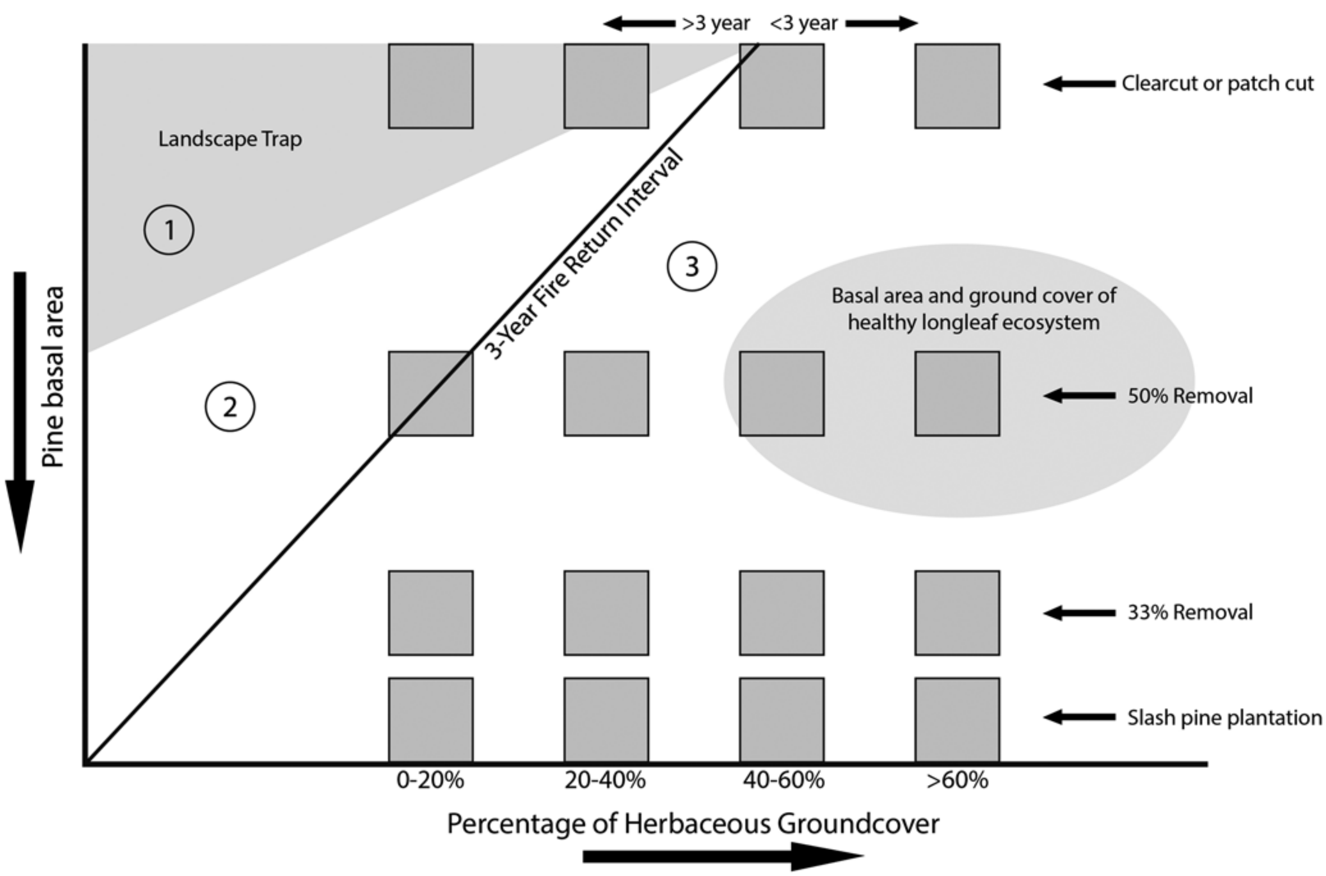

Figure 7. Theoretical model for the interaction between ground cover and pine basal area on fire-return intervals in *Pinus elliottii* plantations of the Apalachicola National Forest, Florida, US. As the percentage of herbaceous ground cover declines, the pine basal area needs to increase. When fuel conditions in the ground cover reduce the ability of the landscape to support fire, the frequency will drop, and the site can enter the landscape trap. Squares are the different treatments/groundcover in the experiment.

(Lindenmayer et al. 2011). As indicated by these experiments, woody species such as *S.repens*, *I.glabra* (gallberry), *M. cerifera*, and *L. lucida* reduce the ability of the ground cover to burn, gradually shifting the ground cover further and further from grassland, and thus reducing the frequency of low-intensity fire. When it does burn, the fire is of high intensity and can easily become a stand replacing event. In the longleaf pine-bunchgrass ecosystem examined here, the trap is a shrubland that can only be avoided through frequent fires that keeps hardwoods and woody shrubs in check.

Canopy removal is not a wise management strategy in stands dominated by woody ground cover. Restoring longleaf using current techniques of intensive site preparation that are used in sandhills (Seamon 1998, Prentiss 2013) as a second treatment may extirpate important herbaceous ground cover species such as wiregrass. Restoration of this mesic flatwoods ground cover would be difficult and costly, suggesting that it is important to minimize the loss of the remaining native grassland vegetation (Walker and Cohen 2009).

Figure 7 summarizes the expected outcome in a *P. elliottii* plantation given canopy removal at different starting points. As in the diagram, the three-year or less fire-return interval requires enough needle cast and herbaceous ground cover to carry the fire (area 3 in Figure 7). Unless the ground cover is at least 40% herbaceous vegetation, fire frequency will fall as the canopy is removed because the continuous fuel bed will be lost (area 2). Under these conditions, standard fire-return intervals and burning conditions will not recover the grassland because it requires more aggressive fire practices. If those practices are not applied, the area will move into the landscape trap (area 1 in Figure 7) where intensive mechanical and chemical treatments will be needed to restore natural processes. For most plantations there is a trade-off between the density of pines and herbaceous ground cover that will determine whether fires will move easily across the forest floor at a less than three-year fire-return interval. For those areas with high-herbaceous ground cover, needle cast is not needed for fire movement, but as the herbaceous ground cover declines, pine density must increase to provide the fine fuels for fire.

High frequency fires that favor the entire *P. palustris* system are needed to restore the longleaf forest in the Apalachicola National Forest and other public lands in the coastal plain. Many restorations begin with a direct, intensive action to reestablish historic abiotic or biotic factors, but activities such as removal of the *P. elliottii* canopy, can be counterproductive since this canopy allows the return of fire across the landscape. Fire is probably the single most important process maintaining the *P. palustris* system by allowing longer-term forest processes to unfold.

While clearcuts are an option that successfully produces a stand of *P. palustris* in the shortest time, there are negative aspects to this management decision. In high-herbaceous areas, where the system can maintain itself through fire, clearcutting would be a quick way to convert the forest. However, for public lands that are responsible for recovery of endangered species, the negative impact of this choice on species such as the red-cockaded woodpecker can put limits on the clearcut options (USFWS 2003). In areas with limited herbaceous cover, common in mesic plantations that received site preparation, clearcutting will promote woody ground cover that does not burn well, leading to a breakdown of the grassland ecosystem.

In sandhill habitats, restoration of the grassland may be possible; however, comparable techniques have not been developed for restoring ground cover in flatwoods. In addition, the current sandhill methods would require cost prohibitive, intensive, large-scale projects on public lands. Thus, land managers should explore the potential of using the *P. elliottii* canopy as a surrogate for *P. palustris* in reforestation programs. While thinning and underplanting can fail when the fire is too hot for the seedlings, nevertheless, by keeping the fire moving across the landscape at the correct frequency, even low survival in the underplanting option may still be adequate to create a seed source for future recruitment. By retaining a variable portion of the existing canopy, even if the canopy comprises less-preferred *P. elliottii*, the essential needle cast fuel for fire is provided, supporting the restoration process.

Land managers frequently observe the current status of the landscape to set their baseline for management of a system. Current forest conditions, however, do not coincide with the processes that shaped the *P. palustris* ecosystem, and this shifted baseline has led to management strategies that may not be appropriate. Continuing in this direction has some similarities to forest management at the turn of the last century when fire was removed to achieve forest recovery. Currently, land managers are considering extensive mechanical treatment to recover longleaf systems, and while these techniques may work (Seamon 1998, Prentiss 2013), the cost, complexity, and scale required for these programs means a very slow process. In the Apalachicola National Forest, it is possible to implement these intensive activities on 303 ha a year (Gary Hegg, US Forest Service, personal communication), but with 35,000 ha to be restored, this is not a practical method for recovery. Using standard practices of prescribed fire to control competition and achieve recovery on large landscapes, although requiring more intermediate stages, would be a more effective process of restoration than any of the current intensive practices.

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