# CONSERVATION OF THE LONGLEAF PINE ECOSYSTEM: ECOLOGY AND SOCIAL CONTEXT

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**ABSTRACT**

Jennifer Kwasny Costanza: Conservation of the longleaf pine ecosystem: ecology and social context
(Under the direction of Aaron Moody)

Worldwide, ecosystems are increasingly influenced by human actions and land use. As a result, landscapes include a mosaic of human land uses along with fragments of relatively natural habitat. Effective conservation requires a consideration of both local sites and the broader social and ecological landscape in which they occur. Partnerships among multiple landowners have become a popular way to implement conservation across broad extents because they can be effective at integrating ecological goals with their social context. My research examines how collaborative partnerships conduct conservation in the longleaf pine ecosystem of the US southeast. Longleaf pine communities provide important habitat for many plants and animals, and when frequently burned, can have among the highest levels of plant diversity of any ecosystem in the world. However, the ecosystem has become severely degraded, and several collaborative partnerships have been established with the goal of restoring the ecosystem.

My research investigates the relationship between local sites and their ecological and social contexts, and the collaborative partnerships that implement longleaf pine ecosystem conservation. First, I examine the relationship between metrics of landscape heterogeneity and local plant species diversity. I then synthesize the strategies used by three collaborative partnerships in the conservation of longleaf pine ecosystems. Finally, I investigate how decisions are made about prescribed burning, a major management tool for restoring the longleaf pine ecosystem.

My results illustrate that heterogeneity in environmental variables measured across a range of scales is related to local plant diversity, suggesting that incorporating broad-scale context into conservation efforts in the longleaf pine ecosystem is important. In addition, a focus on long-term ecosystem sustainability drives the strategies used by successful collaborative partnerships in the longleaf pine ecosystem. However, decisions made by prescribed burn practitioners are risk-averse, and tend to burn sites in good condition, located away from developed areas. Thus, prescribed burning is less likely to accomplish restoration of degraded sites. Finding ways to alleviate the risks associated with burning degraded sites will be crucial for ecosystem restoration. Taken together, my results provide guidelines that will be useful for informing collaborative partnerships and restoring the critically endangered longleaf pine ecosystem.

To my parents, who taught me the value of education and hard work.
and
To Adam, who reminds me to have fun.

In loving memory of my grandma,
Priscilla Slamkowski.
*I'll always cherish the special bond we shared.*

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# CHAPTER 1

# INTRODUCTION

## Background and aim of dissertation

Worldwide, ecosystems are increasingly influenced by human actions and land use. As a result, landscapes include a mosaic of human land uses, with fragments of relatively natural habitat. Because ecological processes occurring locally are influenced by processes that operate across larger extents, effective conservation requires a consideration of both local sites and the broader social and ecological landscape in which they occur. For example, the configuration of habitats, along with the intensity of human land uses in a landscape, helps determine which plant or animal species are able to disperse to any given habitat patch (Turner et al. 2001).

As the importance of ecological processes across large scales has become apparent, ecosystem management has become a dominant paradigm for achieving broad-scale conservation over the last twenty years (Meffe et al. 2002, Yaffee 1999). Rather than focusing on traditional single species or resource-based approaches, ecosystem management takes a holistic viewpoint, recognizing the complexity of ecological processes situated within their social and ecological contexts at broad extents (Christensen et al. 1996).

One way to conduct ecosystem management is via collaborative partnerships among public agencies, private organizations, and other stakeholders aimed at conservation (Wondolleck and Yaffee 2000). Numerous collaborative conservation partnerships have been established across the United States (Keough and Blahna 2006, Doyle and Drew 2008). For instance, conservationists and ranchers in the western US have been able to preserve habitat while improving commodity production by working collaboratively toward a common vision of protecting open spaces (Keough and Blahna 2006). In several partnerships in the eastern US, the Department of Defense has played a crucial role in restoring the longleaf pine ecosystem, while the land managed by the agency has also been used to support military training and human recreation (Rosenzweig 2003). These partnerships are becoming increasingly important ways in which to address conservation goals across broad extents as the human population grows and habitat becomes more fragmented. Collaborative partnerships have been successful at accomplishing ecosystem-based conservation because they can be effective at integrating ecological goals with their social context (Keough and Blahna 2006). Thus, while collaborative partnerships often aim to conserve and restore individual sites, they also implement strategies that affect the broader ecological and social context of these sites. Their management decisions are, in turn, affected by site-level characteristics and social and ecological characteristics of the surrounding landscape (Stankey et al. 2005).

This dissertation aims to examine the links among ecological processes at local sites, their broader context, and the collaborative partnerships that conduct ecosystem conservation (Figure 1.1). My research addresses the following general questions:

1. How and at what scales can the influence of the surrounding ecological and social landscape on local sites be detected? (Chapter 2)

2. What strategies do successful collaborative conservation partnerships employ to affect conservation objectives addressing site-level conditions as well as the social and ecological context of sites? (Chapter 3)
3. How do site-level conditions and the context of sites influence the ecosystem management decisions of collaborative partnerships? (Chapters 4 and 5)

I address my research questions in the context of conservation of the longleaf pine ecosystem in the Southeast US. The longleaf pine ecosystem is an important conservation target. This ecosystem provides essential habitat for a diversity of plant species and several endangered animal species (Van Lear et al. 2005). When frequently burned, longleaf pine ecosystems have among the highest number of plant species at small scales of any ecosystem in the world (Peet and Allard 1993). Due to widespread timber harvesting and fire suppression, the ecosystem has been severely degraded and fragmented, reducing this forest type to a mere 2% of its pre-European settlement range (Frost 2006). As a result, many species that depend on longleaf pine habitat have declined (Van Lear et al. 2005). This decline has prompted Noss et al. (1995) to designate the ecosystem as "critically endangered", and others to call for large-scale restoration involving prescribed burning (Landers et al. 1995, America's Longleaf 2009). Several collaborative conservation partnerships have been established with the aim of large-scale restoration of the longleaf pine ecosystem.

Because the longleaf pine ecosystem now occurs as fragments within landscapes that contain multiple human land uses, it is an ideal system for studying the process of ecosystem management. In particular, my research addresses three fundamental issues in ecosystem management, specifically considering conservation as a collaborative process. These issues are each relevant to a different stage in collaboration, from setting objectives, to determining strategies that will accomplish those objectives, to implementing those strategies. First, in order to achieve conservation goals locally, partnerships must know how and at which scales they should focus their efforts in the broader landscape. Affecting the wrong processes or focusing at inappropriate scales can lead to wasted time or resources for partnerships (Meffe et al. 2002). My research examines the precise scales at which the surrounding landscape influences ecological processes at local sites, and more clearly establishes the link between local sites and their social and ecological contexts. The result gives conservation partnerships better information about where and how to focus their broad-scale efforts.

Second, after establishing conservation objectives, it is important to know which strategies may be most effective for accomplishing those objectives, and which will ensure long-term sustainability of ecosystems. My research investigates the strategies used by successful partnerships and offers a set of guidelines that will inform partnerships about which strategies to implement. Finally, even when the strategies for implementing ecosystem management have been established, implementing them can be challenging. Managing complex ecosystems inherently involves risk and uncertainty, and failing to acknowledge risk may make it difficult to accomplish management objectives. This, in turn, can lead to further ecosystem degradation (Stankey et al. 2003). My research examines how the characteristics of sites and their location within a landscape influence management decisions in collaborative partnerships and sheds light on which factors contribute to risk. Thus, my research results in solutions for implementing ecosystem management strategies.

**Chapter summaries**

Each of my dissertation chapters addresses one or more links among local ecological processes, their social and ecological context, and the efforts of collaborative conservation partnerships in the longleaf pine ecosystem (Figure 1.1). In chapter 2, I consider the link between local plant communities and broad-scale ecological and social factors in the Southeast Coastal Plain ecoregion. When trying to detect the effects of large-scale processes on local communities, it is often difficult to know which variables to use and at which scales to measure them. Using data from a variety of vegetation types in the region, I explore the relationship between local plant species richness and multiple scales of heterogeneity measured with multiple variables. Because the Southeast Coastal Plain contains a high level of plant diversity and endemism (Sorrie and Weakley 2001), local plant species richness is an important ecosystem conservation target there. I show that the best predictor of local plant species richness depends on spatial extent. In particular, at the largest spatial extent measured, heterogeneity of land cover predicts plant species richness better than plant productivity and elevation, and longleaf pine communities occur in regions with the most heterogeneity in land cover. The regional scale in this analysis covered extents of 38,000 ha to 705,000 ha, approximately the scale of a watershed or landscape. The correlation between regional heterogeneity and local richness indicates that conservation efforts must consider the larger landscape when aiming to conserve local sites. The results of this study could help collaborative partnerships who work at similar scales better determine how to focus their efforts, and underscore the importance of broad-scale ecological and social context to local ecological processes.

Once partnerships determine which conservation objectives are important, they must determine which strategies to use to accomplish their objectives. In chapter 3, I examine the strategies used by collaborative partnerships in the longleaf pine ecosystem. I present the results from interviews of participants in three collaborative partnerships in the ecosystem. I show how the fire management strategies used by these three partnerships relate to longleaf pine conservation objectives on individual sites and across regions. Each of these strategies helps to facilitate adaptive management on existing conservation lands and affects the larger landscape context. In particular, they all help alleviate the biggest challenge for conservation and restoration in the longleaf pine ecosystem: how to conduct prescribed burning at ecologically significant scales.

In chapters 4 and 5, I investigate how site-level characteristics and the ecological and social context of sites affect decisions about ecosystem management of longleaf pine. In particular, I determine how stakeholders in a collaborative conservation partnership make decisions about prescribed burning. In these two chapters, I focus on the Onslow Bight, a region on the coastal plain of North Carolina where a partnership has been established for longleaf pine conservation. The region contains a mix of land uses, including rural residential, protected areas, and commodity producing lands.

In chapter 4, I use surveys of stakeholders in the Onslow Bight to determine which criteria they use to prioritize sites for prescribed burning across the region. I show that prescribed burn practitioners are risk-averse, and tend to focus on sites in good condition, located away from developed areas. In chapter 5, I use statistical models to relate the priority criteria to actual management activities in the Onslow

Bight. I use records of recent prescribed burns from Onslow Bight management agencies to show how a suite of ecological and non-ecological factors are related to prescribed burning activity. I extend the findings of chapter 4 to show explore the interaction between the time since a site was last burned and its distance from development: for sites that had not burned in four or more years, burning increased with distance from developed areas. The results from these two chapters indicate that both site-level factors and the configuration of social and ecological factors in the landscape influence management decisions.

In chapter 6, I synthesize the results from each chapter and discuss how my research contributes to the field of conservation biology. I then suggest future directions for study of the ecological and social contexts of conservation, based on my work. Finally, I discuss the implications of my work to conservation partnerships in the longleaf pine ecosystem, and other ecosystems. Taken together, my research provides specific guidelines that will be useful for protecting and restoring critically endangered longleaf pine habitat.

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**Figure**

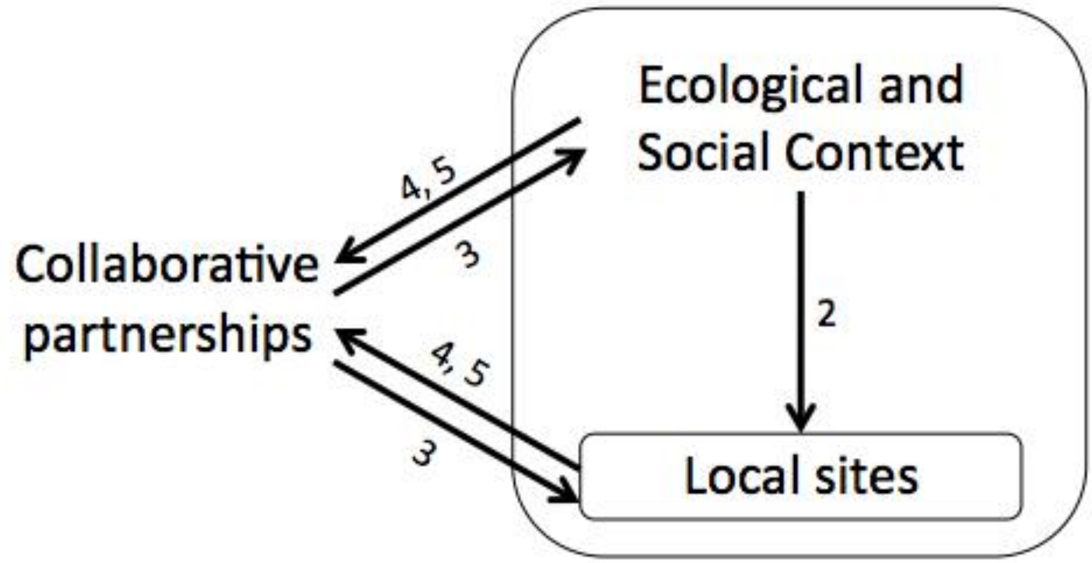


Figure 1.1: Overall framework for ecosystem conservation, which guides the research in this dissertation. Local sites exist within and are influenced by social and ecological context. Collaborative partnerships work directly to maintain and restore local sites, as well as to influence the broader context of sites. The ability of collaborative partnerships to accomplish conservation goals are, in turn, affected by both the condition of local sites and their context. Numbers indicate chapters that explicitly address the linkages among collaborative partnerships, local sites, and their context.

# CHAPTER 2

# MULTI-SCALE HABITAT HETEROGENEITY AS A PREDICTOR OF PLANT SPECIES RICHNESS ON THE SOUTHEAST COASTAL PLAIN, USA


## Abstract

Regional assessments of biodiversity increasingly rely on modeled relationships between multi-scale environmental variables and local species data. Because ecological theory predicts a positive influence of local-, landscape-, and regional-scale spatial environmental heterogeneity on local species richness, metrics that quantify heterogeneity could be important for assessing biodiversity. However, more information is needed regarding how heterogeneity is best measured. I took a modeling approach to determine whether metrics of heterogeneity measured locally and at larger scales are useful predictors of local species richness. Local plant species richness data came from 150 vegetation plots in the Southeast Coastal Plain, USA. At each of four scales, I used either GIS or field data to derive three classes of heterogeneity variables: abiotic factors, plant productivity measures, and locations of vegetation communities. I related those variables to plot-level plant species richness using univariate mixed effects models to determine the best heterogeneity metric at each scale. I then used Markov chain Monte Carlo sampling to fit models that incorporated measures of heterogeneity at multiple scales. When comparing univariate models using all predictors at all scales, I found that mean pH within plots was the best predictor of plant species richness. However, at scales larger than within plots, heterogeneity metrics were better predictors than means, and each of the three classes of variables I used had a distinct scale at which it performed better than the others. Furthermore, two measures of heterogeneity were significantly different on average for longleaf pine communities, which are important conservation targets in the region, than for other communities. These results suggest that when processes occurring at scales larger than vegetation plots need to be incorporated in regional assessments of biodiversity, heterogeneity metrics are potentially important predictors of local plant species richness.

**Keywords**

Carolina Vegetation Survey, elevation, land cover, productivity, landscape scale, regional scale

**Introduction**

Ecological theory predicts that spatially varying environments allow more species to coexist locally than homogenous environments. Environmental heterogeneity can influence local diversity through mechanisms acting at different scales (Ricklefs 1987, Snyder and Chesson 2004, Shmida and Wilson 1985). For example, local variation in resource availability leads to the avoidance of competitive exclusion, allowing more species to coexist (Snyder and Chesson 2004, Chesson 2000). Within a landscape, spatial variation in the composition or configuration of vegetation can lead to spatially structured metapopulations, which can influence local population persistence via mechanisms such as source-sink dynamics and the rescue effect

(Pulliam 1988, Brown and Kodric-Brown 1977). Greater regional heterogeneity increases the size of the regional species pool, or the species that are available to colonize a given local area. Despite the fact that theory predicts a positive influence of environmental heterogeneity at each of these scales on local species richness, few studies have fully investigated this relationship across multiple scales. My study integrates data collected within vegetation plots using GIS and remotely sensed variables in order to examine the relative contribution of heterogeneity at local, landscape, and regional scales to local plant species richness in the Southeast US.

Relating heterogeneity measures to species richness has particular relevance to conservation. Models that relate species richness to continuous variables are important tools for assessing biodiversity across large extents. Continuous variables can provide more information about the processes responsible for biodiversity than other approaches such as indirect mapping of biodiversity via habitat classification, which ignores variability within habitats (Nagendra 2001). In addition, models using continuous variables allow direct application of the continuum concept of ecology, in which species and their assemblages sort along gradients (Austin 1999). Therefore, it is worth examining how various types of heterogeneity relate to local species richness, and in particular whether heterogeneity measures can be useful in distinguishing species-rich communities within a region.

Thus far, little work has been done to determine which heterogeneity variables, measured using which metrics at which scales are relevant for modeling species richness. Measures of local heterogeneity often come from field data within or near the sites where species richness is sampled and is measured terms of variation in resource availability or vegetation structure (Gould and Walker 1997, Davies et al. 2005). Across landscapes, heterogeneity is often measured in terms of variation in land cover or vegetation productivity. Palmer et al. (2002) proposed that variation in the spectral properties of remotely sensed images should be related to species richness. A suite of image texture metrics (St-Louis et al. 2006) can be used to characterize variability in vegetation productivity across a landscape. Regional heterogeneity is most often characterized in terms of topographic, climate or land cover variation and is often summarized within the boundaries of ecoregions (Kerr et al. 2001). For each of these scales and variables, heterogeneity has been measured using a variety of metrics, including standard deviation, variance, and coefficient of variation.

In this study, I used data from vegetation communities sampled on the Coastal Plain of North and South Carolina (NC and SC), USA, to examine the relationship between local plant species richness (within 20 x 20 vegetation plots) and measures of heterogeneity. I characterized heterogeneity in terms of the variability of vegetation structure, the variability of abiotic environmental variables, and community diversity at each of four scales. For each vegetation plot, I measured heterogeneity in terms of these variables within the plot, within habitat patches, across habitats, and across regions. For each environmental variable, I computed the same suite of indices at each scale to allow comparison among variables and among scales. Specifically, I asked:

1. Are measures of heterogeneity measured locally, as well as at larger scales, useful for predicting local plant species richness?
2. Which heterogeneity variable at each of these scales is the best predictor of plant species richness?

I hypothesize that heterogeneity measures at all scales are useful predictors of local species richness, and all heterogeneity measures will be positively correlated with local plant species richness. Because at any given scale, the ecological processes influencing local species richness differ, I predict that the heterogeneity metric most local related to species richness will differ for each scale examined here.

## Methods

### *Study Area*

The Southeast Coastal Plain provides a good context in which to study the relationship between habitat heterogeneity and plant species richness. The region is home to a rich diversity of plant species, including a large number of endemics (Sorrie and Weakley 2001). A variety of plant communities exist there as well, including longleaf pine savannas and flatwoods, pocosins, bottomland hardwood forests, and tidal marshes. Vegetation on the coastal plain is highly influenced by soil characteristics and elevation. Species-rich longleaf pine ecosystems occur on more sandy soils, while pocosin vegetation occurs where soil organic matter content is high. Subtle changes in these soil characteristics as well as elevation and geographic distance can lead to large variation in local plant species richness in the region (Christensen 2000, Peet 2006).

Longleaf pine ecosystems are important conservation targets in the region (America's Longleaf 2009). These communities provide habitat for many plant and animal species, including the federally-endangered Red-cockaded Woodpecker (*Picoides borealis*) and can contain among the highest levels of understory plant species richness of any ecosystem in the world (Peet and Allard 1993). However, regional vegetation maps based on classification of values in satellite imagery suffer from low accuracy for longleaf pine communities (McKerrow 2006). Therefore, incorporating measures of heterogeneity into models of plant species richness may be particularly helpful for distinguishing and characterizing these diverse ecosystems.

*Data*

Species richness data

Species richness data came from 150 vegetation plots in NC and SC, in the Middle Atlantic Coastal Plain ecoregion (Environmental Protection Agency 2004, Figure 2.1). Plot data are part of the Carolina Vegetation Survey (CVS) database, and were collected between 1998 and 2007. CVS follows a consistent data collection protocol and is a long-term effort to inventory and characterize the plant composition in the natural communities of the Southeast (Peet et al. 1998). Plots in the database are located throughout NC and SC, but are not uniformly distributed across the region (Figure 2.1). Plots in the CVS database vary in size, but all plots used here contain four intensively sampled 10 m x 10 m quadrats, in which the identity of each vascular plant species has been recorded and environmental data have been collected. I summed the total number of plant species across the four quadrats as my measure of plant species richness.

Heterogeneity data

Heterogeneity was measured in terms of three types of variables: abiotic, productivity, and vegetation community type. Each of these variables was measured at four scales for each plot location: within-plot, within-habitat, neighborhood, and regional (Table 2.1). The only exception was that vegetation community heterogeneity was not measured within vegetation plots, because vegetation plots were explicitly located in areas assumed to be representative of a single community type.

For within-plot heterogeneity measures, I used habitat data collected in CVS vegetation plots. Within each of the four intensively sampled quadrats, a soil sample was collected. Soil chemistry analyses were performed on the samples by Brookside Laboratories, Incorporated, New Knoxville, Ohio. For my within-plot abiotic variables, I used measurements of soil pH and percent organic matter content taken from each quadrat. In addition to soil metrics, the basal area of all stems greater than 2.5 cm dbh was measured within each plot. I used the total basal area per quadrat, in units of $m^2$. To calculate heterogeneity for the soil variables and basal area, I computed the variance, standard deviation, range, and coefficient of variation (CV) of values among quadrats in each plot.

To derive heterogeneity metrics at neighborhood, within-habitat, and regional scales, I used data from GIS coverages of environmental variables. First, I delineated the extents across which heterogeneity metrics would be calculated. To delineate neighborhoods, I employed circular buffers surrounding each plot location, with radii of 150 m, 450 m, and 1380 m, corresponding to areas of 7 ha, 64 ha, and 600 ha, respectively. I chose these sizes because they approximate the neighborhoods recommended by Riitters et al (2000) as appropriate scales for summarizing landscape patterns. To delineate the within-habitat scale, I extracted all contiguous pixels mapped as vegetation in the 2001 National Land Cover Database (NLCD, Homer et al. 2007) and calculated heterogeneity within those vegetated areas only, using the same three radii surrounding each plot location. To delineate regions, I used unique polygons within the

EPA's Middle Atlantic Coastal Plain ecoregion. These polygons correspond to a finer level of division than Level IV ecoregions. There were 17 of these regional polygons containing vegetation plots in my study area. These regions ranged from 380 $km^2$ to 7050 $km^2$ (38,000 ha to 705,000 ha) in size, and had a mean area of 1821 $km^2$ (182,100 ha).

I used three types of variables to measure heterogeneity from GIS and remotely sensed data at within-habitat, neighborhood, and regional scales: elevation, productivity, and land cover. I used a 1999 digital elevation model (DEM) from the National Elevation Database to derive elevation data at all three scales (U.S. Geological Survey 1999). I used the Normalized Difference Vegetation Index (NDVI) as a measure of productivity. NDVI is an often-used index that has been shown to correlate well with aboveground net primary productivity (Pettorelli et al. 2005). For within-habitat and neighborhood scales, I used NDVI data from 14 Landsat images from the growing seasons of 2000-2002 that had previously been mosaicked as part of the 2001 NLCD land cover classification (Homer et al. 2004). Across ecoregions, I used NDVI from the MODIS satellite platform (MOD13Q1, collection 5.0, NASA 2008). For each pixel in the MODIS data, I calculated the mean NDVI value from all images from 2001-2007. Therefore, my measure of productivity at the regional scale represents an aggregate that likely corresponds to longer-term persistent patterns of productivity. I used this single mean image to extract heterogeneity metrics. Within the three sizes of habitat patches and circular neighborhoods, as well as region polygons, I calculated the mean, range, variance, standard deviation, and coefficient of variation (CV) of all elevation and productivity pixels. For land cover heterogeneity metrics, I used the 2001 Gap Analysis

Program's (GAP) land cover map (Southeast Gap Analysis Project 2008). I calculated the variety of land cover classes, as well as Simpson's Index (Simpson 1949) of land cover diversity. Simpson's Index was used because it has been shown to be less sensitive to rare cover types, and thus to classification errors in land cover data, than other diversity indices (Nagendra 2002). Therefore, while land cover variety represents the richness of land cover types, Simpson's Index emphasizes the evenness component of land cover diversity. The DEM, Landsat NDVI and GAP data have 30 m resolution. MODIS NDVI data have a resolution of 250 m.

*Analysis*

To examine the effects of single measures of heterogeneity on plant species richness, I used linear mixed effects models. I fit random intercepts models using maximum likelihood estimation with region as a random effect. At each within-plot, within-habitat, neighborhood, and regional scale, I fit a separate model for each heterogeneity metric, as well as the mean. I also fit multiple regression models using each heterogeneity metric together with the mean, both with and without interaction terms. Within-plot, within-habitat, and neighborhood metrics were treated as level-1 predictor variables here, while regional metrics were level-2 predictors. By grouping the data into regions, these mixed effects models incorporate similarities among vegetation communities sampled here in a more ecologically meaningful way than would incorporating a measure of simple geographic distance.

I fit linear mixed effects models using normal distributions with both untransformed and log-transformed species richness as the response, as well as generalized linear mixed models using Poisson distributions. I compared the results of these three using AIC to determine which type was most appropriate for my species richness data. To compare these models, I scaled the AIC from the log-normal models to the raw response for comparison. I fit all linear mixed effects models using the lme function in the nlme package (Pinheiro et al. 2009) in R (R Development Core Team 2009). I also fit generalized additive models (GAMs) to the species richness data using a smoother for each predictor and examined the general shape of the relationship using the mgcv package (Wood 2006) in R. Thus, I determined whether to model the relationship as linear or to use a higher-order polynomial relationship in the linear mixed effects models.

I used the approach of Burnham and Anderson (2002) to determine which heterogeneity metrics predicted plant species richness for each variable at each scale. For models using regional variables, I computed AICc based on a sample size equal to the number of regions (groups). I used an extra sum-of-squares F-test to compare models containing each of the heterogeneity metrics for each variable type at each scale to the unconditional means model, which contains no predictors but still accounts for structure in the data because data are grouped by ecoregion. I also used the Burnham and Anderson approach to compare all heterogeneity metrics within a given scale to determine which heterogeneity variable best predicted species richness for each scale. To quantify the proportion of variation in the species richness data explained in each of the univariate models, I calculated level-1 and level-2 pseudo-$R^2$ statistics from the variance components of the mixed effects models (Singer and Willett 2003).

Next, I examined the relative effects of level-1 and level-2 heterogeneity measures together on plant species richness. Because the appropriate choice for degrees of freedom in mixed effects models is unknown, particularly when combining parameters from different levels in the model, I took a Bayesian approach for this part of my analysis. I used the arm (Gelman et al. 2010) package of R, which interfaces with WinBUGS (Lunn et al. 2000). I used Markov chain Monte Carlo (MCMC) sampling to fit mixed effects models with random intercepts containing local and regional variables. My models had locally uniform priors for fixed effects and non-informative priors for random effects, and I sampled for 10,000 iterations. This approach allowed me to sample from the posterior distributions of ratios of level-1 to level-2 coefficients occurring at different levels of a multilevel model. I used the best heterogeneity metric for each variable, whether level-1 or level-2, and combined it with a corresponding metric calculated at the other level. Thus, the two predictors had the same units in each model, and the ratio of level-1 to level-2 coefficients corresponded to the relative influence of the two predictors.

Finally, in order to examine whether the best heterogeneity predictors could be useful in distinguishing longleaf pine communities from other areas, I separated vegetation plots into two categories: those sampled in longleaf vegetation (N = 31 plots), and all others (N = 119). I performed a t-test to determine whether the means were significantly different between the two sets of plots for the best heterogeneity variables at each scale.

## Results

GAMs fitted to smoothed predictors suggested linear relationships between species richness and all of the metrics except mean within-plot pH. A quadratic relationship was suggested for mean pH, so I used a quadratic term in all models containing mean pH. I assumed a linear relationship between plant species richness and each of the other variables. In addition, my comparison of AIC among normal, log-normal, and Poisson distributions indicated that the linear mixed effects model with normal distribution and log-transformed species richness was most appropriate, so I present results from those models here.

While the means of all variables measured within plots predicted richness better than measures of heterogeneity, at larger scales, a heterogeneity metric was always a better predictor of species richness than the mean in cases when the unconditional means model was not selected (Table 2.2). For 450 m and 1380 m within-habitat grains, heterogeneity metrics were the best predictors and better than the unconditional means model for both elevation and NDVI. Simpson's index was the best land cover predictor at all within-habitat grain sizes. None of the models incorporating NDVI or land cover across neighborhoods were better than the unconditional means model, but for elevation at all neighborhood grain sizes, heterogeneity metrics were the best predictors of plant species richness. At the regional scale, the CV of elevation and land cover variety were the best predictors and were better than the unconditional means model, but none of the models incorporating NDVI metrics across regions were better than the unconditional means model. Multiple regression models combining the mean and one heterogeneity metric were not better than univariate models in any case.

I compared the best predictors within each scale (Table 2.3). Of all variables at the within-plot scale, mean pH was the best predictor of species richness. Within habitats, NDVI at 450 m was the best predictor and had a negative relationship with species richness. Across neighborhoods, the variance of elevation at 150 m was the best predictor, and was positively related to species richness. Across regions, land cover variety was the best predictor of plant species richness, and the relationship was positive. A comparison of models using these four predictors showed that mean within-plot pH was the best overall predictor of plant species richness. The variance of elevation across a neighborhood with radius 150 m was the best overall heterogeneity predictor.

Results from the MCMC analysis show that the same type of heterogeneity had varying effects at local and regional scales. Because the best measure of land cover heterogeneity was regional land cover variety, I used a model combining that metric with the same metric calculated in neighborhoods within 1380 m of plot locations. The posterior distribution of the ratio of the coefficients for within-habitat and regional heterogeneity in that model had a median of 0.90 and a 95% credibility interval below 1.00 (Figure 2.3a). This indicates that on average for land cover, a one-unit change in heterogeneity surrounding vegetation plots leads to the same change in species richness as a 0.90-unit change in regional heterogeneity does. Therefore, regional land cover heterogeneity has a greater influence on species richness than local land cover heterogeneity. For the bivariate elevation model, I combined variance measured across a 150-m radius neighborhood with regional elevation variance. The posterior distribution of the ratio of level-1 to level-2 coefficients has a median of 1.04, and a 95%

credibility interval greater than 1.00 (Figure 2.3b). Therefore, a one-unit change in elevation locally nearly always has a greater effect on species richness than an equivalent regional change. Finally, I combined standard deviation of NDVI in habitat patches within 450 m from vegetation plots with regional NDVI standard deviation. The posterior distribution of the ratio is highly skewed, with a median of 0.02, and a credibility interval between $1.4 \times 10^{-5}$ and $5.2 \times 10^{1}$ (Figure 2.3c). Thus, the ratio of level-1 to level-2 coefficients in this model is highly variable, probably because regional NDVI heterogeneity is not a significant univariate predictor.

I conducted one-sided Welch's t-tests to test for significant differences between longleaf and non-longleaf plots in the best heterogeneity variables: NDVI within habitats, elevation across neighborhoods, and land cover across regions. Results from the t-tests showed that NDVI heterogeneity measured within habitats was on average significantly lower for longleaf plots than for non-longleaf plots (Figure 2.4a). There was no significant difference in neighborhood elevation heterogeneity on average among longleaf and non-longleaf plots (Figure 2.4b). However, mean regional land cover heterogeneity was significantly greater for longleaf plots (Figure 2.4c). On average, longleaf plots had higher species richness (57.4 +/- 5.3 species) than non-longleaf plots (47.6 +/- 2.2 species, two-sample $t(41) = 1.70$, $p = 0.048$).

## Discussion

Ecological processes act at different scales to influence local species richness (Shmida and Wilson 1985, Levin 2000). I investigated the relationship between local plant species richness and variables measured across a variety of spatial scales. At scales larger than vegetation plots, local plant species richness was related to heterogeneity, and heterogeneity variables were significantly different between longleaf pine and non-longleaf communities. The strongest association between local plant species richness and heterogeneity occurred at different scales for different variables. Heterogeneity of NDVI, elevation, and land cover were the best predictors at within-habitat, neighborhood, and regional scales, respectively. Overall, among all variables at these three scales larger than plots, elevation heterogeneity across neighborhoods was the best predictor of species richness, and the relationship was positive.

Within vegetation plots, mean pH was the best predictor, and predicted species richness better than any other variable or metric used in this study. Heterogeneity likely matters at this scale (Chesson 2000), but the level of environmental variation within plots may be too small to capture with the metrics and variables in this study or with the precision recorded in the CVS database. The inherent characteristics of the vegetation plots used in this analysis could account for the fact that within plots, the means of variables were better predictors than heterogeneity metrics. Because vegetation plots were located to inventory sites that are characteristic of a single vegetation community, variation in environmental variables within plots is likely minimal.

Local plant species richness was most strongly associated with elevation heterogeneity measured across neighborhoods. This result indicates that processes occurring across neighborhoods have a greater effect on local species richness than processes occurring within habitats or at regional scales. For example, greater variability among habitats across neighborhoods could result in increased source-sink dynamics among habitat patches, which act to maintain local population sizes via the rescue effect (Pulliam 1988, Brown and Kodric-Brown 1977). However, my results show that variation in elevation across neighborhoods was not significantly different for longleaf and non-longleaf plots. On the Southeast Coastal Plain, different vegetation communities result from subtle changes in elevation, and this variation can lead to considerable differences in plant species richness and composition even within the longleaf pine ecosystem (Peet 2006).

Land cover heterogeneity across regions showed a positive relationship with local richness and had a greater influence on richness than land cover heterogeneity within habitats. Regional land cover heterogeneity was significantly higher for longleaf plots than all other plots. Ecologically, this relationship is likely due to the fact that in the Southeast Coastal Plain, species-rich longleaf pine communities generally exist in smaller patches or in regions of higher habitat fragmentation while communities, such as pocosins, that contain fewer plant species often still exist in large expanses (Christensen 2000). In addition, and cover likely relates to local plant species best when measured across regions because the accuracy of digital land cover classifications is highest when the data is summarized at large extents (Hollister et al. 2004).

Within habitats, NDVI heterogeneity showed a negative relationship with species richness. In fact, the dominant relationship for all heterogeneity variables measured within habitats was negative (Table 2.3). Furthermore, longleaf plots had significantly lower values of within-habitat NDVI heterogeneity than all other plots. The negative relationship is contrary to my hypothesis that the heterogeneity-richness relationship is positive at all scales. This relationship is likely a direct result of the way in which patches were delineated in this study. I delineated patches based on areas of contiguous vegetation according to NLCD land cover data. Because relatively species poor communities in the Southeast, such as pocosin, exist within larger expanses of vegetation, patch sizes for these vegetation types are likely higher. Consequently, there is more potential for variation within these larger patches, and heterogeneity values would be greater. Indeed, patch sizes surrounding plots with lower than average values of NDVI heterogeneity had a mean size of 30.4 ha, while plots with higher values of NDVI heterogeneity had a mean patch size of 38.9 ha.

Compared to other plots examined here, those in longleaf pine communities were on average higher in species richness and had significantly different values for within-habitat NDVI heterogeneity and regional land cover heterogeneity. The continuous nature of the heterogeneity variables are helpful for regional assessments because they allow a determination of the statistical distribution of environmental conditions over which species-rich longleaf communities are likely to occur. In contrast, discrete habitat classifications do not allow such a determination. For example, longleaf plots fall in a number of land cover classes in the NLCD 2001 land cover classification (Homer et al. 2007), all of which contain plots in other vegetation communities (Table 2.4). Woody wetlands, the class on which the majority of longleaf plots fall, also contains the majority of other plots.

The results of this analysis are broadly consistent with, but extend the findings of previous studies. Other studies have examined the relationship of heterogeneity metrics measured at a single scale to species richness measured at the same scale. For example, across landscapes, St-Louis et al. (2006) showed that variability in vegetation productivity was related to landscape-scale bird species richness. In addition, a study by Kerr et al. (2001) showed that the variety of land cover across ecoregions was an important predictor of regional butterfly richness. Thus, my results showing the importance of NDVI heterogeneity within habitats, and land cover heterogeneity across regions correspond to those previous findings. However, while other studies have shown a relationship between local heterogeneity and local plant richness, I found no significant relationship between richness and local heterogeneity in my study.

My results can be related to species pool theory, which states that there are environmental and geographic factors that act at different scales to filter the total species pool and determine local species composition and richness. Following the terminology of Kelt (1995) and Belyea and Lancaster (1999), the ecological species pool, or the species available to colonize any local area, is a subset of the total species pool that has been filtered by dispersal constraints and the environment. Heterogeneity measured across regions represents variability in the number of habitat types within an ecoregion, and likely represents longer-term processes, such as soil formation, that would also influence the total species pool in a region. Therefore, the positive regional heterogeneity-local richness relationship I found could suggest that regional heterogeneity acts to increase local species richness by increasing the number of species in the total species pool, providing a larger group of species available before dispersal and environmental filters.

The suite of species that has been filtered by dispersal constraints is called the geographic species pool. In my study, neighborhood heterogeneity represents variability in habitat among habitat patches that surround a plot location. This scale may be similar to the scale at which plants disperse from neighboring habitat patches. Thus, greater variability among habitats surrounding a site increases the number of species that are able to disperse to a given site. The positive relationship I found between neighborhood heterogeneity and local richness suggests that heterogeneity at this scale is associated with decreased dispersal constraints, and therefore increases the size of the geographic species pool.

The different subset of species in the total species pool that has been filtered by environmental constraints is called the habitat species pool. Heterogeneity measured within habitats in this study is at the scale of environmental filtering. The negative relationship I found suggests that increased heterogeneity represents increased environmental filtering within habitat patches, which leads to a smaller habitat species pool. Local internal dynamics such as competition determine which species in the ecological species pool actually establish at a given site. It has been argued that within-plot heterogeneity corresponds to decreased local competition, which promotes species coexistence (Chesson 2000) and thus local richness. Although I tried to find evidence for that in this study, my results do not show a relationship between local heterogeneity and local species richness.

Another potential factor accounting for the heterogeneity-richness relationships seen here are the historical and current human land use patterns in the Southeast Coastal Plain. In this analysis, the neighborhood and regional scales incorporated variability across both areas with human land use, in addition to relatively natural areas. On the Southeast Coastal Plain, conversion to agriculture and other human development occurred first in most the fertile longleaf pine communities, where highest plant species richness occurs (Frost 2006). The positive correlation between richness and heterogeneity at neighborhood and regional scales could therefore be due to increased habitat fragmentation at those scales.

Measuring and monitoring diversity across broad scales is important to conservation. At these scales, local measures of species richness at plot locations often must be extrapolated across regions using predictive models based on GIS and remotely-sensed data. My results have implications for these prediction-based assessments of plant species richness. When modeling local species richness across broad extents, heterogeneity measures are better predictors than the means of variables such as NDVI, elevation and land cover. My results show that models that incorporate these continuous variables, at a variety of scales, can be useful in predicting species richness, and for distinguishing communities of known conservation importance. Specifically, by showing that at within-habitat and neighborhood scales, local species richness could be predicted by variation in unclassified spatial data, I found support for the spectral variation hypothesis, proposed by Palmer et al. (2002) as a tool that can inform surveys of species richness.

Furthermore, because I found that heterogeneity at large scales is correlated to local richness, my study shows that conservation of species rich communities must involve not only conserving local sites, but also a consideration of processes that occur at a variety of scales surrounding those sites. The within-habitat scale here, measured within contiguous vegetation at extents of 7 ha to 6000 ha, corresponds most closely to the scale of a single forest stand or conservation preserve. Therefore, my results indicate that conservation and management of an entire preserve affects local plant communities. The neighborhood scale measured variability across vegetation and non-vegetation at the same extents, and represents the scale of a preserve plus the surrounding land uses, while the regional scale, measured at extents of 38,000 ha to 705,000 ha, is close to the scale of a small watershed. The influence of neighborhood and regional heterogeneity on local richness indicates that conservation efforts must consider the larger landscape when aiming to conserve local sites. Indeed, taking an approach such as ecosystem management, which works to achieve conservation while integrating broad-scale ecological and social factors across regional extents (Christensen et al. 1996), would be successful here.

My study examines whether heterogeneity variables are useful predictors of plant species richness. This study does not aim to develop the best multivariate models to predict richness, but rather to examine the richness-heterogeneity relationship using a range of easily computable heterogeneity metrics derived from ecologically meaningful variables across a variety of scales. Other factors, including disturbance history, certainly have an important influence on plant species richness in the region and should be included in any comprehensive modeling effort. My results suggest that measures of heterogeneity at multiple scales will be useful to incorporate into future models of plant species richness. Therefore, my results will inform future efforts to model plant species richness using factors across a variety of spatial and ecological scales.

## Conclusions

As expected, this study shows that heterogeneity metrics are useful predictors of local species richness, and the best heterogeneity predictor differs by scale. Local species richness is determined by processes operating at a variety of scales, from local to regional. My results suggest that heterogeneity metrics developed from spatial data at multiple scales can help predict geographic variability in local richness possibly by acting as surrogates to measure the relative effects of these processes. These results will help future efforts to model species richness, and will also help conservationists perform prediction-based regional assessments of biodiversity.

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## Tables

Table 2.1: Scales, grain sizes, predictor variables, and metrics included in heterogeneity analysis.

| Level[a] | Scale | Grain size | Abiotic[b] | Productivity[b] | Vegetation community[c] |
|---|---|---|---|---|---|
| 1 | Within-plot | | | | |
| | | 400 $m^2$ | Soil pH and OM[d] | Basal area | N/A |
| 1 | Within-habitat | | | | |
| | | 150 m radius | Elevation | NDVI | Land cover |
| | | 450 m radius | Elevation | NDVI | Land cover |
| | | 1380 m radius | Elevation | NDVI | Land cover |
| 1 | Neighborhood | | | | |
| | | 150 m radius | Elevation | NDVI | Land cover |
| | | 450 m radius | Elevation | NDVI | Land cover |
| | | 1380 m radius | Elevation | NDVI | Land cover |
| 2 | Region | | | | |
| | | Ecoregions | Elevation | NDVI | Land cover |

[a]Indicates level of predictor in mixed effects models.
[b]Mean, variance, standard deviation, range, coefficient of variation were calculated.
[c]Simpson's diversity index and variety were calculated.
[d]Soil organic matter (%).

Table 2.2: Results from univariate mixed effects models. Boldface indicates the best model for a given scale, based on AICc $w_i$.

| Scale | Variable and radius | Uncond means | Mean | Variance | Stdev | Range | CV | Variety | Simpson | Log-likelihood | AICc[a] | P-value[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Within-plot | | | | | | | | | | | | |
| | pH | | **1.00** | | | | | | | -644.21 | 1298.84 | <0.001 |
| | OM | | **0.74** | | | | | | | -664.54 | 1337.35 | 0.01 |
| | Basal area | | **0.85** | | | | | | | -659.87 | 1328.02 | <0.001 |
| Within-habitat | | | | | | | | | | | | |
| | Elevation 150 m | **0.32** | 0.12 | 0.13 | 0.16 | 0.16 | | | | * | * | *N/A* |
| | Elevation 450 m | | | 0.35 | **0.45** | | | | | -664.97 | 1338.22 | 0.01 |
| | Elevation 1380 m | 0.22 | | **0.32** | 0.20 | | | | | -666.71 | 1341.41 | 0.09 |
| | NDVI 150 m | **0.29** | 0.20 | 0.14 | 0.17 | 0.11 | 0.10 | | | * | * | *N/A* |
| | NDVI 450 m | | | | **0.63** | | | | | -664.31 | 1336.61 | 0.01 |
| | NDVI 1380 m | 0.16 | | 0.20 | **0.35** | | 0.15 | | | -666.28 | 1340.55 | 0.06 |
| | Land cover 150 m | | | | | | | | **0.71** | -665.66 | 1339.59 | 0.03 |
| | Land cover 450 m | | | | | | | 0.25 | **0.60** | -665.75 | 1339.77 | 0.03 |
| | Land cover1380 m | | | | | | | 0.26 | **0.59** | -665.72 | 1339.72 | 0.03 |
| Neighborhood | | | | | | | | | | | | |
| | Elevation 150 m | | | **0.80** | | | | | | -662.47 | 1333.22 | <0.001 |
| | Elevation 450 m | | | 0.24 | **0.55** | | | | | -664.15 | 1336.57 | 0.01 |
| | Elevation 1380 m | | | **0.59** | 0.38 | | | | | -663.12 | 1334.51 | 0.002 |
| | NDVI 150 m | **0.28** | 0.24 | 0.12 | 0.12 | 0.12 | 0.13 | | | * | * | *N/A* |
| | NDVI 450 m | **0.31** | 0.25 | 0.12 | | | | | | * | * | *N/A* |
| | NDVI 1380 m | **0.35** | 0.14 | 0.14 | | | | | | * | * | *N/A* |
| | Land cover 150 m | **0.50** | | | | | | | | * | * | *N/A* |
| | Land cover 450 m | **0.58** | | | | | | | | * | * | *N/A* |
| | Land cover1380 m | **0.58** | | | | | | | | * | * | *N/A* |
| Regional | | | | | | | | | | | | |
| | Elevation | | | | | **0.53** | | | | -664.72 | 1337.71 | 0.01 |
| | NDVI | **0.49** | | | | | | | | * | * | *N/A* |
| | Land cover | | | | | | | **0.94** | | -663.49 | 1338.32 | 0.003 |

Values represent AICc $w_i$ for each metric for a given measure and radius, for all models with $\Delta$ AICc less than 2.

[a] * indicates the unconditional means model was better than models containing any of the metrics as predictors

[b]P-values are from an extra sum-of-squares F-test.

Table 2.3: Results of model comparison among the best univariate models for each extent. Boldface indicates the best univariate model for a given extent, based on Δ AICc.

| Scale | Model | Radius | Log-likelihood | K[a] | AICc | Δ AICc | $w_i$ | p-value[b] | Level-2 $R^{2\,d}$ | Level-1 $R^{2\,d}$ | Shape |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Within-plot | | | | | | | | | | | |
| | Unconditional means | | -668.13 | 3 | 1342.42 | 14.40 | 0.00 | | | | |
| | **Mean pH** | | **-644.21** | **4** | **1296.70** | **0.00** | **1.00** | **< 0.001** | **0.57** | **0.24** | **Inverted U** |
| | Mean Organic matter | | -664.54 | 4 | 1337.35 | 40.65 | 0.00 | 0.01 | 0.24 | 0.03 | Neg. linear |
| | Mean Basal area | | -659.87 | 4 | 1328.02 | 31.32 | 0.00 | < 0.001 | -0.04 | 0.12 | Neg. linear |
| Within-habitat | | | | | | | | | | | |
| | Unconditional means | | -668.13 | 3 | 1342.42 | 5.53 | 0.03 | | | | |
| | Land cover heterogeneity | 150 m | -665.66 | 4 | 1339.59 | 2.70 | 0.10 | 0.03 | -0.10 | 0.04 | Neg. linear |
| | Land cover heterogeneity | 450 m | -665.75 | 4 | 1339.77 | 2.88 | 0.09 | 0.03 | -0.12 | 0.04 | Neg. linear |
| | Land cover heterogeneity | 1380 m | -665.72 | 4 | 1339.72 | 2.83 | 0.10 | 0.03 | -0.10 | 0.04 | Neg. linear |
| | Elevation heterogeneity | 450 m | -664.97 | 4 | 1338.22 | 1.34 | 0.20 | 0.01 | 0.16 | 0.03 | Pos. linear |
| | Elevation heterogeneity | 1380 m | -666.71 | 4 | 1341.69 | 4.80 | 0.04 | 0.09 | 0.13 | 0.01 | Pos. linear |
| | **NDVI heterogeneity** | **450 m** | **-664.31** | **4** | **1336.89** | **0.00** | **0.39** | **0.01** | **-0.02** | **0.06** | **Neg. linear** |
| | NDVI heterogeneity | 1380 m | -666.28 | 4 | 1340.83 | 3.94 | 0.06 | 0.06 | 0.02 | 0.02 | Neg. linear |
| Neighborhood | | | | | | | | | | | |
| | Unconditional means | | -668.13 | 3 | 1342.42 | 9.19 | 0.01 | | | | |
| | **Elevation heterogeneity** | **150 m** | **-662.47** | **4** | **1333.22** | **0.00** | **0.58** | **< 0.001** | **-0.05** | **0.08** | **Pos. linear** |
| | Elevation heterogeneity | 450 m | -664.15 | 4 | 1336.57 | 3.35 | 0.11 | 0.01 | 0.11 | 0.05 | Pos. linear |
| | Elevation heterogeneity | 1380 m | -663.12 | 4 | 1334.51 | 1.29 | 0.31 | 0.002 | 0.08 | 0.06 | Pos. linear |
| Regional | | | | | | | | | | | |
| | Unconditional means | | -668.13 | 3 | 1342.42 | 4.10 | 0.09 | | | | |
| | Elevation heterogeneity | | -664.72 | 4 | 1340.77 | 2.45 | 0.21 | 0.01 | 0.45 | 0.00 | Pos. linear |
| | **Land cover heterogeneity** | | **-663.49** | **4** | **1338.32** | **0.00** | **0.70** | **0.003** | **0.57** | **0.00** | **Pos. linear** |

[a]Number of parameters estimated in the model.

[b]P-values are from an extra sum-of-squares F-test comparing each univariate model to the unconditional means model.

[d]Indicates the pseudo-$R^2$ values calculated from components of the variance matrix.

Table 2.4: Percentage of longleaf versus non-longleaf vegetation plots that fall within each habitat type, according to NLCD land cover classification.

| Type of plots | N | Herbaceous | Evergreen Forest | Woody Wetlands | Other |
|---|---|---|---|---|---|
| Longleaf | 31 | 19% | 19% | 39% | 23% |
| Non-longleaf | 119 | 2% | 10% | 71% | 18% |

**Figures**

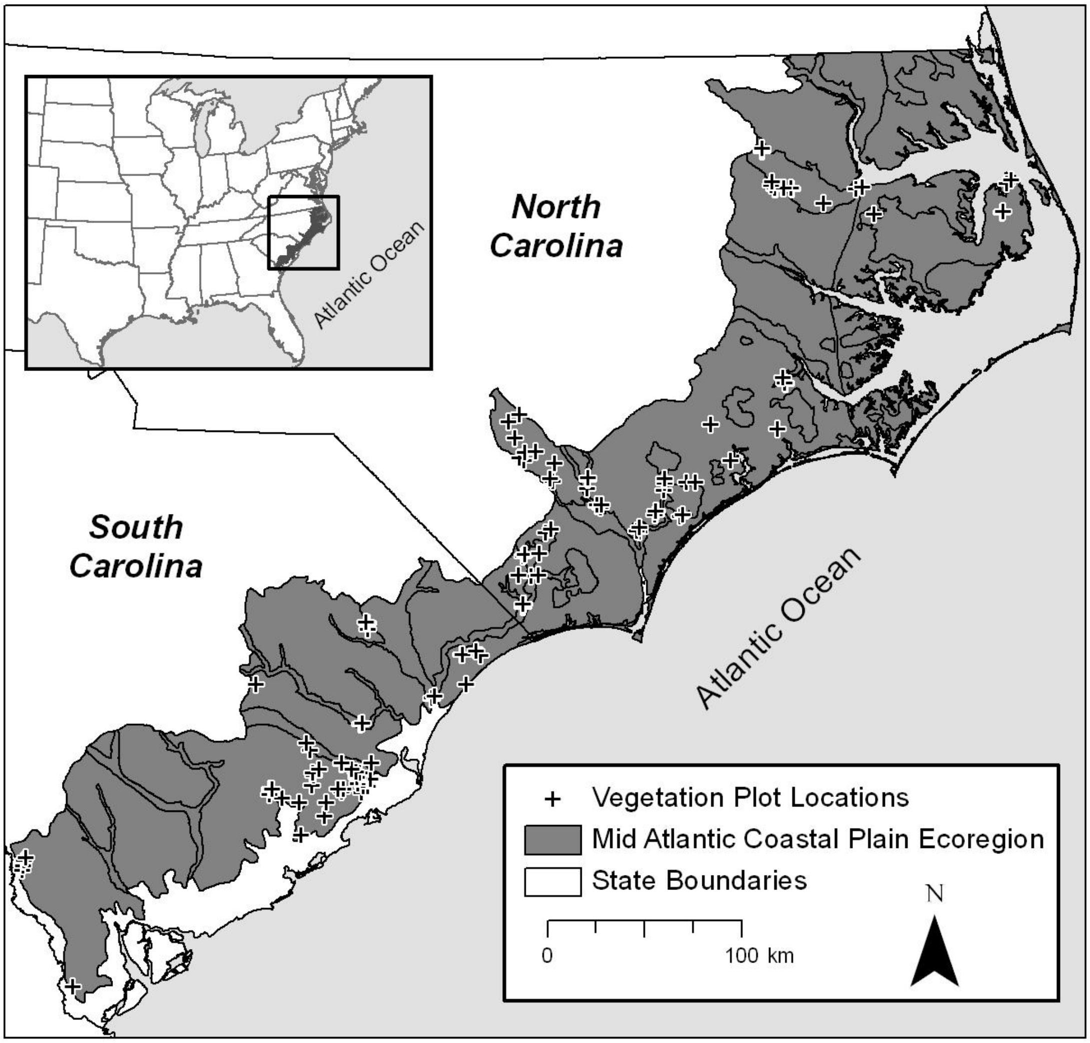


Figure 2.1: Study area in the Middle Atlantic Coastal Plain ecoregion.

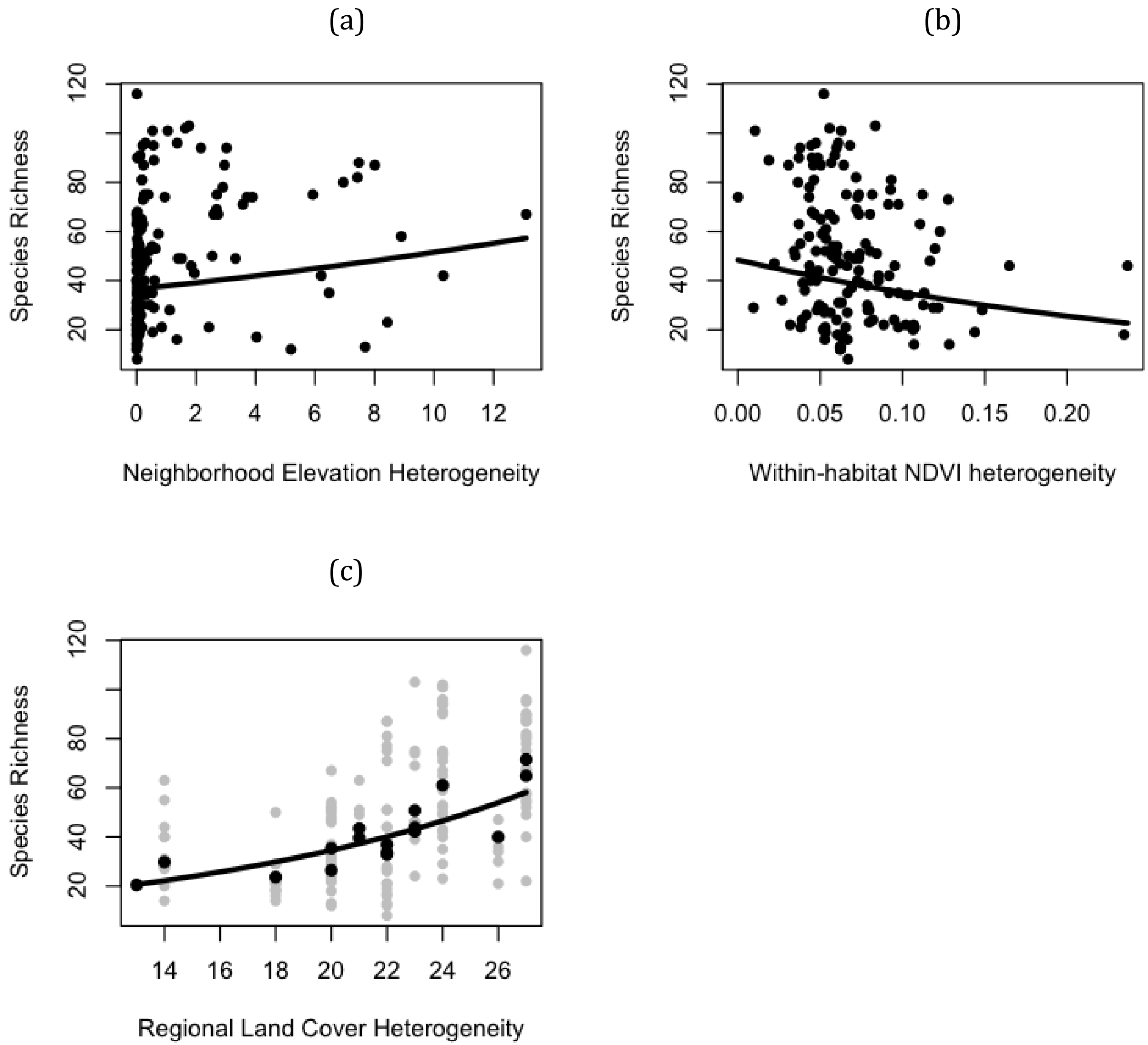


Figure 2.2: The relationship between species richness and (a) within-habitat NDVI heterogeneity, measured as the standard deviation of NDVI across habitat patches, (b) neighborhood elevation heterogeneity, measured as the variance in elevation across neighborhoods (c) regional land cover heterogeneity, measured as the variety of land cover classes. The lines represent the fitted values for the population. In (c) the light dots represent all data, and dark dots represent fitted values for groups.

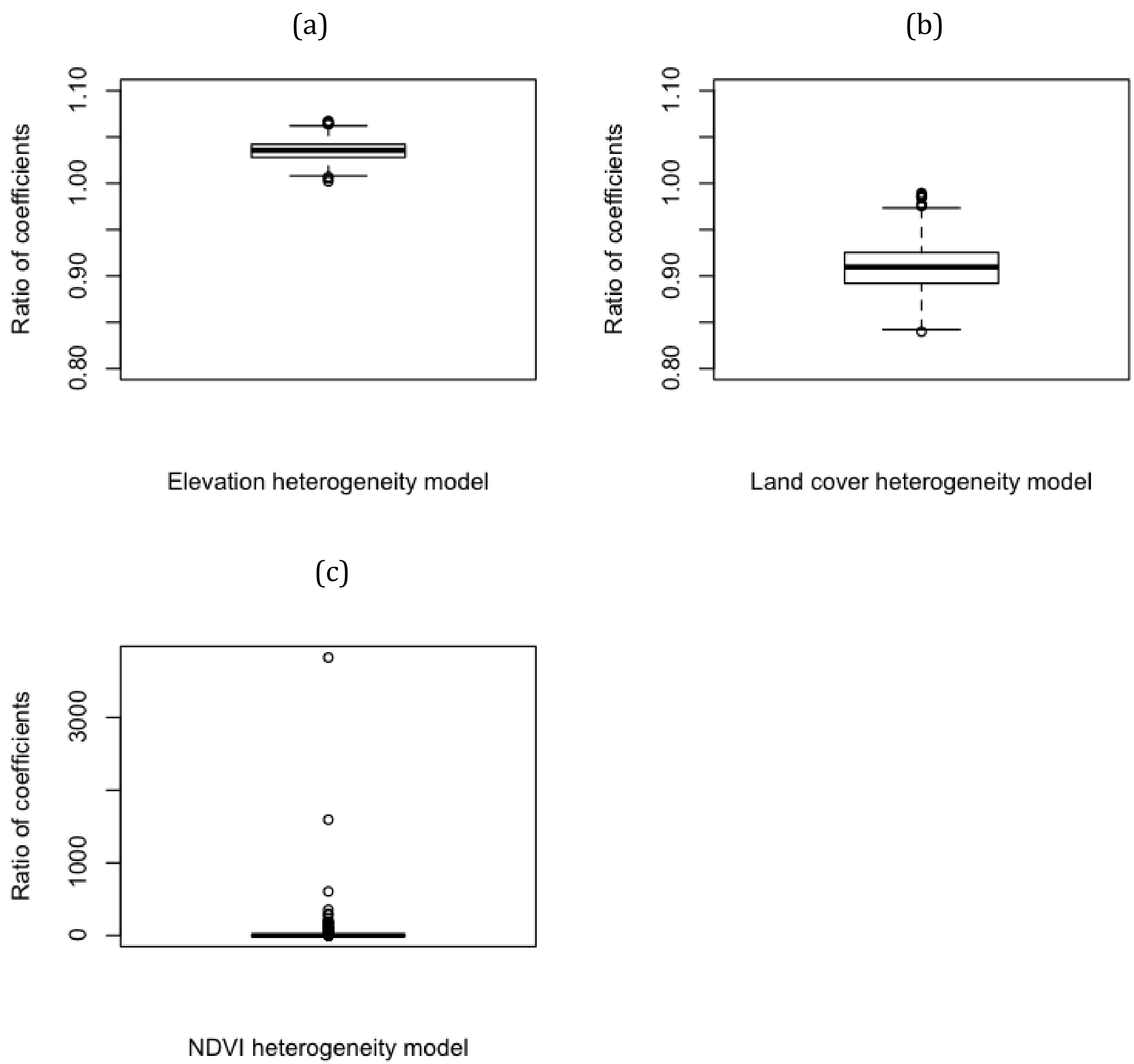


Figure 2.3: Boxplots showing the posterior distributions of the ratio of level-1 to level-2 coefficients from the MCMC analysis for (a) elevation heterogeneity, (b) land cover heterogeneity, and (c) NDVI heterogeneity.

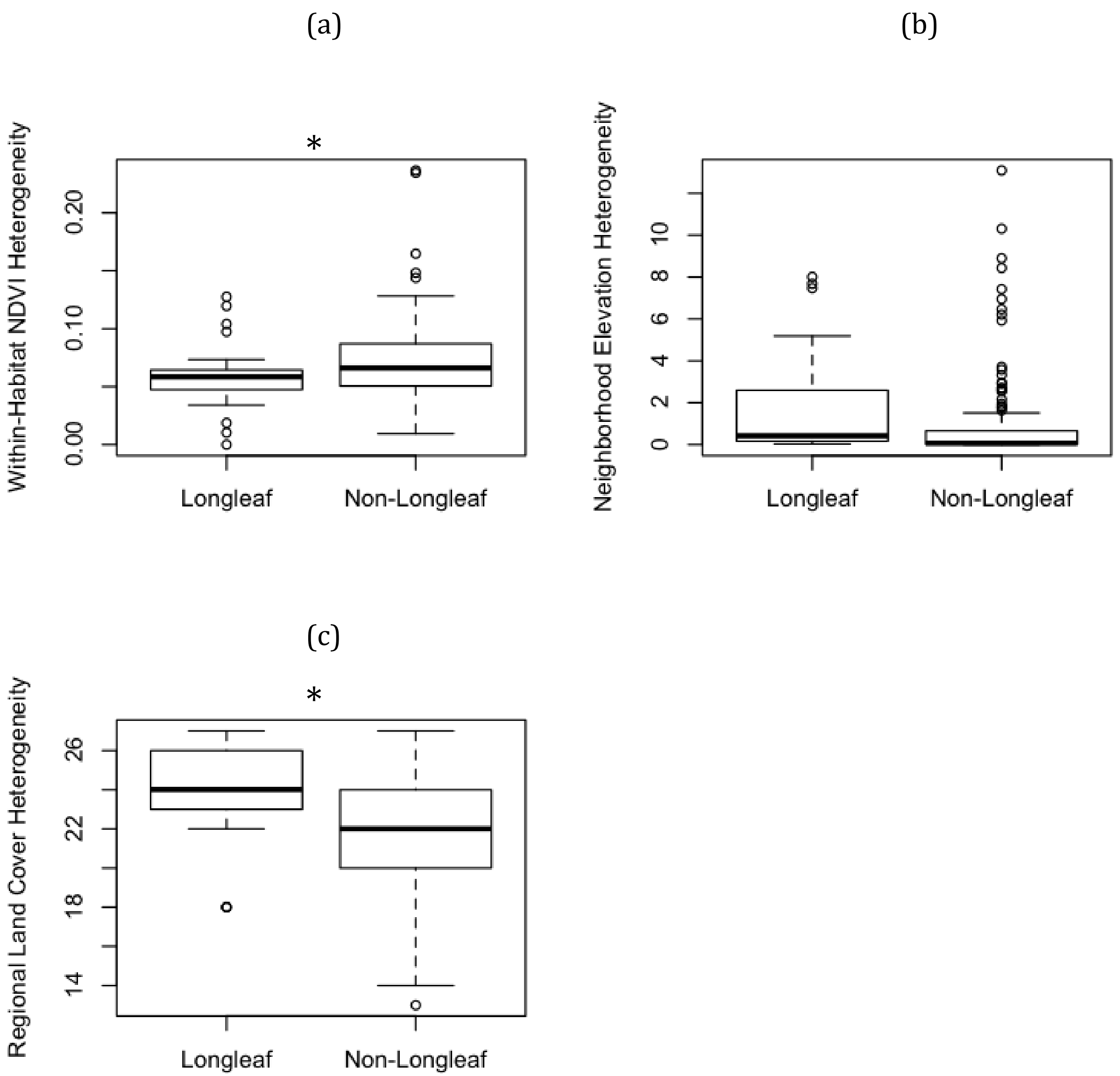


Figure 2.4: Boxplots showing the distribution of (a) within-habitat NDVI heterogeneity, (b) neighborhood elevation heterogeneity, and (c) regional land cover heterogeneity among plots in longleaf pine communities versus non-longleaf plots. Asterisks above the plots indicate significant differences according to t-tests ($p < 0.05$).

# CHAPTER 3

## LESSONS LEARNED IN COLLABORATIVE CONSERVATION: STRATEGIES USED BY PARTNERSHIPS IN THE LONGLEAF PINE ECOSYSTEM


### Abstract

Collaborative partnerships among public and private entities are a popular way to accomplish ecosystem management and conservation objectives. Many strategies for effective collaboration have been suggested in the literature; however, those strategies have rarely been related to the stated conservation objectives for a particular ecosystem. In this chapter, I asked: which strategies are being used by collaborative partnerships in the longleaf pine ecosystem of the US Southeast to accomplish conservation objectives there? I summarized the most important objectives for longleaf pine conservation from the scientific literature and conservation documents. I then conducted interviews of participants in collaborative partnerships to determine which strategies they are using, and how those strategies relate to conservation objectives. Interviews resulted in a set of major strategies that are being used by partnerships in the longleaf pine ecosystem: (1) Find common ground while leveraging the strengths of individual partners; (2) facilitate communication and information sharing among partners; (3) establish a mechanism for sharing resources among partners; (4) focus on public outreach to nearby landowners; (5) communicate with local governments. I examine the ways partnerships are using these strategies, and discuss how each of them helps address one or more of the conservation objectives in the longleaf pine

ecosystem. These strategies emphasize long-term sustainability of partnerships and resilience of the ecosystem; therefore, they will be useful for informing the efforts of other partnerships in the longleaf pine ecosystem and elsewhere.

**Keywords**

communication with local governments; conservation objectives; ecosystem resilience; long-term sustainability; public outreach

**Introduction**

With the decline of biodiversity and scientists' increased awareness of the complexity of ecological processes, ecosystem management has become a dominant paradigm for accomplish conservation objectives over the last twenty years (Keough and Blahna 2006, Yaffee 1999). Rather than focusing on traditional single species or resource-based approaches, ecosystem management takes a holistic viewpoint, recognizing the complexity of ecological processes situated within a social context across broad extents (Christensen et al. 1996). One way to conduct ecosystem management is via collaborative partnerships among public agencies, private organizations, and other stakeholders aimed at conservation (Wondolleck and Yaffee 2000). These partnerships are becoming increasingly important ways in which to address conservation goals across broad extents as the human population grows and habitat becomes more fragmented. Indeed, numerous successful collaborative conservation partnerships have been established across the United States (Keough and Blahna 2006).

Collaborative partnerships have been successful at accomplishing ecosystem-based conservation because they are effective at integrating ecological goals with their social and economic contexts (Keough and Blahna 2006, Government Accountability Office [GAO] 2008). For example, conservationists and ranchers in the western US have been able to preserve habitat while improving commodity production by working collaboratively toward a common vision of protecting open spaces (Keough and Blahna 2006). Several studies have summarized recommended strategies for effective collaboration. These strategies include: developing a transparent collaborative decision-making process (Cortner and Moote 1999, Meffe et al. 2002), developing a set of balanced goals (Keough and Blahna 2006), leveraging resources (Wondolleck and Yaffee 2000), employing multidisciplinary data (Rigg 2001), and conducting adaptive management (Stankey et al. 2003). While numerous strategies have been recommended for successful collaboration, few authors have explicitly investigated which of these strategies are relevant for addressing stated conservation objectives in a particular ecosystem. Furthermore, most studies have examined collaborative partnerships in the western US, across landscapes where a few agencies or individuals own the majority of the land. Relatively little work has been done to determine the strategies being used by regional partnerships in the eastern US, where the land is divided among a greater number of landowners and habitat generally is more intermixed with urban and residential development (Radeloff et al. 2005).

In this chapter, I examine the strategies used by collaborative partnerships for conservation of the longleaf pine ecosystem of the US Southeast. This ecosystem provides essential habitat for a diversity of plant species and several endangered animal species, but has been severely degraded (Van Lear et al. 2005). In the longleaf ecosystem, many collaborative partnerships among public and private stakeholders have begun, and several have been widely successful in achieving ecological objectives while balancing social and economic goals (Rosenzweig 2003). In this chapter, I ask: which strategies are used by successful collaborative conservation partnerships to address conservation objectives in the longleaf pine ecosystem? First, I review the major conservation objectives for the longleaf pine ecosystem. Then, using data from interviews of participants in three partnerships, I synthesize collaborative strategies and examine which conservation objectives those strategies help achieve. The result is a summary of how collaborative strategies can be applied in practice, in order to inform conservation efforts in the longleaf pine ecosystem and in other degraded ecosystems.

**Background: conservation of the longleaf pine ecosystem**

Longleaf pine was once the most abundant ecosystem in the Southeast, covering approximately 37 million ha (Frost 1993). When frequently burned, longleaf pine ecosystems have among the highest number of plant species at small scales of any ecosystem in the world (Peet and Allard 1993). Due to widespread timber harvesting and fire suppression, the ecosystem has been severely degraded and fragmented, reducing this forest type to a mere 2% of its pre-European settlement range. Of this small portion, only 9% is able to support the native plant and animal species that depend on the habitat (Frost 2006). As a result, populations of species such as the endangered Red-cockaded Woodpecker (*Picoides borealis*) that depend on longleaf pine habitat have declined (Van Lear et al. 2005). This decline has prompted Noss et al.

(1995) to designate the longleaf ecosystem as "critically endangered". Of the 1.05 million hectares of extant longleaf habitat, remnant old-growth stands currently exist as scattered fragments totaling 5100 ha, mainly on public lands (Varner and Kush 2004). The rest of the extant longleaf pine habitat is approximately evenly split between public and private landowners (America's Longleaf 2009). Therefore, many have called for collaborative efforts among public and private landowners to conserve and restore habitat connectivity across large extents (Van Lear et al. 2005, Landers et al. 1995, Hoctor et al. 2006).

Scientists and conservation professionals have recommended several objectives for achieving the goal of broad-scale conservation of the longleaf pine ecosystem. Here, I synthesize those recommendations into four themes.

*Objective 1: Improve and maintain existing longleaf pine habitat*

Maintaining areas that are already able to support the majority of plants and animals that depend on the longleaf pine ecosystem should be the first objective in conservation (Van Lear et al. 2005, America's Longleaf 2009). In addition, improving degraded sites that are already in conservation ownership is important. Allowing and encouraging fire as an ecosystem process is the most essential component of managing longleaf pine habitat (Van Lear et al. 2005). Frequent fires promote understory plant biodiversity, as well as the sparse understory and midstory vegetation structure that are needed as habitat for many of the animal species in the ecosystem (Van Lear et al. 2005). Currently, prescribed fire is the major tool used for restoration and maintenance of longleaf habitat. However, conducting prescribed burns can be challenging because agencies as well as private individual landowners often do not have the money, staff, or equipment they need to conduct the level of prescribed burning that would most benefit the habitat (Hiers et al. 2003). Furthermore, real and perceived risks to public health and property if a fire escapes can lead to risk averse management agencies that are often not able to accomplish all of their management objectives (Maguire and Albright 2005). Overcoming these barriers to burning is a key to maintaining and restoring longleaf pine habitat.

*Objective 2: Expand and connect habitat in a coordinated fashion*

Connecting habitat fragments benefits conservation and management of longleaf pine. Recent evidence has shown that corridors connecting isolated longleaf patches increase native plant species richness at large scales. Furthermore, the influence of corridors on richness increases over time, and spills over into adjacent, non-longleaf pine habitats (Damschen et al. 2006, Brudvig et al. 2009). In addition, acquiring lands adjacent to existing habitat makes management easier: conducting prescribed burning in a block surrounded by other habitat can carry less risk than burning near residential areas or other development. Therefore, acquisition of new conservation land must be prioritized based on its proximity to existing habitat or strategic location between longleaf fragments (America's Longleaf 2009). However, as the human population of the Southeast grows, assessed property values near expanding residential areas rise, and there is increasing pressure to develop forestland that is not currently protected (Wear and Newman 2004), making it more difficult for management agencies and conservation organizations to acquire additional land. Nonetheless, conserving large blocks of habitat, regardless of condition, will help facilitate future longleaf pine management and restoration efforts.

*Objective 3: Improve management on privately-owned forest lands*

Privately owned sites can be important reservoirs of biodiversity, and management techniques that maintain the ability to sustain frequent fire are most successful at promoting biodiversity on these sites (Mitchell et al. 2006). However, on private land, much of the existing longleaf has not been burned recently (Outcalt 2000), or is managed primarily for timber yield and not necessarily to provide high-quality habitat (Outcalt and Sheffield 1996). In addition, much of the land that once contained longleaf is now loblolly or slash pine plantation. Therefore, improved management on private land is an important objective for conservation of the longleaf pine ecosystem.

*Objective 4: Promote a variety of land uses across the remainder of the landscape that are compatible with conservation objectives*

Increasing urbanization is the leading threat to forest sustainability in the Southeast (Wear 2002). Urbanization limits the use of prescribed burning because it results in expansion of the wildland-urban interface (WUI) near sites that need to be burned. Smoke management concerns and regulations make planning and implementing WUI burns more challenging (Wade and Mobley 2007). On the other hand, human land uses that satisfy economic or social needs can be compatible with biodiversity conservation. In particular, land used for recreation (Heuberger and Putz 2003), or military training (Lachman et al. 2007) has the potential to support habitat protection goals. For this reason, promoting and accepting a variety of land uses, where appropriate throughout a region, will promote overall conservation efforts while supporting human needs in the landscape.

## Methods

*Partnerships included*

In reality, many conservation or management actions rely on collaborations among multiple landowners or stakeholders; however, there are several formally established partnerships whose goals include broad-scale conservation of the longleaf pine ecosystem. In this study, I included participants from three formal partnerships (Figure 3.1): The Onslow Bight Conservation Forum, North Carolina (hereafter, "Onslow Bight Partnership"); The North Carolina Sandhills Partnership (the "Sandhills Partnership"); and the Gulf Coastal Plain Ecosystem Partnership, Florida and Alabama ("GCPEP"). The three partnerships were chosen because they have each been recognized as national examples of effective collaborative conservation (Rosenzweig 2003, Lachman et al. 2007, White House Conference on Cooperative Conservation 2005). Therefore, other partnerships can likely learn from the strategies they employ.

The three partnerships have similar structures. Each has undergone a formal planning process, including outlining a formal boundary and identifying goals and objectives. The Onslow Bight Partnership was formalized in 2003 with a Memorandum of Understanding (MOU) among several public and private agencies, including the US Marine Corps at Camp LeJeune, The Nature Conservancy, the NC Wildlife Resources Commission, and the Croatan National Forest. The partnership was established with the overall goal of "discussion among the participants concerning the long-term conservation and enhancement of biological diversity and ecosystem sustainability" in the Onslow Bight Landscape, a 1 million-hectare area on the coastal plain of North Carolina (Onslow Bight Conservation Forum 2003; Figure 3.1). The Onslow Bight Partnership has been recognized as a successful example of collaboration by the White House Conference on Collaborative Conservation (2005) and the Government Accountability Office (2008).

The Sandhills Partnership was established in 2000 among public and private agencies, including the US Army at Fort Bragg, the US Fish and Wildlife Service, the NC Wildlife Resources Commission, and The Nature Conservancy in the Sandhills Ecoregion of North Carolina (Figure 3.1). The mission of the Sandhills Partnership is to develop a conservation strategy for the Red-cockaded Woodpecker, the longleaf pine ecosystem, and other ecosystems in the ecoregion. To date, the partnership has facilitated protection of over 6,000 hectares of land and has been recognized as a model for collaborative conservation (Lachman et al. 2007).

GCPEP was established in 1996 for ecosystem conservation in northwest Florida and south Alabama (Figure 3.1). The mission of GCPEP is to develop long-term strategies to abate threats and improve ecosystem health in the region (Compton et al. 2006). Agencies such as The Nature Conservancy, Eglin Air Force Base, the private Nokuse Plantation, and the Northwest Florida Water Management District participate. It was one of the first formal collaborative partnerships established in the country and has been recognized as a model for collaborative partnerships (Rosenzweig 2003, Lachman et al. 2007).

*Interviews*

I conducted one-on-one interviews of a total of 16 representatives from the three partnerships: I interviewed four representatives from the Onslow Bight, and six representatives each from the Sandhills Partnership and GCPEP. In each of the partnerships, subjects who were interviewed represented a variety of types of organizations, and were active participants who regularly attended partnership meetings. In all three partnerships, subjects included, at minimum, one representative from a public federal agency, a public state agency, and a private conservation organization. Interviews were semi-structured and were conducted in person, or over the phone if necessary. Each subject was asked general questions about the overall objectives and strategies used in his or her partnership, followed by more specific follow-up questions about the strategies used to achieve each of the longleaf pine conservation objectives described above (see Appendix 1 for interview guide). An audio recording of each of the interviews was made, and the recording was later transcribed.

Because the partnerships have similar structures, I chose to analyze strategies across the three partnerships and not treat each as a separate case study so that a more robust set of strategies could be developed. I performed a qualitative analysis of the interview data using Atlas.ti version 6.1 (Atlas.ti GmbH 2010). I looked for general themes that emerged across responses and identified strategies that were used by all three partnerships. I also focused on cross-cutting strategies: those that have the potential to influence more than one of the objectives of longleaf pine conservation.

This allowed identification of a robust set of strategies being used across all three partnerships to achieve conservation of the longleaf pine ecosystem.

## Results

The interview analysis resulted in a list of five strategies that collaborative partnerships use to achieve large-scale conservation. Each of these strategies helps achieve one or more conservation objectives in the longleaf pine ecosystem (Table 3.1).

*Strategy 1: Find common ground among all partners while leveraging the strengths of individual partners*

In collaborative partnerships, primary missions of stakeholders can vary markedly. For that reason, interview subjects stressed that finding common ground among partners by working together to develop a conservation plan is an essential foundation for guiding partnership efforts. A partnership's initial planning process can be a crucial first step in developing cohesion and encouraging the commitment of individual partners in the group toward accomplishing all types of conservation objectives:

> I really felt like when that [planning] process was all over that everybody, all the partners, kind of owned a piece of that process, so it felt like their interests had been represented. So everybody for the most part felt good about that and then everybody moved forward from there…that was a real key to a lot of the future successes.

In addition, while a common goal is important, interview participants stated that incorporating a varied mix of landowners can be an asset if a partnership is able to take advantage of the respective strengths of each partner. As a result of their partnerships, participants said they have been able to successfully initiate projects with "non-traditional" or "unexpected" partners that had access to different resources. For example, private organizations such as The Nature Conservancy can purchase land quickly, military agencies have access to money for acquisition, and some other public federal and state agencies have money or expertise to support land management. Often, there is a single partner agency or representative who is essential to the partnership:

> Certainly over the last few years the Department of Defense…is one place that has had consistent funding for land conservation groups. They are deeply engaged in monitoring of federally endangered species. They have a very comprehensive prescribed fire program. So the resource [they bring] is really what has made this [partnership] go.

Participants stated that when partners are able to contribute in a unique way, they feel positively about their contribution and remain engaged in the partnership.

Interview subjects pointed out that after a plan is developed, partnerships are in a better position to take advantage of funding opportunities that specifically target land acquisition projects with benefits to multiple parties. Therefore, this strategy specifically benefits the objective of expanding and connecting longleaf pine habitat (Table 3.1). In addition, because planning and leveraging strengths of all partners means each partner is more engaged in the process, all other conservation objectives in the longleaf pine ecosystem can be facilitated (Table 3.1).

*Strategy 2: Facilitate communication and information sharing among partners*

Once partners have agreed on a common mission, bringing partners together to communicate about what they are doing and what they know is the next step in accomplishing conservation objectives. Interview subjects consistently stated that increased communication among partners is one of the most important reasons that partnerships result in increased ability to manage and acquire land.

At least biannually, each of the three partnerships has formal meetings in which all participants gather to discuss business and provide updates on recent activities. In addition, each has a set of working groups that meet more often to address specific projects. For example, the Sandhills Partnership has working groups focused on: outreach, land protection, recovery of the local Red-cockaded Woodpecker population, longleaf pine ecosystem management, and reserve design.

Both during these formal meetings and outside the meetings, communication among members of the partnerships is done in two ways. First, formal sharing of data or expertise helps guide management efforts. Many partners already have some data or knowledge that they can offer to other partners. Where additional information is needed, collaborative development and sharing of data via cooperative research or modeling efforts can be a benefit. Interview subjects mentioned sharing information among partners on endangered species occurrences, fire management effects, and invasive species management, especially within their working groups. In particular, sharing information on Red-cockaded Woodpeckers has proven useful in the longleaf pine ecosystem. Some partners have a history of collecting data or managing land to promote woodpeckers, and can share their experiences with others. In other cases, partnerships have developed new data or used models to make future predictions and inform management activities.

Second, more casual information sharing, both during partnership meetings and as a result of contacts made in a partnership, is often beneficial:

> "How are you doing this? How are you doing that? What's been your experience with that?" That to me has been the most valuable thing. I can just pick up the phone and call somebody. Of everything, that's the most important to me on a daily basis to help us with management.

Partners share information about how to conduct management activities, especially prescribed burning (Table 3.1). They also share knowledge related to conservation land acquisition, such as informing other partners about a landowner that would be willing to sell land to a partner. In this way, partners become more aware of what others in the landscape are doing, and can better coordinate all management and conservation efforts (Table 3.1).

*Strategy 3: Establish a mechanism for sharing resources among partners*

Similar to sharing information, facilitating the sharing of resources such as equipment or trained personnel is an important way conservation partnerships can facilitate management in the longleaf pine ecosystem. Because agencies often differ in the resources they can access, establishing a mechanism by which these resources can be shared among agencies is an important strategy in partnerships. Often, obtaining additional personnel or equipment from partners may enable an agency to conduct prescribed burning where it would not otherwise be possible. Likewise, one agency loaning resources to other partners can be essential for reaching conservation goals:

> They'll call me a few days in advance and say… "Will I be able to borrow a dozer and an operator from you for the duration of the burn?" The answer is almost always yes, as long as we're not chasing wildfires, so we'll send a bulldozer and an operator fifty miles over to help them burn

> for that day. It's great for my guy. He gets to see how another agency carries out the burn, and gets to burn in a very complex environment.

One useful tool for sharing resources, particularly for prescribed burning, that several interview subjects mentioned was a memorandum of understanding (MOU). An MOU allows partner agencies establish mutual interest in management activities and their willingness to commit resources such as equipment or personnel to aid other partners whenever it is convenient to them (Table 3.1). An MOU is typically not legally-binding, but is symbolic of partner intentions: "if you can get them all together and say, 'yeah, we want to work together on this', and they'll sign a MOU at the highest levels of their agency, that is extremely important because that does open the door for cooperation down the road."

*Strategy 4: Focus on public outreach via a consistent message*

Interview subjects stated that lack of public understanding about the importance of land conservation or management techniques is a barrier to land conservation. One way they have been able to overcome this barrier is through increased public education and outreach. Partnerships have been particularly effective at outreach when all participants develop and adopt a consistent message:

> We're all talking the same message. So through osmosis if you continue to say it long enough, it just becomes the norm. Everybody is saying, "oh, yeah, we protect pine trees now for a multitude of reasons, and it's better to conserve than to destroy land", and then it just becomes second nature.

According to interview subjects, one of the outreach efforts that has been effective has been educating the public about the importance of prescribed burning. In addition, interfacing with private forest landowners about management strategies they can use to maximize both ecological and economic benefits is another component of public outreach mentioned by participants interviewed:

> There's a lot of work with private landowners… They can't turn [their land] into conservation land, but we work with them on best management practices and [show them how] to practice prescribed burning when they can. We show them the benefits of doing that, how if they incorporate that into their management strategies in the long run it will help them.

The result of outreach is that the public understands the importance of land conservation and management, and, instead of constraining conservation efforts, can benefit conservation. This strategy directly impacts management on private forest land, and benefits longleaf pine management and land acquisition efforts in general (Table 3.1).

*Strategy 5: Develop a channel of communication with local governments*

City and county governments are responsible for local land use planning and zoning regulations across counties and within municipalities. Therefore, interview participants stressed that communication with these entities about longleaf pine conservation is important for promoting a range of compatible land uses:

> I think overall the greatest measure of success is if we can basically interface successfully with the communities and the counties who have control over the land use planning and get them to become more part of the collaborative process so that we can start looking at long term decision making that will sustain the conservation objectives as well as the economic priorities of the area; find that balance for what we call quality of life.

Developing a positive relationship with local governments helps ensure that land use across a region will be compatible with conservation objectives over the long term.

Therefore, while this strategy directly allows partnerships to promote compatible land uses, it indirectly facilitates the ability to accomplish the other longleaf pine conservation objectives as well (Table 3.1). For example, partnerships can encourage local governments to locate recreational areas or dense development away from longleaf habitat in order to reduce risk from prescribed burning to these areas.

*Challenges for partnerships*

Although many respondents identified public outreach and interfacing with local governments as two important strategies, these were the strategies identified as being most challenging to implement:

> However [what we] haven't really done and [are] just starting to think about is broadening this group beyond just these core conservation or government agencies. Your opportunities are going to be limited if you're just talking to this small group of like-minded agency representatives. [Right now] it's very effective and the conversations go very smoothly because there's not a lot of dissent, but when you try to take this partnership's [goals] to the community at large, you don't necessarily have somebody who can speak for a private landowner or a local elected official.

Interview subjects mentioned that many partners are often reluctant to be in the public eye, either because they have no experience doing so, or because they have had a negative experience with public opinion in the past. In addition, it may be difficult to engage with the appropriate group of citizens. For example, a partnership may work in several counties, spanning the jurisdiction of multiple county and municipal governments. Determining which agencies are appropriate to engage, and maintaining communication with all of them can be difficult and time-consuming. Similarly, targeting private landowners can be challenging because these individuals do not often have an organizing body or representative that can interface with a partnership like public agencies or conservation organizations can.

Another challenging strategy, according to interview participants, was developing a common goal and comprehensive plan. Reaching consensus on the plan took a long time, but it was worthwhile in the end.

## Discussion

Collaborative partnerships have become an increasingly popular way to accomplish ecosystem management and conservation objectives within their social context. Indeed, for ecosystems that span large areas such as longleaf pine, partnerships are essential. I investigated the strategies used by successful partnerships in the longleaf pine ecosystem, and how those strategies can accomplish conservation objectives in that ecosystem. Interviews of participants in these partnerships resulted in five strategies most relevant to conservation objectives in the longleaf pine ecosystem.

These strategies each help address one or more objectives of longleaf pine conservation, and also parallel the recommendations found in other literature on collaborative management (Table 3.2). The strategy of finding common ground among partners helps partnerships achieve success in all objectives. Having a plan can increase the ability of partnerships to demonstrate that a proposed project will benefit multiple entities, which can be especially helpful when applying for funding sources. One example of funding designed to encourage partnerships is the Collaborative Forest Landscape Restoration program, which was recently established by Congress under the

Omnibus Public Land Management Act of 2009 (P.L. 111-1). After successfully working as a group, partnerships can earn credibility and name recognition, which can be beneficial when applying for funding in the future. This strategy directly corresponds to the principle of building on common ground offered by Wondolleck and Yaffee (2000), and Cortner and Moote's (1999) principle that although it may be more difficult to reach a decision collaboratively than unilaterally, doing so will have long-term benefits (Table 3.2). It results in ownership of the problem and process, as pointed out by Wondolleck and Yaffee (2000).

The second and third strategies listed here, information and resource sharing, are particularly helpful for conducting adaptive management on existing longleaf pine habitat. There are opportunities that are specifically designed to help partnerships share knowledge and information. For example, the U.S. Fire Learning Network facilitates the sharing of knowledge regarding the use of prescribed fire, both by bringing representatives from multiple agencies together periodically to share information, and encouraging the development of ecological models and data to inform fire management (Fire Learning Network website: http://www.tncfire.org/training_usfln.htm). Thus, partnerships can take advantage of opportunities that individual entities are less able to leverage. Sharing information relates to the principle that collaboration is best achieved through joint research and fact finding (Wondolleck and Yaffee 2000), and allows decisions to be made according to sound ecological science (Christensen et al. 1996, Table 3.2). Sharing resources was mentioned as an important benefit of collaboration by the GAO's report (2008).

Public outreach and communication with local governments are two important strategies for collaborative partnerships in the longleaf pine ecosystem because lack of public awareness can hinder prescribed burning or land acquisition, meaning that the public can ultimately have a large influence over the conservation of the ecosystem (Mitchell and Duncan 2009). Outreach and education of the public helps improve management on private lands, and can also improve public awareness about prescribed burning. This strategy is similar to principles of public participation, and recommendations about providing economic incentives for implementing management (Gilmore 1997, Table 3.2). Interfacing with local governments helps to accommodate human land uses in balance with ecological goals across a large extent. Interview subjects said that this strategy is essential for long-term planning and sustainability of partnerships. Many authors have discussed integrating social goals and human land use as a foundational principle of ecosystem management (Christensen et al. 1996, Table 3.2, Grumbine 1994).

Interview subjects stated that communicating with the public and local governments can be challenging. To overcome these challenges, public outreach can start small (Wondolleck and Yaffee 2000). Initiating outreach efforts by targeting one or small number of landowners, government representatives, or other citizens who live or work near a core habitat area can be a valuable way to develop a clear, effective message about conservation or management efforts (Meffe et al. 2002). For example, education of those living nearby about the reasons for conducting prescribed burning can go a long way toward changing negative public attitudes toward burning (Toman et al. 2006). Then, that initial experience can inform future, expanded outreach efforts by the partnership.  Landowners or residents with whom the partnership has successfully worked can be a voice to other citizens about the importance of conservation in the landscape. Prescribed fire councils can be particularly effective vehicles for interfacing with local governments about the importance of land use planning and zoning that is compatible with prescribed burning (Coallition of Prescribed Fire Councils website: http://www.prescribedfire.net/).

Offering information on how maintaining good quality longleaf habitat can be economically feasible can be of particular help engaging private landowners in conservation efforts (Van Lear et al. 2005).  Several federal incentives for managing private lands already exist, such as the Natural Resources Conservation Service's Wildlife Habitat Incentives Program (WHIP), and Environmental Quality Incentives Program (EQIP).  These programs provide cost sharing and technical assistance for management of critical wildlife habitat, including burning and other silvicultural efforts. In the future, the potential for income from carbon sequestration credits or harvesting woody biomass, if done sustainably, may serve as an incentive for better forest management by private landowners. Partnerships can focus on making information about these programs available to private landowners.

The strategies suggested here are important for achieving conservation goals in the future.  Outreach to private forest owners is one strategy that is likely to be increasingly important and challenging in the future.  Extensive turnover in forest timberland ownership has recently occurred in the Southeast, and much of the land once owned by the forest products industry was sold to timber investment management organizations (TIMOs) or real estate investment trusts (REITs) (Wear et al. 2007). TIMOs and REITs use timberland as property for investment. Thus, they are more likely than traditional forest products companies to manage strictly for productivity (Jin and Sader 2006), which may preclude their willingness to accomplish other objectives such as promoting biodiversity. In addition, this shift in ownership means that increased parcelization of land is likely in the South: where one large forest products company previously may have owned a single parcel, the same land may now be divided among many TIMOs (Wear et al. 2007). Therefore, a concerted effort at engaging these landowners about conservation using a consistent message will be more likely to be effective than separate efforts by individual partners.

Sharing information about land management is another strategy that is likely to become more important in the future. The potential effects of climate change could make land management more challenging. For example, under some scenarios, warmer, drier climate is predicted in the Southeast, which could lead to quicker drying of vegetation, causing increased mortality of longleaf pines from fires (Varner et al. 2005). Under these conditions, prescribed burning would also be more challenging to implement, with fewer days meeting suitable weather conditions for burning. Researchers and land managers throughout the Southeast can work together to explore the potential impacts of climate change on the longleaf pine ecosystem. Partners can promote controlled experiments to examine the potential impacts of burning in dry conditions, and communication among stakeholders can disseminate this information among researchers and managers.

While partnerships can be effective in accomplishing conservation goals, there are both criticisms and challenges to sustaining the collaborative process. Some have argued that collaboration can lead to a decision that is the “least common denominator” when a consensus-based approach is used (GAO 2008). In addition, partnerships often have organizational challenges.  If they focus their efforts too broadly, they can actually get mired in day-to-day activities and lose sight of big-picture goals because they have insufficient resources to accomplish their objectives (Bonnell and Koontz 2007). Furthermore, although several public federal agencies have policies that mandate collaboration with the public and other stakeholders, there are often barriers to engaging in collaboration that come both from within and outside these agencies (Koontz and Bodine 2008). Challenges such as these make sustaining collaborative partnerships difficult.

Although there can be challenges with sustaining any partnership, the strategies presented here are likely to promote successful partnerships over the long term. Thus, they can inform the efforts of partnerships in the longleaf pine ecosystem, as well as other ecosystems. In particular, engaging a wide variety of partners in conservation efforts toward a common vision, and using that vision as the basis for a consistent message for outreach to private landowners and government agencies ensures a broad base of support for conservation and collaborative decision-making in the long term. Then, future conservation challenges, including climate change and changes in land use and land ownership, can more easily be addressed through a concerted effort among all stakeholders involved.

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## Tables

Table 3.1: The ways in which each collaborative strategy helps address conservation objectives in the longleaf pine ecosystem. ** Indicates predominant objective each strategy addresses.

| Strategies \| Objectives | Adaptive management on existing habitat | Expand and connect habitat | Improve management on private lands | Promote a variety of land uses |
|---|---|---|---|---|
| 1. Find common ground among all partners while leveraging strengths of individual partners | Can leverage money for management via partners who have money | ** Can leverage money for land acquisition through grants that favor partnerships, or through partners who have money | Initial planning process helps partners feel invested in all activities | Initial planning process helps partners feel invested in all activities |
| 2. Facilitate communication and information sharing among partners | ** Sharing knowledge gained through experience, collecting ecological data and modeling future scenarios make management more efficient | Sharing information about landowners who may be willing to sell their land enables more land acquisition | Sharing information about landowners who are willing to promote biodiversity | Communication makes all activities more efficient |
| 3. Establish a mechanism for sharing resources among partners | ** Sharing equipment for burning, especially through an MOU, enables management that would not otherwise be possible | If resources are shared for management, more money or resources may be available for other activities | If resources are shared for management, more money or resources may be available for other activities | If resources are shared for management, more money or resources may be available for other activities |
| 4. Focus on public outreach to landowners and residents via a consistent message | A consistent message to residents about the benefits of fire helps change public attitudes about burning | More landowners may consider land protection options if they are aware of the importance of conservation | ** Education and incentives encourage landowners to conduct compatible management | Residents may be more willing to accept alternative land uses |
| 5. Develop a channel of communication with local governments | Promoting compatible land uses near areas that require burning minimizes risk from prescribed burning and facilitates management | Local governments may decide to acquire land for conservation; may lessen opposition to acquisition by federal, state, or conservation orgs. | Emphasis on long-term planning and sustaining economic priorities may improve relationships with private landowners | ** Helps identify land use decisions that will maximize long-term conservation and economic goals |

Table 3.2: Strategies for collaborative conservation of the longleaf pine ecosystem, and related concepts in the literature.

| Strategy for longleaf | Major related concepts from the collaboration and ecosystem management literature |
|---|---|
| 1. Find common ground among all partners while leveraging strengths of individual partners | Building on common ground: Wondolleck and Yaffee 2000, Meffe et al. 2002<br>Collaborative decision-making: Cortner and Moote 1999<br>Ownership of the problem and process: Wondolleck and Yaffee 2000 |
| 2. Facilitate communication and information sharing among partners | Joint research and fact finding, share knowledge and information: Wondolleck and Yaffee 2000<br>Decisions based on ecological science: Christensen et al. 1996 |
| 3. Establish a mechanism for sharing resources among partners | Leveraging resources, including funds: Government Accountability Office 2008 |
| 4. Focus on public outreach to landowners and residents via a consistent message | Educate the public: Wondolleck and Yaffee 2000<br>Provide incentives: Government Accountability Office 2008, Gilmore 1997 |
| 5. Develop a channel of communication with local governments | Identify and balance a broad range of values: Lee 1993<br>Integrating social values: Rigg 2001; Christensen et al. 1996<br>Accommodating human land use in light of ecological goals: Grumbine 1994 |

**Figure**

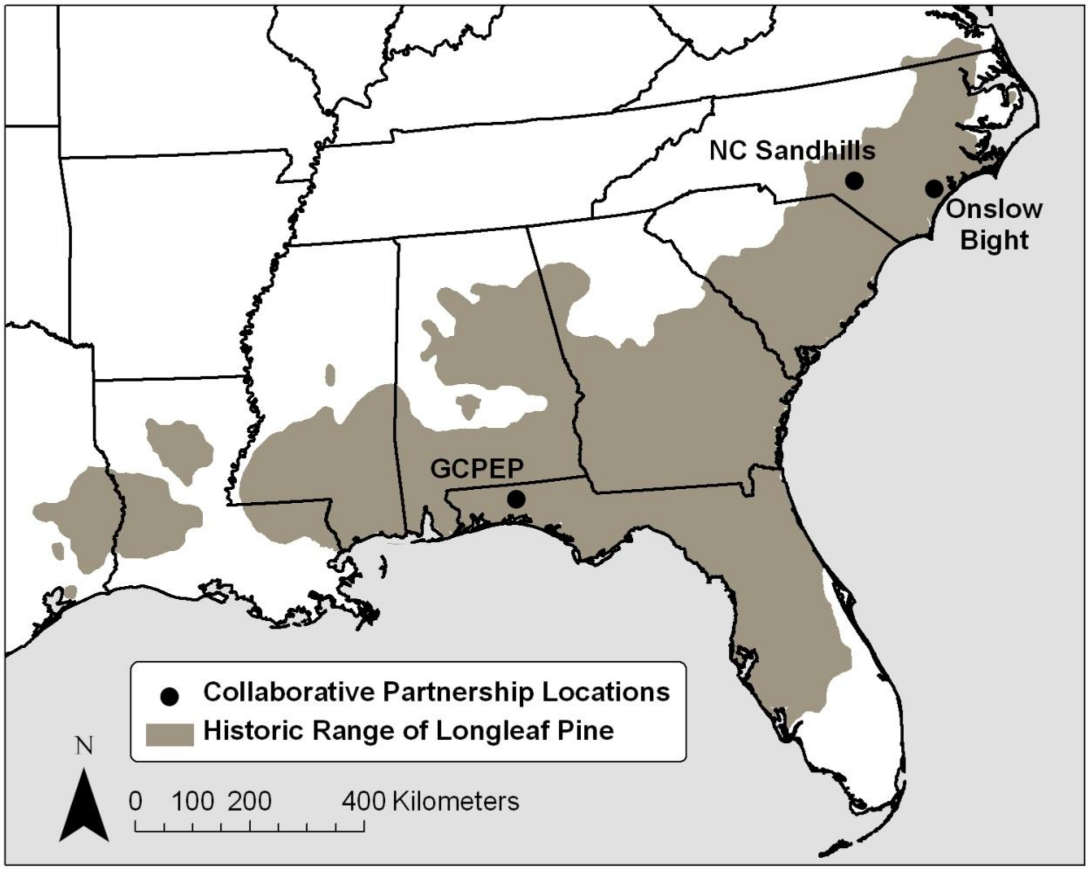


Figure 3.1: Locations of the three collaborative partnerships in which interview subjects participate. Historic range of longleaf pine data came from the U.S. Geological Survey (1999), based on Little (1971).

# CHAPTER 4

# STAKEHOLDER PRIORITIES AND RISK PERCEPTION IN COLLABORATIVE MANAGEMENT OF PRESCRIBED BURNING


## Abstract

Successful ecosystem management depends on the ability to plan for uncertainty and risk. However, research suggests that decisions regarding the use of prescribed fire may be risk-averse, which could present a threat of further degradation to fire-dependent ecosystems. Because multi-agency partnerships increasingly work cooperatively to plan and implement burning programs, it is important to examine how risks influence prescribed burning decisions for various types of stakeholders. Using a survey of individuals involved in the planning and implementation of prescribed fire in the Onslow Bight region of North Carolina, I examined how the constraints and priorities for burning in the longleaf pine ecosystem differed among three stakeholder groups: prescribed burn practitioners from agencies, practitioners from private companies, and non-practitioners. Stakeholder groups did not differ in their perceptions of constraints to burning, and development near potentially burned sites was the most important constraint identified. The top criteria used by stakeholders to decide where to burn were the time since a site was last burned, and a site's ecosystem health. There were no differences among stakeholder groups in the ways in which the ecological benefits of burning influenced decisions, but the groups differed in their perceptions of risks. Prescribed burning priorities of the two groups of practitioners,

and particularly practitioners from private companies, tended to be influenced by risk, especially in sites that have not experienced burning recently or are in the wildland-urban interface. Specifically, my results imply that practitioners view prescribed burning decisions as a choice between a risky alternative with an uncertain outcome (conduct burning) and an alternative whose outcome is certain (do not burn). I suggest that to prevent degradation of fire-dependent ecosystems, partnerships should aim to enable management to operate under a wider range of uncertainty, through public outreach, financial incentives, and changes to agency policies.

**Keywords**

ecosystem management; fire-dependent ecosystem; longleaf pine; management constraints; restoration; risk aversion; wildland-urban interface

## Introduction

The success of ecosystem management depends in part on planning for inherent uncertainty regarding the results of management actions (Christensen et al. 1996, Meffe et al. 2002). Failure to accept uncertainty in management, along with the desire to minimize perceived risks from management actions can lead to a bias toward inaction that can result in few accomplishments in the long-term, and further ecosystem degradation (Stankey et al. 2003, Gunderson 1999). Management decisions regarding prescribed burning of fire-dependent ecosystems may be particularly influenced by risk and uncertainty (Maguire and Albright 2005). For example, there can be short-term risks that prescribed fires will become out-of-control and damage human health or property. In addition, failure to implement burning also carries risk of negative effects from future wildfires. Avoiding short-term damages that could result from prescribed burning may be more compelling to managers than a focus on the ecological benefits of burning, which are realized over the long term (Donovan and Brown 2007). This bias occurs in part because managers and agencies tend to view prescribed burning as a choice between certain and uncertain outcomes, and to over-estimate the certainty of no action (Maguire and Albright 2005). Because of these biases, some researchers have suggested that fire management decisions are risk-averse (Maguire and Albright 2005). However, recent studies have pointed to the need for a comprehensive analysis of how risks versus ecological benefits influence fire management decisions (Donovan and Brown 2007, O'Laughlin 2005). For areas in which prescribed burning is being implemented across large regions with multiple stakeholders involved, it is particularly important to assess the perceptions of risks and benefits among management entities. My study investigates stakeholder priorities for prescribed burning in a fire-dependent ecosystem in order to determine how perceptions of risks and ecological benefits contribute to decision-making.

Increasingly, prescribed burning is being planned and implemented across mixed-use landscapes for large-scale restoration of fire-dependent ecosystems (Hiers et al. 2003, Sisk et al. 2006, Noss et al. 2006). Managers must balance the risks and benefits of fire when deciding where to burn, and these decisions in turn affect the potential for success in large-scale restoration of fire-dependent ecosystems. In addition, constraints such as development near potential burn areas and shortage of trained personnel make it difficult to conduct prescribed burning over ecologically significant extents (Allen et al. 2002, Van Lear et al. 2005, Taggart et al. 2009). In landscapes that contain a mixture of protected areas, residential, and commodity producing lands, prescribed burning is particularly constrained due to the wildland-urban interface (WUI). Fear of liability for damage to human health or property could decrease the likelihood of using prescribed fire, especially because residents in the WUI tend to have negative perceptions of prescribed burning as a management tool (Winter and Fried 2000).

In contrast to relatively independent efforts put forth by individual land managers throughout a region, the formation of regional partnerships among conservation stakeholders are developing in many areas, including within major fire-adapted ecosystems such as ponderosa pine in the US southwest and longleaf pine in the US southeast (Sisk et al. 2006, Compton et al. 2006). These partnerships necessarily include stakeholders whose priorities for burning and perceptions of risk may differ from one another. Stakeholders from public agencies and private conservation organizations may make risk-averse decisions due to systemic biases at higher organizational levels (Maguire and Albright 2005, Christensen 2003). In particular, individual landowners and small, non-industrial private companies who conduct prescribed burning may perceive more risks from burning because they are more directly liable if found negligent. Balancing the risks associated with burning, the ecological benefits of burning, and the risks that may result from not burning presents challenges to decision making in these multiple-stakeholder partnerships. A comprehensive look at how stakeholders make decisions about prescribed burning can shed light on how and why their activities are influenced by perceptions of risks and benefits.

I used surveys to investigate how the perceived risks and benefits of prescribed burning differ among stakeholders in a regional multi-agency conservation partnership, and how these are translated into the prioritization of land for burning across the region. I also compared these prescribed burning priorities with restoration priorities identified by ecologists who have knowledge of the landscape and ecosystem, but who are not directly involved in burning. Specifically, I asked:

1. What factors constrain prescribed burning in a regional landscape of intermixed rural residential, protected areas, and commodity producing lands?
2. Do stakeholder groups differ in the criteria they use to prioritize sites for burning?
3. Do stakeholder groups differ in the extent to which their priorities are motivated by the risks versus ecological benefits of prescribed burning?

I hypothesize that development near prospective burned areas is the most important constraint on prescribed burning, and is also the most important criterion used by all stakeholder groups to prioritize sites for burning. I also predict that prescribed burn practitioners (hereafter "practitioners"), and particularly those from private forestry companies, identify more risks from burning than non-practitioners. Finally, I predict that the priorities of non-practitioners are motivated more by the ecological benefits of prescribed burning than the priorities of practitioners.

## Methods

*Study area*

I conducted my study in the Onslow Bight, a region of the North Carolina (NC) coastal plain (Figure 4.1) where a multi-agency partnership has been established for conservation of longleaf pine, an ecosystem in which prescribed burning is an important management tool (Van Lear et al. 2005). The Onslow Bight covers 1.23 million hectares, from the inner coastal plain to the barrier islands. Prior to European settlement, an estimated 659,000 hectares, or 54% of the landscape was covered in longleaf pine, much of it wet or mesic longleaf pine-wiregrass savanna (Frost and Costanza, unpublished). Other portions of the Onslow Bight were predominantly pond pine pocosin or wet hardwood forest. Today, approximately 19% of the landscape is longleaf pine, 15% is pocosin, and 23% is a mixture of other communities, including bottomland forest, marsh, and coastal dune vegetation (Southeast Gap Analysis Project 2008). Managed pine plantations cover 22% of the Onslow Bight, and 21% is either developed or has been converted to agriculture (Southeast Gap Analysis Project 2008). The twelve counties in the Onslow Bight region had a combined population of 886,000 in 2000 (U.S. Census Bureau 2000). Brunswick County is experiencing one of the highest population growth rates in the United States currently, and three other counties are also in the top 20% of the state for projected future growth (NC Office of State Budget and Management, 2008).

Major public landholdings in the Onslow Bight include US Marine Corps Camp LeJeune (US Department of Defense), Croatan National Forest (US Forest Service), Cedar Island National Wildlife Refuge (NWR, US Fish and Wildlife Service), and several Game Lands (NC Wildlife Resources Commission, NC WRC). Collectively, these comprise 15% of the landscape. Private agencies such as The Nature Conservancy (TNC, 1%) and the NC Forestry Foundation (Hofmann Forest, 3%) also manage land in the Onslow Bight. Since 2000, an average of 40,000 hectares per year of prescribed burning has been conducted in the landscape, mainly on publicly owned land. Land management agencies working in the Onslow Bight differ in their primary goals, which range from management of wildlife habitat, to forestry, to military training. The land management agencies in the region have formed the Onslow Bight Fire Partnership (OBFP) to increase the capacity for prescribed burning in the region, through mutual exchange of resources and knowledge (OBFP, 2005).

*The longleaf pine ecosystem*

In longleaf pine (*Pinus palustris*) savannas and woodlands in the southeastern US, implementation of prescribed burning across landscapes plays a critical role in conservation and management. The longleaf pine ecosystem was once the dominant habitat in the southeastern US along the coastal plain and outer piedmont from Texas to Virginia (Frost 1993). When frequently burned (every one to three years), the understory plant communities in longleaf pine ecosystems have among the highest levels of understory plant species richness of any ecosystem in the world (Peet and Allard 1993). Due to widespread timber harvesting and fire suppression, longleaf forests have been severely degraded and fragmented, reducing this forest type to only 3% of its pre-European settlement range (Frost 1993). As a result, populations of species such as the endangered Red-cockaded Woodpecker (*Picoides borealis*) that depend on longleaf pine habitat have declined (Van Lear et al. 2005). This decline has prompted Noss and others (1995) to designate longleaf ecosystems as "critically endangered", and others to call for large-scale restoration efforts involving prescribed burning to conserve and restore habitat connectivity in the ecosystem (Van Lear et al. 2005, Landers et al. 1995, Hoctor et al. 2006). Partnerships among private and public stakeholders are essential to overcoming barriers to burning and facilitating prescribed burning of longleaf pine ecosystems (Van Lear et al. 2005, America's Longleaf 2009).

*Surveys*

Three stakeholder groups were included in this study: prescribed burn practitioners from agencies, practitioners from private companies, and non-practitioners. Non-practitioners included individuals who provide input to burn managers or fire contractors, but do not directly prioritize or themselves conduct prescribed burning activity. This group included academic researchers as well as botanists, wildlife biologists and others who may work in the same agencies as burn practitioners. The other two groups included agency and private individuals who plan and conduct prescribed burning. Agency practitioners included those who work directly for public agencies or private conservation organizations. Practitioners from private companies included respondents who work for private forestry consulting companies and fire contractors, and who usually conduct burning for individual landowners or small companies such as hunting clubs.

Prior to the survey, three focus groups were conducted during a meeting of the OBFP. A total of fifteen people representing all stakeholder groups participated in the focus groups. Participants were asked to describe the criteria they use to determine which areas get priority for burning, as well as some of the constraints they face when burning. The result was a set of constraints and criteria that are used to determine priorities, which I used as a starting point for developing an in-depth online survey.

The surveys asked respondents to indicate the relative importance of each of a series of predefined constraints to burning that I identified from the focus group discussions. Respondents were also given a list of predefined ecological and non-ecological criteria and were asked to indicate which are important for prioritizing sites for burning, according to their knowledge or experience (Table 4.1). Respondents were then asked follow-up questions regarding the rationales behind their top five ranked criteria. Rationales mentioned during the focus groups were listed as potential answers on the survey, and were related to risks and benefits, as well as other potential reasons for criteria, such as agency mandate and funding sources. Thus, they were related to risks and benefits, but also represented other types of motivations behind decision-making. For all questions, respondents were given an option to add answers not appearing in the predefined list. See Appendix 2 for a sample of questions from the online survey.

For the online survey, the sample population consisted of people who had participated in or been affiliated with the OBFP or the NC Prescribed Fire Council. Email addresses for contacts were obtained through the NC Prescribed Fire Council and the OBFP. The surveys and data collection were administered via Qualtrics, a set of online survey tools including secure data storage and advanced features such as the ability to automatically skip questions that do not pertain to certain respondents (http://www.qualtrics.com). Because my survey population consisted of professionals with access to the Web and email, an Internet survey was well-suited for my study (Dillman et al. 2009).

*Analysis*

Using analysis of variance (ANOVA) tests, I examined the importance value of each constraint, and differences among stakeholder groups in the number of criteria respondents listed as important for burn priorities. I also used chi-square and Fisher's exact tests to examine differences among stakeholder groups for each constraint and each criterion, and to test whether the number of important criteria per individual differed among stakeholder groups. I chose to use ANOVA and chi-square tests rather than multivariate techniques such as factor analysis or structural equation modeling in order to avoid the loss of meaning in data that results multivariate analysis. The follow-up questions in the web survey allowed an in-depth examination of the rationales for each criterion. Because respondents were only asked follow-up questions for criteria they ranked in the top five, I analyzed follow-up questions only for criteria that more than half of all respondents indicated were important. I used an alpha level of 0.05 for all statistical tests. All analysis was done using R (R Development Core Team 2008).

## Results

The online survey was sent to 162 people, including 39 non-practitioners, 67 practitioners representing agencies, and 56 practitioners representing companies. A total of 104 responses were received, 87 of which were complete and included in this analysis. Of these, 26 responses were from non-practitioners (67% of all non-practitioners contacted), 40 from practitioners who represented agencies (60% of agency representatives), and 21 from practitioners who represented private companies (38% of private company representatives). Respondents included 35 respondents from state agencies, 17 from federal agencies, and one from a local government agency. There were 19 responses from independent contractors, and 9 who worked for private companies. The remaining respondents were from academia, or were unemployed.

*Constraints*

The most important constraint for all respondents was the presence of development near areas to be burned (Figure 4.2). Inappropriate weather conditions, smoke management regulations, high fuel loads, and shortage of resources such as money or equipment were also highly ranked. The other six constraints were given lower rankings (Figure 4.2). There was a significant difference in importance across constraint types for all respondents combined (ANOVA: $F_{10,919} = 12.38$, $p < 0.001$).

*Criteria for prioritization*

Respondents added several criteria that were not in the list provided in the survey. In some cases, the additional criteria were restatements of predefined criteria. For example, I considered "presence of a diverse understory" the same as the predefined "overall ecosystem health". There were two criteria added by respondents that were distinct from the list provided in the survey (Table 4.1). The three groups did not differ in the number of ecological criteria used to determine burning priorities, however non-practitioners used significantly fewer non-ecological criteria than the other two groups (see Figure 4.3; ANOVA with Tukey HSD groups: $F_{2,84} = 14.289$, $p < 0.001$). Non-practitioners also used fewer total criteria for determining burning priorities than either group of practitioners (ANOVA with Tukey HSD groups: $F_{2,84} = 3.93$, $p = 0.02$). The two criteria named as important by the highest number of respondents were: (1) the time since a site was last burned, and (2) the overall ecosystem health of a site (Figure 4.4). Other important criteria were: (3) whether a site occurs in the wildland-urban interface (WUI), (4) whether there are firebreaks surrounding a site (5) whether threatened or endangered species (aside from Red-cockaded Woodpeckers) are found at a site, and (6) whether Red-cockaded Woodpeckers occur at a site. For these six criteria, I analyzed the respondents' stated rationales for considering them important. The other four criteria were named by fewer than half of the total respondents (Figure 4.4).

For six out of ten criteria, groups did not differ in the proportion of respondents indicating that the criterion was important (Figure 4.4). These included the two most consistently rated criteria: the time since a site was last burned, and the overall ecosystem health of a site. Of the other four criteria, the location of the WUI ($\chi^2$ (2, N = 87) = 6.70, $p$ = 0.04), the presence of firebreaks ($\chi^2$ (2, N = 87) = 18.48, $p$ < 0.001), and whether the site is managed for timber ($\chi^2$ (2, N = 87) = 15.65, $p$ < 0.001) were rated as important criterion by private practitioners more frequently than the other two groups. Conversely, non-practitioners and practitioners from agencies named whether a site experienced frequent fire prior to European settlement as an important criterion significantly more often than practitioners from private companies ($\chi^2$ (2, N = 87) = 8.44, $p$ < 0.02).

The priority of a site depended on the amount of time since it was last burned, with sites burned two to fifteen years ago having the highest priority (ANOVA with Tukey HSD groups, $F_{6,469}$ = 61.92, $p$ < 0.001). Regardless of stakeholder groups, more respondents said that sites with good ecosystem health are higher priorities for burning than sites with poor health (overall proportions were 69.8% and 30.2%, respectively). Stakeholder groups differed in whether they considered sites within the WUI to be priorities over sites outside the WUI. Compared with practitioners from private companies, a significantly higher proportion of practitioners from agencies focused on sites within the WUI (overall $\chi^2$ (2, N = 43) = 11.478, $p$ = 0.003; agency practitioners and private practitioners Fisher's exact test: N = 33, $p$ = 0.001).

*Rationales*

Of the 36 rationales behind the top six priority criteria that were presented on the survey, 19 were named by more than 33% of respondents who were asked about them.  Seven of these were related to ecological benefits, eight to fire risk, and four to other types of rationales.

Ecological benefits

Rationales implying ecological benefits were related to the time since a site was last burned, overall ecosystem health, the presence of firebreaks, threatened and endangered species, and Red-cockaded woodpeckers.  For all rationales relating to benefits, there were no significant differences among stakeholder groups in the proportion of respondents who considered them important (Figure 4.5).

Fire risk

Four of the rationales related to fire risk showed differences among stakeholder groups in the proportion of respondents who named them (Figure 4.6).  Two of these were related to reduced risk in recently-burned areas.  More respondents from both practitioner groups agreed that fire behavior is more predictable in recently-burned areas (overall $\chi^2$ (2, N = 68) = 13.401, $p$ = 0.001) and smoke management is easier in these areas (overall $\chi^2$ (2, N = 68) = 11.442, $p$ = 0.003).  The other two rationales with differences among stakeholder groups relate to increased risk in the WUI.  Significantly more practitioners from agencies than non-practitioners agreed that fuel buildup in the WUI increases risk of wildfire (overall Fisher's exact test:  N = 43, $p$ = 0.03). Significantly more practitioners from private companies from agencies named the difficulty with smoke management in the WUI (overall Fisher's exact test:  N = 43, $p$ = 0.02).

Other rationales

There were no differences among groups for the four other rationales identified as important by greater than 33% of respondents. Three of these rationales were related to agency goals and mandates: (1) My or my agency's primary goal is to manage for Red-cockaded woodpeckers (named by 76% of respondents); (2) Either my agency or I am mandated to manage for threatened or endangered species (55%); (3) Either my agency or I receive funding to manage for Red-cockaded Woodpeckers (35%). The fourth rationale was related to reducing costs: Burning sites with firebreaks requires less investment (53%).

## Discussion

The coordination of diverse conservation interests into multi-stakeholder cooperative conservation partnerships is an increasingly common model for conservation management (Wondolleck and Yaffee 2000). Several such partnerships have been established to restore fire-dependent ecosystems such as grasslands, longleaf pine and ponderosa pine forests (for example: Compton et al. 2006, McDonald 2002, Romme et al. 2003). Previous studies have suggested that the decisions of fire managers may be risk-averse (Maguire and Albright 2005, Donovan and Brown 2007). However, different stakeholder groups bring different perspectives to decisions about prescribed burning for ecosystem management. In order to better understand multi-stakeholder conservation management decisions, I examined how constraints, priorities, and rationales behind prescribed burning varied among stakeholders in a regional-scale cooperative conservation framework. To my knowledge, my research is the first to examine the prescribed burning priorities of multiple stakeholder groups, and to explicitly examine the rationales behind priorities. My results show that stakeholder groups in the Onslow Bight differ little in their perceptions of the constraints to burning. Development nearby was the most important constraint, indicating that the WUI is the biggest limitation on burning activities. There were some differences among groups in the criteria they use to prioritize prescribed burning. Private practitioners identified the greatest number of important criteria per respondent, but all groups used the same number of ecological criteria to prioritize sites. For the rationales related to ecological benefits of burning, there was no difference among stakeholder groups in the proportion of respondents who named them. Therefore, counter to my expectations, stakeholder groups tend to consider the ecological benefits of fire similarly when making decisions about which areas to burn.

Differences among stakeholder groups in criteria or rationales almost always pertained to risk perceptions. Groups differed in both the degree to which their prescribed burning priorities were influenced by risk, and the way in which risk matters. Both groups of practitioners tend to make decisions about burning that are more risk-averse than those of non-practitioners. Several risk-related rationales were named more often by both groups of practitioners than non-practitioners. In particular, for practitioners, burning recently-burned sites carries less risk than burning non recently-burned sites. This indicates practitioners may experience "certainty bias" (Maguire and Albright 2005). They tend to view decisions about prescribed burning as a choice between a risky alternative (implement burning) and an alternative with a certain outcome (do not burn). In reality, both alternatives present risk. In longleaf pine, as in other fire-dependent ecosystems, burning carries risk of damage to nearby property, harm to human health from smoke, or damage to existing longleaf pine trees if fires become too hot (Varner et al. 2005). Risks associated with not burning include loss of biodiversity, and growth of a dense, flammable woody understory, which can lead to hotter, more damaging fires than the low-intensity fires that occur in frequently-burned stands (Varner et al. 2005, Brockway and Lewis 1997).

While practitioners were more risk-averse than non-practitioners, the two groups of practitioners also differed from one another in how risks associated with the WUI affected their decisions. A higher proportion of practitioners from private companies than agency practitioners considered the WUI an important criterion for determining burning priorities, and assigned a higher priority to sites outside the WUI to avoid smoke management problems. Conversely, agency practitioners and non-practitioners assigned a higher priority to sites inside the WUI. This suggests that practitioners from private companies have a greater tendency to use mental discounting to weight the immediate risks from burning in the WUI higher than the long-term risks of wildfire after fuel accumulation due to not burning (Maguire and Albright 2005).

Because practitioners from private forestry companies generally are under contracts from private individuals and do not own the land they burn, they are likely not as focused on long-term consequences of a prescribed burning regime. Therefore, their focus on avoiding negative consequences in the short-term is not unexpected. Furthermore, recent federal legislation that recommends the use of prescribed burning as a tool to minimize the effects of wildfires may serve to reduce the risk aversion in public agencies (National Fire Plan and Healthy Forest Restoration Act, O'Laughlin 2005). However, with the projected increase in urbanization and decrease in forested area throughout the US (Nowak and Walton 2005), constraints on burning in the WUI are likely to become more widespread, thus increasing the risk of further decline of species that depend on fire-maintained longleaf pine forest.

In order to minimize perceptions of risk in the WUI, one important strategy for partnerships in the ecosystem should be to provide information and facilitate incentives for private landowners to use prescribed burning there. In addition, partnerships should focus on collaboration with communities and local governments to minimize and manage growth near critical natural areas and corridors. Studies have shown that public outreach campaigns can be effective in building public awareness about fire management (Toman et al. 2006). In particular, partnerships can focus on educating people about how prescribed burning can act to lessen the risk of an uncontrolled wildfire. Such an effort could make use of data developed by the Southern Wildfire Risk Assessment, which produced spatial data representing the relative level of concern for wildfires as well as a wildfire susceptibility index for the US Southeast. Either of these data sets could be used to demonstrate to the public the need for prescribed burning by showing where areas of relatively high risk or probability of wildfire occur in a given landscape.

Increased risk perception on sites that have not been burned recently, along with the likely future increase in WUI, has implications for conservation of species that depend on the longleaf pine ecosystem. Many threatened or endangered animal species, including the Red-cockaded Woodpecker, require longleaf pine forests with an open midstory. In addition, there are 16 federally threatened or endangered plant species associated with the longleaf pine ecosystem for which fire suppression is cited as a reason for listing (Van Lear et al. 2005). Improving and increasing habitat for these plant and animal species at ecologically appropriate scales requires re-introducing fire into degraded sites, especially in corridors between core natural areas (Hoctor et al. 2006). However, the constraints on burning in long-unburned sites imply the potential for further degradation of those sites. Such degraded sites may be less attractive for conservation buyers and more prone to being converted to development, which could increase the total area in WUI. Given the constraints on burning in long-unburned sites and in the WUI, reintroduction of fire into long-unburned sites now, before future development takes place, is paramount to enhancing habitat for species that depend on longleaf pine forest.

On the other hand, increased perception of risk associated with burning long-unburned longleaf sites also implies less willingness to accept a longer fire return interval for some sites in any given landscape. This also presents risk to the longleaf pine ecosystem. Although many longleaf pine communities probably burned every 3 years on average prior to European settlement, there were also likely longleaf sites in any given landscape were protected from fires and experienced a longer return interval (Frost 2006). Thus, failing to accept the risks associated with burning less often on some longleaf sites may lead to a loss of important longleaf communities that would have existed with a longer fire return interval.

The perceptions of risk by fire practitioners could play an important role in the long-term persistence of all fire-dependent ecosystems. I found evidence of risk-averse prescribed burning decisions in my study. However, fire management decisions in the US southeast may actually be less subject to risk aversion than in other regions of the US. Several southeastern states have passed laws recognizing the utility of prescribed burning as a land management tool and limiting liability of trained professionals who implement burning (Yoder et al. 2003). In other areas, particularly in the US west, prescribed burners are subject to liability without proof of negligence (Sun 2006). In addition, prescribed fire councils have been established in all southeastern states to promote the appropriate use of prescribed fire and overcome barriers, while only some western states have established fire councils (Coalition of Prescribed Fire Councils: http://www.prescribedfire.net/). Therefore, the potential for risk perceptions to negatively impact fire-adapted ecosystems such as ponderosa pine in the western US may be even greater than for the longleaf pine ecosystem.

This study did not include individual landowners, who can be instrumental in guiding and conducting ecosystem management and restoration (Sisk et al. 2006, Van Lear et al. 2005). Many individual landowners use contractors to conduct their burning, so landowner priorities and rationales to some extent may be reflected in responses given by practitioners from private companies. In addition, an extension of this work should be to incorporate stakeholders from the general public: community groups, government agencies, and other residents with a general interest in conservation. Including those groups could help engage the public and educate residents about the need for fire. To further quantify the potential effects of management decisions on the longleaf pine ecosystem, multi-stakeholder priorities for burning could be modeled spatially in a GIS, and decisions about where to burn under different risk, benefit, and constraint scenarios could be charted for a landscape like the Onslow Bight. Furthermore, a quantitative assessment of the ecological and economic costs that could be incurred by potential wildfires in the absence of prescribed burning should be conducted in order to inform cost-benefit analyses of conducting prescribed burning. More generally, to better inform the prospects for ecosystem management and restoration, ecologists and social scientists need to more fully develop the body of knowledge regarding the social factors that constrain implementation of ecosystem management in practice.

**Conclusions**

As expected, prescribed burning decisions are influenced by perceptions of risk, particularly in the WUI and in sites that have not experienced fire recently. Counter to my expectations, all stakeholders agreed on the ecological benefits of burning. However, practitioners tend to perceive more risks than non-practitioners, and the short-term risks of burning in the WUI affect decisions made by private practitioners most. If the factors that contribute to perceptions of risk persist or worsen, the use of prescribed burning as a tool for ecosystem management and restoration will be in jeopardy. Promoting better land use planning to lessen development in the WUI is one strategy to ameliorate a major cause of risk. In addition, and perhaps more importantly, allowing practitioners to operate under a wider range of uncertainty is critical to minimizing perceived risks, especially in long-unburned areas. Increased acceptance of uncertainty and risk could be achieved via fundamental changes to institutional policies within agencies or management companies, including financial incentives that allocate more resources to burns or other mechanical treatments to reduce fuel loads in high-risk areas. Collaborative conservation partnerships like the Onslow Bight Fire Partnership and prescribed fire councils can be ideal vehicles through which to advocate these changes. When inherent uncertainty in ecological processes and management actions is acknowledged, management decisions can be part of an adaptive learning process that is effective at reversing the decline of degraded ecosystems.

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## Tables

Table 4.1: Ecological and non-ecological burn priority criteria named by focus group participants and used in the online surveys, as well as criteria that were added by survey respondents.

| Criteria |
|---|
| Ecological: |
| Overall ecosystem health of a site |
| Whether a site contains threatened or endangered species |
| Whether a site is habitat for red-cockaded woodpeckers |
| Whether a site experienced frequent fire during presettlement |
| Presence of undesired exotic plants at a site |
| Non-ecological: |
| Time since the last burn on a site |
| Presence of firebreaks at a site |
| Location of the wildland-urban interface (WUI) on or near a site |
| Whether a site is being managed for timber |
| Proximity of a site to other burned sites |
| Added by respondents†: |
| Soil type (1) |
| Potential for pine straw production (1) |

†Number in parentheses indicates the number of respondents who named the criterion.

## Figures

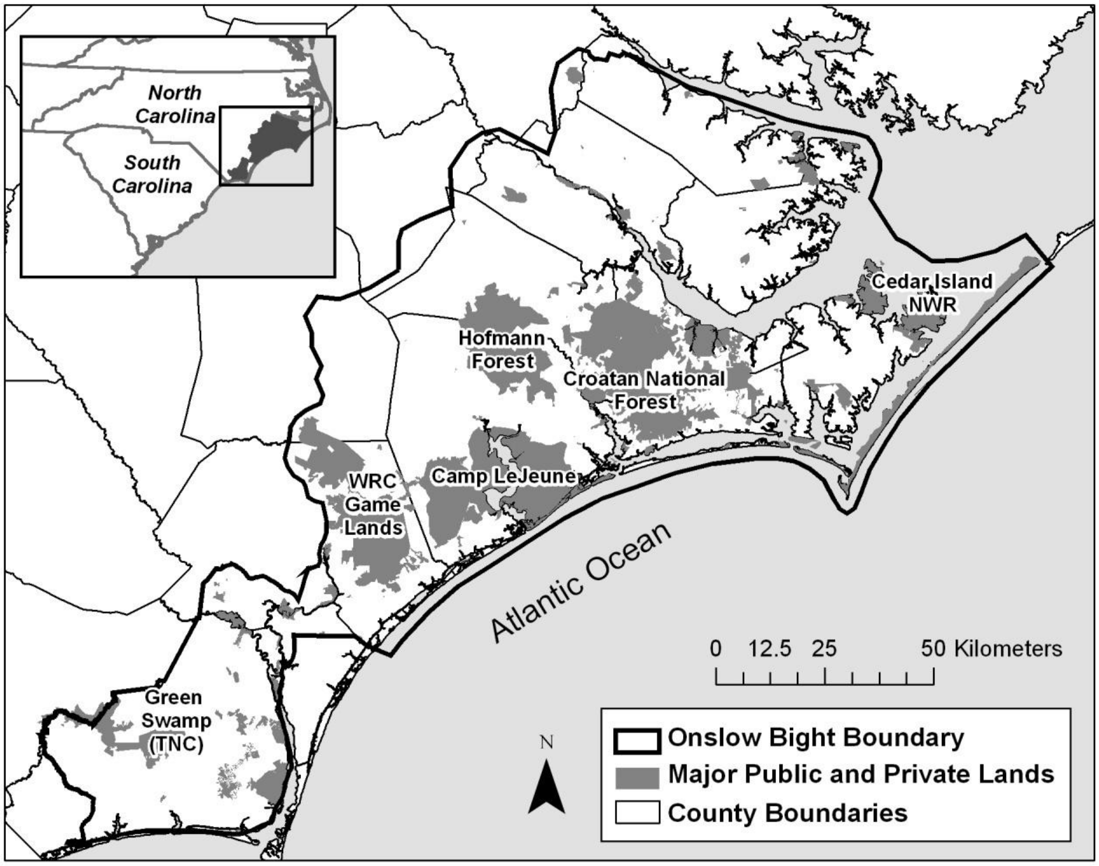


Figure 4.1: The Onslow Bight landscape. TNC stands for The Nature Conservancy, WRC is the North Carolina Wildlife Resources Commission, and NWR means National Wildlife Refuge.


Figure 4.2: Constraints on burning and their mean importance for all respondents.

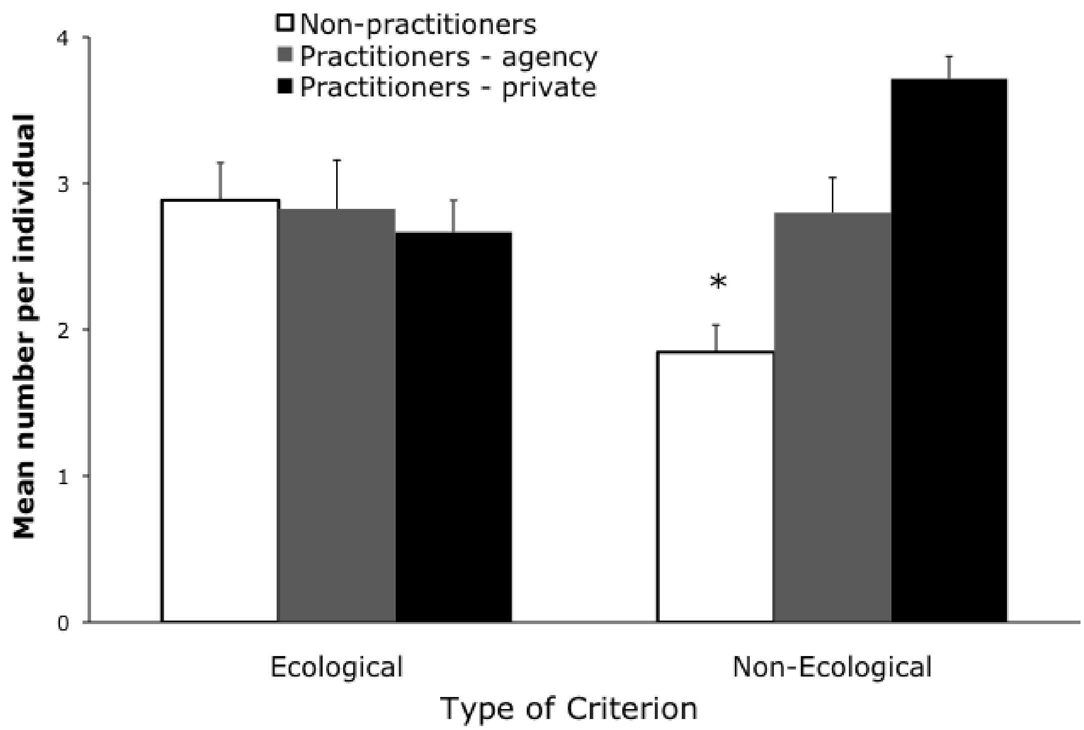


Figure 4.3: Mean number of important ecological and non-ecological criteria named per respondent in each stakeholder group. Asterisk indicates that non-practitioners named significantly fewer non-ecological criteria than the other two groups, according to ANOVA with Tukey HSD groups ($p < 0.05$). Error bars indicate + 1 standard error of the mean.

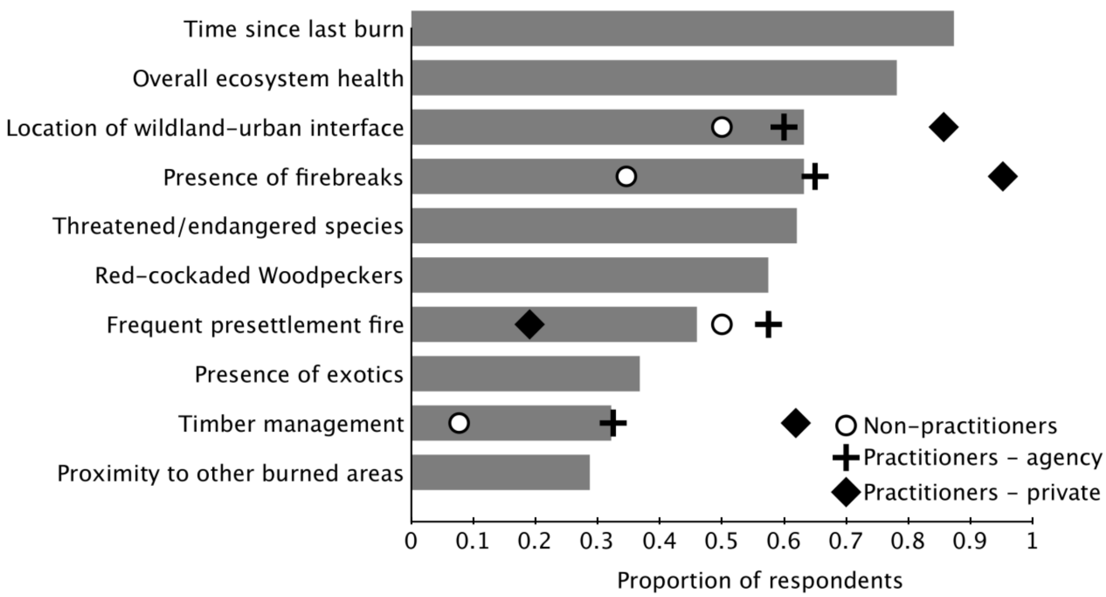


Figure 4.4: Proportion of survey respondents who indicated each criterion is important for determining burn priorities. Bars represent proportions of the overall survey population, while circles, crosses, and diamonds are only shown for criteria that show significant differences among stakeholder groups.

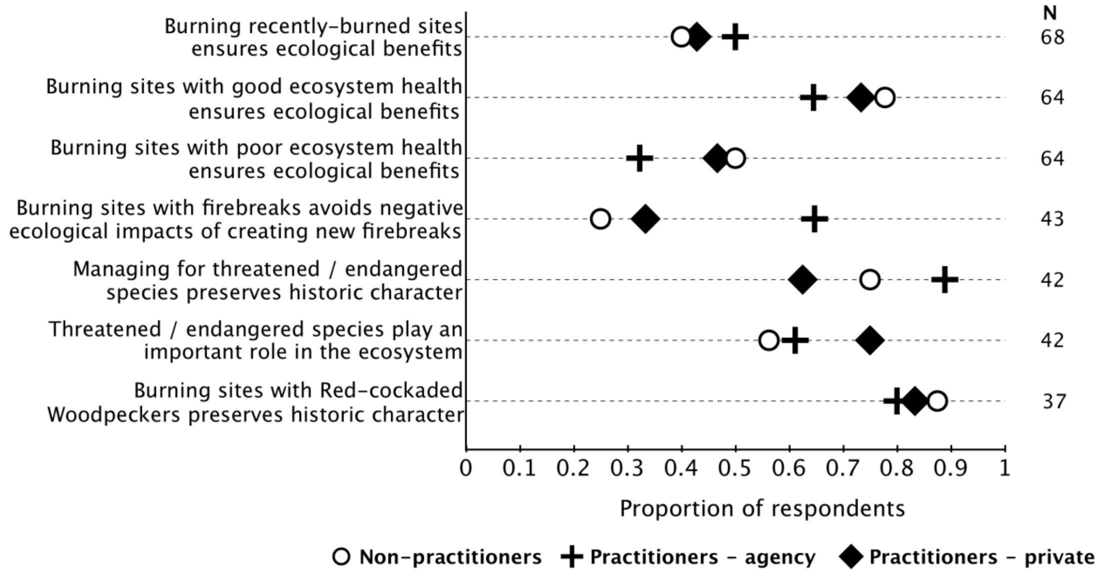


Figure 4.5: Proportion of survey respondents who agreed with each rationale related to the ecological benefits of burning. There were no significant differences among groups for any of these rationales.

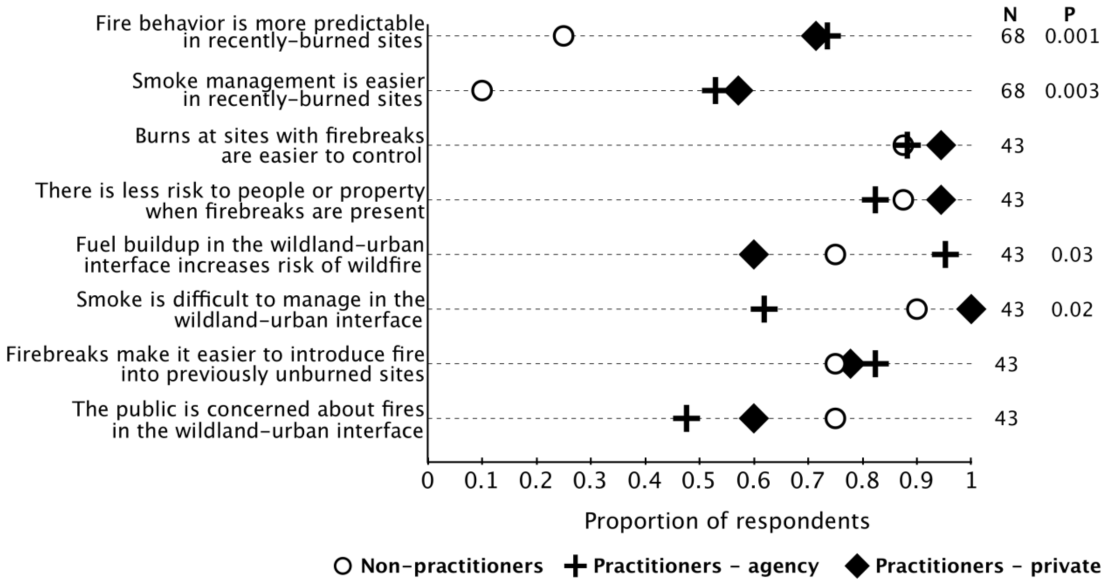


Figure 4.6: Proportion of survey respondents who agreed with each rationale related to the risks of burning. P-values are listed for rationales for which there is a significant difference among stakeholder groups.

# CHAPTER 5

# RISKS, BENEFITS, AND THE POTENTIAL FOR RESTORATION OF A FIRE-DEPENDENT ECOSYSTEM

## Abstract

Scientifically informed conservation and restoration goals do not always align with what is accomplished in practice. This may be particularly true for ecosystem restoration involving prescribed burning. Risk of a prescribed burn becoming out of control, particularly in a landscape that includes human land uses, may lead to risk-averse prescribed burning decisions that result in little restoration accomplished It is important to understand how prescribed burning decisions are influenced by both the potential ecological benefits of burning as well as risk, and which factors contribute to perceptions of risk. I investigated how risks and benefits influenced prescribed burning of the longleaf pine ecosystem by six land-management agencies in the Onslow Bight region of North Carolina. Using GIS and logistic regression, I related prescribed burn records for the period 2004-2007 to criteria that stakeholders in the region had previously said were important for determining priorities for burning. My analysis showed that sites in good ecological condition, containing conservation targets such as Red-cockaded Woodpeckers or other threatened and endangered species, were more likely to be burned than degraded sites. Therefore, prescribed burning focused on maintaining sites in good condition, rather than restoration of degraded sites. Furthermore, prescribed burning was more likely to be conducted on sites that carried less risk because they were easier to burn. In particular, the likelihood of being burned for sites that had gone four or more years without burning increased with distance from developed land. These results suggest that the focus on maintaining sites in good condition may result from increased perception of risks associated with burning long-unburned sites near developed areas. Improving knowledge of the effects of reintroducing fire into long-unburned areas would help reduce uncertainty regarding fire effects in degraded sites.

**Keywords**

ecosystem management; fire-dependent ecosystem; longleaf pine; management constraints; restoration; risk aversion; wildland-urban interface

**Introduction**

Scientifically informed restoration and conservation goals do not always align with what is accomplished in practice, producing the so-called "research-implementation gap" (Knight et al. 2008). The research-implementation gap has been noted, for example, in ecosystem restoration projects using prescribed burning. Prescribed burning is essential for the restoring and maintaining fire-dependent ecosystems (Noss et al. 2006, Landers et al. 1995). In these ecosystems, the ecological benefits of fire include production or maintenance of open habitat (Van Lear et al. 2005), stimulation of seed dispersal and germination (Keeley and Fotheringham 1998), and promotion of local plant and animal diversity (Covington and Moore 1994, Peet and Allard 1993). Where natural fires have become uncommon or are suppressed to avoid damage to human health or property, routine prescribed burning can be used to maintain ecosystem function. Government agencies and conservation organizations find it increasingly difficult, however, to meet stated prescribed burning goals (Christensen 2003). This results in part because of general risk aversion among land managers, particularly for decisions regarding prescribed burning (Stankey et al. 2003). In this study, I use records of prescribed burning in a fire-dependent landscape to investigate how risks and ecological benefits influenced implementation of prescribed fire by management agencies there.

Burning does carry ecological and non-ecological risks. In areas that have not burned recently, accumulation of fuels can result in excessive fire intensity, leading to high plant mortality (Varner et al. 2009), detrimental effects on wildlife habitat (Tiedemann et al. 2000), and an increase in the chance that prescribed fire will get out of control. Thus, land managers may be less inclined to burn degraded sites, possibly reducing the potential area available for ecosystem restoration, or requiring mechanical fuel reduction. In regions that contain a mixture of land uses, implementing prescribed burning can present further risks. Burning near residential or urban development carries short-term risk of damage to human health or property, either from fires becoming out of control or from smoke production (Wade and Mobley 2007). Negative perceptions of fire by the public can increase the difficulty of using prescribed fire near developed areas as well (Winter and Fried 2000). Failure to implement prescribed burning near developed areas also carries risk in the long term, however, because the chance of costly wildfires increases if fuels are allowed to accumulate near developed areas.

Avoiding short-term damages that could result from prescribed burning can be more compelling to land managers than a focus on the ecological benefits of burning, which are realized over the long term (Stankey et al. 2003, Donovan and Brown 2007). This may be in part because managers tend to mentally discount long-term future consequences, weighing the short-term risks from burning higher than the long-term ecological benefits of burning (Maguire and Albright 2005). Managers also may experience “certainty bias”, whereby they are inclined to view prescribed burning as a choice between an alternative whose outcome is certain (do not burn), and one that is uncertain (conduct burning), and over-estimate the certainty of no action (Maguire and Albright 2005). In reality, the choice not to burn carries its own set of risks and uncertainty, including the possibility of a more severe wildfire in the future, or loss of biodiversity. The tendency toward inaction due to risk aversion results in few accomplishments in the long-term, and can bring further ecosystem degradation (Stankey et al. 2003, Gunderson 1999). Therefore, recent studies have pointed to the need for a comprehensive analysis of how fire management is influenced by risks versus ecological benefits (Donovan and Brown 2007, O'Laughlin 2005).

While risk and uncertainty are inherent parts of ecosystem management (Stankey et al. 2005), finding strategies to help managers understand and assess these risks and make better decisions regarding prescribed burning will be crucial for achieving restoration goals. In order to identify and implement such strategies, it is important to better understand which factors influence prescribed burning activities currently. I investigated how perceived ecological benefits and risk-related factors were related to recent prescribed burning in longleaf pine habitat within a mixed-use region of North Carolina. Large-scale restoration and management using prescribed fire in this ecosystem is thus a major conservation goal in the southeastern US (America's Longleaf 2009). However, current rates of prescribed burning may be insufficient to accomplish ecosystem-wide restoration of longleaf pine (Van Lear et al. 2005).

In 2007, I conducted a survey of prescribed burning practitioners in order to determine which ecological and non-ecological criteria were important for setting burning priorities in the landscape (Chapter 4). Here, I examine how those criteria influenced actual burning activities. I used GIS to model the criteria across the region, and logistic regression to relate records of recent prescribed burns from land management agencies to ecological, non-ecological, and both sets of modeled criteria. The relationship between ecological criteria and burning activities will shed light on how ecological benefits influence prescribed burning, while non-ecological criteria allow me to investigate how risks affect burning. Thus, I am able to quantitatively tease apart the relative influences of these risks and benefits on prescribed burning activities. I posed the following two questions relating to the use of prescribed fire to restore longleaf pine within protected areas in a region containing a mix of urban, residential, and commodity-producing lands:

1. Are ecological benefits and risk-related criteria important in determining whether a site is burned?
2. Have recent prescribed burning activities in that region focused on maintaining sites in good condition, or on restoring degraded sites?

I hypothesized that while ecological benefits have some influence, risk-related factors are more important in determining whether a site is burned. Furthermore, I predicted that prescribed burning activities as a whole tend to focus on sites that need to be maintained and thus carry minimal ecological and non-ecological risk from burning, rather than on restoring degraded sites.

## Study system and area

*The longleaf pine ecosystem*

In longleaf pine savannas and woodlands implementation of prescribed burning across landscapes plays a critical role in conservation and management. The longleaf pine ecosystem was once the dominant habitat in the southeastern US along the coastal plain and outer piedmont from Texas to Virginia (Frost 1993). When frequently burned (every one to three years), the understory plant communities in longleaf pine ecosystems have among the highest levels of understory plant species richness of any ecosystem in the world (Peet and Allard 1993). Due to widespread timber harvesting, fire suppression, and development, longleaf pine forests have been severely degraded and fragmented, reducing this forest type to only 3% of its pre-European settlement range (Frost 1993). As a result, populations of plant and animal species that depend on longleaf pine habitat, including the federally-endangered Red-cockaded Woodpecker (*Picoides borealis*) have declined (Van Lear et al. 2005). This decline has prompted Noss and others (1995) to designate longleaf ecosystems as “critically endangered,” and others to call for large-scale restoration efforts involving prescribed burning to conserve and restore habitat connectivity in the ecosystem (Landers et al. 1995, Hoctor et al. 2006).

*The Onslow Bight*

I conducted my study in the Onslow Bight, a region of the North Carolina (NC) coastal plain (Figure 5.1) where a multi-agency partnership has been established for conservation of the longleaf pine ecosystem. The Onslow Bight covers approximately 1 million hectares, from the inner coastal plain to the barrier islands. Prior to European settlement, an estimated 48% of the landscape was covered in longleaf or mixed pine habitat, much of it wet or mesic longleaf pine-wiregrass savanna (C. C. Frost and J. K. Costanza, unpublished data). Other portions of the Onslow Bight were predominantly pond pine pocosin or wet hardwood forest. Today, approximately 19% of the landscape is longleaf pine, 15% is pocosin, and 23% is a mixture of other communities, including bottomland forest, marsh, and coastal dune vegetation (Southeast Gap Analysis Project 2008). Managed pine plantations cover 22% of the Onslow Bight, and 21% is either developed or has been converted to agriculture (Southeast Gap Analysis Project 2008). The ten counties in the Onslow Bight region had a combined population of 653 000 in 2000, and this population is expected to grow 29% by 2020 (NC Office of State Budget and Management [NC OSBM], 2008). In particular, the population of Pender County is projected to increase by 74% by 2020 (NC OSBM 2008).

Major public landholdings in the Onslow Bight include US Marine Corps Camp LeJeune (US Department of Defense), Croatan National Forest (US Forest Service), Cedar Island National Wildlife Refuge (NWR, US Fish and Wildlife Service), and several designated game lands (NC Wildlife Resources Commission, NC WRC). Collectively, these comprise 15% of the landscape. The Nature Conservancy (TNC, 1%) also manages land in the Onslow Bight. Land management agencies working in the Onslow Bight differ in their primary goals, which range from management of wildlife habitat, to forestry, to military training. All of the major land management agencies in the region have joined to form the Onslow Bight Fire Partnership (OBFP) to increase the capacity for prescribed burning in the region, through mutual exchange of resources and knowledge (OBFP 2005).

## Methods

### *Collection of prescribed burn data*

I compiled GIS data delineating the locations of prescribed burn compartments and prescribed burns conducted between 1989 and 2007 from the six land-management agencies that conduct the majority of burning in the Onslow Bight: Camp LeJeune, Croatan National Forest, Cherry Point, Cedar Island NWR, NC WRC, and TNC. Burn compartments represent land parcels that are managed by an agency as a single unit for burning but have not necessarily all been burned. I used soil survey data (SSURGO) (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture 2008) to select burn compartments that are predominantly on soils with relatively low organic matter content, as these soils can support longleaf pines. This allowed me to identify land that currently support longleaf pine communities or that could be restored to longleaf. The result was a set of 698 prescribed burn compartments covering a total area of 52,226 hectares across the region. I used burn compartments to represent sites for which burning decisions are made.

In addition to the six agencies listed above that conduct prescribed burning on conservation land in the Onslow Bight, other entities such as the North Carolina Division of Forest Resources and several small contractors conduct prescribed burning on privately-owned lands in the region. However, the spatial accuracy of their burn records was unsuitable for this analysis. There are limited geographically-coded records of wildfires, and the majority of these were in pocosin vegetation, not longleaf. So wildfire data were not used in this analysis.

Records of prescribed burning were in the form of GIS polygon data delineating burned areas from 1989 - 2007, which fell within but were not necessarily contiguous with burn compartment boundaries. While some prescribed burning was conducted before 1989, the majority of burning in longleaf pine ecosystems began in the late 1980s and early 1990s (Pyne 1997). Therefore, the majority of prescribed burning history in this landscape is likely captured in the records I compiled. Because results from previous surveys of stakeholders indicated that a site's burn history over the previous 15 years was an important criterion for determining whether a site would be burned, I used records for those years that were preceded by at least 15 years of burn history data (2004 – 2007) as the response variable in regression analysis. For this response variable, for each year during the period 2004 – 2007, I labeled a burn compartment as "burned" for a given year if 50% or more was burned. By requiring half or more to be burned, I maximized the likelihood that burn compartments I designated as "burned" corresponded to actual management decisions made, and were not the result of nearby fires burning into adjacent burn units. I used the full history of prescribed burning, beginning in 1989, to create a set of predictor variables, as discussed below.

*Spatial analysis of prescribed burn criteria*

I previously surveyed stakeholders in the Onslow Bight landscape to determine how the characteristics of a given site affect decisions about whether or not to burn that site (see Chapter 4 for a full description of the survey design and results). The survey listed a set of ecological and non-ecological site characteristics (Table 5.1), and asked respondents to indicate whether they use those characteristics as criteria to decide whether a site has priority for prescribed burning. Ecological criteria relate to conservation targets or objectives, while non-ecological criteria relate to other factors that influence burning, such as those that make sites easier to burn. Ecological criteria that were important were: ecosystem health of sites, whether a site had experienced frequent presettlement fire, whether a site contained habitat for red-cockaded woodpeckers, and the location of other threatened or endangered species. Non-ecological criteria were: the location of firebreaks, a site's proximity to other burned areas, timber management activities on a site, the time since a site was last burned, and the location of the wildland-urban interface.  I developed spatial data representing these ecological and non-ecological criteria as predictors in my analysis. I used a variety of existing GIS data sets to model these criteria across the region based on how survey respondents described them (see Table 5.1 for data and sources). The only criterion used by stakeholders that I excluded from analysis was the presence of invasive species. A comprehensive assessment and mapping of invasive species locations has not been done in the region, and the spatial accuracy of locations that have been mapped is poor (M. Buchanan, NC Natural Heritage Program, pers. comm.).

I used records of prescribed burning to create three burn history criteria defined by stakeholders as important for determining whether a compartment should be burned in any given year (Table 5.1). First, for each burn compartment, I determined the number of years since the previous burn. I used burn records for the period 1989 – 2006 to calculate the time since the previous burn for compartments as of 2007. Similarly, I used burn records through 2005 to calculate time since burn for 2006, and likewise for 2005 and 2004. Second, I calculated the number of times each burn compartment burned over the ten years prior to each year from 2004 to2007. Third, for each given year (from 2004 to 2007), I calculated the distance from each burn compartment to the nearest site that had been burned in the previous five years. These metrics each varied for any given burn compartment over the recent four-year period 2004 – 2007 (Table 5.1).

The rest of the metrics used as predictor variables were derived from static GIS data; therefore, their values were consistent for any given burn compartment over the four-year period (Table 5.1). To model each burn compartment's ecosystem health, I used metrics related to canopy and midstory cover derived from LiDAR data collected in 2001 (Breckheimer et al., unpublished) and calculated the mean values within each burn compartment. I used road and stream data to delineate firebreaks in the landscape, and calculated the minimum distance from each burn compartment to each of these. In addition, survey respondents said they use locations of Red-cockaded Woodpecker nesting sites, also known as "clusters", and foraging habitat to determine whether sites are burned. I used NC Natural Heritage data to calculate the distance from burn compartments to the nearest active and inactive clusters. Using data from a recent study by Breckheimer et al. (unpublished) that delineated woodpecker foraging habitat, I calculated the proportion of each burn compartment that contained this habitat category. I also used data and publications from the NC Natural Heritage Program to calculate each burn compartment's minimum distance to known occurrences of threatened or endangered plant and invertebrate species whose habitat depends on fire.

I calculated the minimum distance from each burn compartment to managed pine plantations in 2001 as mapped by the Southeast GAP Analysis Project (Southeast Gap Analysis Project 2008). To define the wildland-urban interface (WUI) I calculated the minimum distance from each burn compartment to any developed land class mapped in the 2001 National Land Cover Database (Homer et al. 2007) for burn compartments. All of these data layers were produced in raster format, with a resolution of 30 m. All GIS operations were performed in ArcGIS 9.3.1 (Environmental Systems Research Institute [ESRI] 1999-2010).

*Statistical analysis*

I used logistic regression to test whether and how ecological and non-ecological criteria were associated with actual prescribed burning activities. The response variable was the binary variable indicating whether each burn compartment was burned or unburned each year over the period 2004 –2007. Hereafter, burn compartments are referred to as "sites". Modeled prescribed burn priority criteria were used as predictor variables. Most of these criteria were continuous variables, with the exception of the time since last burn, which was treated as a categorical variable (see Table 5.2). To explain the incidence of burning, I constructed three different models including the pool of variables related only to ecological criteria, variables related only to non-ecological criteria, and a full model including all variables. Using ecological variables only, I could examine whether burning was focused on maintaining sites in good ecological condition, or on restoring degraded sites. Using only non-ecological variables allowed me to examine the relative influence of non-ecological risks on prescribed burning. The full model allowed me to determine whether these variables acted together to influence recent burning activities.

Because the burn status of sites was followed over time, the data in this study consist of repeated measurements on the same site, as well as separate measurements on different sites. A design such as this can lead to correlation among observations coming from the same site. For example, a site's burn status in a given year can affect the decision to burn in following years. To properly account for this correlation I ultimately used the method of generalized estimating equations (GEE) to fit a marginal (population averaged) model to the data (Zeger et al. 1988). However, I began by using generalized linear models (GLM) and generalized additive models (GAM), which do not account for this correlation, because these allow more flexible model selection that incorporates examination of non-linear relationships, and higher-order interactions among variables. I fit a GLM using a binary distribution and all possible ecological predictor variables. I conducted model selection manually, systematically examining all possible combinations of linear predictors and using change in AIC as the determinant for model selection. Because the pool of possible predictors came from criteria that burn practitioners had said were important, there was a low risk of fitting a model using a set of predictors that was not meaningful.

Before deciding on the optimal GLM, I looked for non-linear relationships by fitting a GAM using smoothed splines for each of the predictors. If the GAM suggested a higher-order relationship for any predictor, appropriate terms were added to the GLM model, and a change in AIC test was conducted to make sure the added term was significant. I also checked for statistically significant interactions between any two variables, and included those interactions only where ecologically meaningful.

When I had determined the optimal model using GLM, I used GEE to fit a model to the data using the set of predictors. When a nonlinear link function is used in a GLM, as was the case here where a logit link was coupled with a binomial response, a method such as GEE that estimates the population model directly is preferred over fitting a conditional (mixed effects) model (Fieberg et al. 2009). In GEE, a working correlation structure is incorporated in an estimating equation from which point estimates of parameters and robust measures (sandwich estimates) of their uncertainty are obtained. These sandwich estimates are typically much larger than the standard errors that are obtained from a GLM under the assumption of independence. Therefore, I used GEE to further screen predictor variables that were significant in the GLM. I chose the optimal working correlation structure from among independent, exchangeable, AR(1), or unstructured on the basis of the goodness of fit metric called the “quasi-likelihood under the independence model information criterion” (QIC) (see Hardin and Hilbe 2003 for an explanation of various working correlation structures and QIC). Correlation structures that yield lower QIC values are preferred.

I repeated the model selection steps outlined above to select a model using only non-ecological criteria. After fitting the optimal GEE and selecting the appropriate correlation structure for the non-ecological model, I sought to reduce the number of categories in the variable representing the number of years since last burn. The initial variable had eighteen categories, making its effects in the model difficult to interpret. A visual inspection of the effect of time since last burn on the probability of a site being burned for the optimal model suggested at least three categories for this variable: 1-3 years, 4-5 years, and > 5 years since burn, with the latter category showing no discernable difference from zero (Figure 5.2). I fit GEE models with various combinations of years since last burn and compared them using $QIC_u$, a modified version of AIC that can be used with GEE (Hardin and Hilbe 2003). In $QIC_u$, the likelihood has been replaced by a quasi-likelihood criterion, and the model with the lowest $QIC_u$ is preferred. A comparison of $QIC_u$ values indicated that dividing the first category into two was preferred. Therefore, the four categories of time since last burn in the optimal model were: 1 year, 2-3 years, 4-5 years, and > 5 years.

Beginning with the pool of predictors that were significant in each of the first two models, I used the same model selection approach to select a model that incorporated both ecological and non-ecological variables. I compared the optimal model for each of the three pools of predictors using $QIC_u$. To discriminate between model predictions of incidence versus non-incidence of burning, I used the minimized difference threshold (MDT) as a cutoff value. The MDT has been recommended for use in ecology when under-prediction and over-prediction (errors of omission and commission) are equally undesirable (Jimenez-Valverde and Lobo 2007). This threshold minimizes the difference between sensitivity and specificity, or true positive and true negative rates, thus giving an equal chance to errors of commission and omission. All statistical analyses were done using R software (R Development Core Team 2009), along with the contributed packages mgcv (Wood 2006), geepack (Halekoh et al. 2006), and ROCR (Sing et al. 2005).

**Results**

On average, during the period 2004 – 2007, the six management agencies burned 8256 hectares of longleaf pine habitat annually (16% of longleaf pine sites; see Table 5.3). Model selection using QIC resulted in optimal models and correlation structures using each of the three pools of predictors (Table 5.2). An exchangeable correlation structure in which incidence of burning was negatively correlated among years was selected for the GEE model using ecological predictors, according to QIC. For the models incorporating either only non-ecological predictors or both sets of predictors, an unstructured correlation was selected by QIC. In the latter two models, probability of burning in 2004 and 2007 was positively correlated, but among all other pairs of years was negatively correlated. This correlation structure accounts for the fact that when a site is burned, it is less likely to be burned the next two years, but more likely to be burned after three years.

The model using non-ecological criteria performed better than the model with ecological criteria (AUC = 0.71 and AUC = 0.68, respectively, Figure 5.3). The model with both criteria performed better than each of the other two (AUC = 0.74, Figure 5.3), and was selected over the other two based on $QIC_u$. In addition, the model with both sets of predictors had the highest values of sensitivity and specificity (0.67), compared with the other two models (Table 5.4).

I used the coefficients from the models with ecological and non-ecological predictors to calculate odds ratios, or the factor change in odds of being burned with a specified unit change in the value of a predictor (Figures 5.4 and 5.5; see Appendix 3 for coefficient estimates). In the model with ecological predictors, for every 1 km farther away from an active Red-cockaded woodpecker cluster, odds of burning decreased significantly by a factor of 0.92 (Figure 5.4). Similarly, odds of burning a site decreased significantly for sites farther from threatened and endangered species of plants and invertebrates, and with increased midstory cover. Sites that were farther from inactive Red-cockaded woodpecker clusters had increased odds of being burned, and the relationship was quadratic, so this increase was significant only for sites beyond 10 km from inactive clusters. Sites with higher canopy cover had significantly increased odds of being burned as well.

Of the non-ecological predictors that were significant, odds of burning decreased with the amount of timber on a site, the portion of a site that had never been burned, and with distance from a recent burn (Figure 5.5). Odds of burning increased with area of sites, and with distance from a road. There was a significant interaction between distance from development and the time since a site had last been burned. The effect was significant for sites that had last been burned 4-5 years prior only. In that category of time since burn, sites that were further from development had a higher probability of burning (Figure 5.6). Probability of burning also increased with distance from development for sites that had burned greater than five years prior, but the effect was not significant in that case.

The full model with both sets of predictors had coefficients that were similar to those of the other two models (see Appendix 3), and thus the odds ratios of predictors are similar. However, in the full model, the distance from threatened or endangered species was no longer a significant predictor, and distance from inactive woodpecker clusters no longer showed a quadratic relationship (Table 5.2).

**Discussion**

Results from this analysis indicate that both ecological and non-ecological factors were associated with recent prescribed burning. A consideration of the optimal model incorporating ecological criteria alone, without non-ecological risk factors, shows that sites in better ecological condition were more likely to be burned. Sites that were closer to active Red-cockaded Woodpecker clusters and threatened or endangered species occurrences, those that were farther from inactive clusters, and those with lower midstory cover had increased odds of being burned. Many of these variables are likely correlated across the landscape. For example, active woodpecker clusters are found in sites with low midstory cover. These results indicate that prescribed burning was more likely to be used in sites that required maintenance of good habitats, rather than for ecological restoration on degraded sites.

Statistical results for the model including only non-ecological criteria indicate a decreased likelihood of burning on sites that presented more risk to burning. Sites with a smaller portion that was previously unburned, those that were farther from roads, and those that were closer to other recent burns were more likely to be burned. Proximity to recently burned sites could be important for several reasons. First, burning near recently burned sites poses less risk if a fire becomes out of control because recently burned sites have less fuel accumulation. In addition, it could be easier to burn sites adjacent to recently burned sites because firebreaks would already be established.

In addition, sites that had not been burned for at least four years showed an increasing likelihood of prescribed fire with increasing distance from development. In longleaf pine ecosystems, herbaceous plant growth and pine needle accumulation in the understory, along with infill of woody plants in the midstory, increases with the time since last burn, leading to a build-up of fuels. Therefore, the time since a site was last burned can be thought of, in part, as a proxy for understory and midstory fuel buildup. Past studies have emphasized limitations to burning near development (in the so-called wildland-urban interface [WUI]) in longleaf pine ecosystems and in others (Wade and Mobley 2007, Winter and Fried 2000, Taggart et al. 2009). While my results agree with these past studies, they highlight that the influence of the WUI on burning depends on the condition of sites in the WUI. The distinction shown in my results between recently- and non-recently burned sites indicates that not all sites are difficult to burn in the WUI.

The results of this study suggest that the prescribed burning decisions made by land managers are guided by both ecological benefits and non-ecological risks. Land managers may avoid burning on ecologically degraded sites as a result of mental discounting (Maguire and Albright 2005). They likely weigh the lower short-term risk from burning sites in good condition over the longer-term ecological benefits that would result from burning degraded sites. Furthermore, the interaction between distance from development and the time since sites were last burned suggests that land managers use both mental discounting and certainty bias together to assess risk and determine which sites to burn. Implementing burning on sites that have not been burned recently carries risk of uncertain outcomes, including unanticipated fire effects and more intense fires than on sites that have been recently burned. Therefore, certainty bias may cause land managers to weigh the certainty of inaction on these sites higher than the uncertain outcomes from conducting burning. Moreover, when a site that has not been burned is near urban or residential development, managers may use mental discounting to consider the more immediate risk of a prescribed burn becoming out of control and destroying property higher than the risk of destruction due to a catastrophic wildfire in the future after further fuel accumulation.

Results from modeling suggest that increased risk of a prescribed burn becoming out of control when burning in degraded habitat (i.e. that has not been burned recently) makes burning there less likely. While the use of prescribed burning to maintain good habitat is important, restoration of additional longleaf pine habitat is essential for large-scale conservation of the ecosystem (America's Longleaf 2009). Less than 10% of the existing longleaf pine habitat is in a condition sufficient to support most of its native plant and animal species (Frost 2006). There are 16 federally threatened or endangered plant species associated with the longleaf pine ecosystem for which fire suppression is cited as a reason for listing (Van Lear et al. 2005). In addition, many threatened or endangered animal species, including the Red-cockaded

Woodpecker, depend on the open midstory that results from frequent burning. Improving habitat for these plant and animal species at ecologically appropriate scales requires re-introducing fire into degraded sites, especially in corridors between core natural areas (Hoctor et al. 2006).

Restoring the longleaf pine ecosystem will require reintroducing fire into sites that have never been burned, or have not been burned recently. It is on these sites that burning is most influenced by proximity to development. In the US, development adjacent to protected areas is projected to increase in the future (Wade and Theobald 2009); thus any risks from burning near development are likely to worsen. Therefore, increasing restoration will require decreasing the risks from burning near development. Working with local communities to promote development away from areas that need to be restored would be one way to help encourage future developments to be compatible with prescribed burning. In addition, increasing public awareness of the benefits of fire through outreach to local communities can alleviate negative perceptions of burning and help facilitate large-scale restoration with prescribed burning (Mitchell and Duncan 2009, Toman et al. 2006).

Increasing scientific knowledge of the effects of fire reintroduction on degraded sites would go a long way to reducing uncertainty, and thus help clarify the risks of burning those sites. For example, one important negative effect of reintroducing fire into degraded pine ecosystems is the potential for increased overstory tree mortality. Recent studies of the effects of fire reintroduction into longleaf pine and ponderosa pine (*Pinus ponderosa*) forests suggests that increased tree stress and mortality is linked to smoldering combustion of forest floor organic matter (Varner et al. 2005, Stephens and

Finney 2002). However, more work remains to be done to determine the mechanisms behind this effect, the weather and moisture conditions under which it occurs, and the land management practices that would prevent such mortality, such as mechanical treatment prior to burning (Varner et al. 2009).

Results from logistic regression indicate that both ecological and non-ecological variables were associated with recent prescribed burning activity in the Onslow Bight. Of the two models including only one set of predictors, the model with non-ecological predictors performed better than the model with ecological predictors. These results suggest that as a whole, the potential ecological benefits of burning were not as important in determining which sites in the region were burned as non-ecological risk-related criteria.

However, the model incorporating both non-ecological and ecological variables performed best overall and indicates that ecological risks of burning degraded sites, as well as risks to human health or property, both influenced whether sites were burned. This model had an AUC of 0.74, indicating that it can correctly distinguish burned versus unburned areas approximately three-quarters of the time. Thus, the model could be improved. One set of predictors that is missing from this study and could be added relates to factors that constrain burning on a day-to-day basis. Limited resources, including personnel and equipment, and unsuitable weather conditions often constrain the amount of burning a single agency or group of agencies can conduct (Chapter 4). These constraints could be incorporated into a more sophisticated modeling framework. Furthermore, to extend the current study, the statistical relationships found could be used to model future likelihood of burning on degraded sites, given projected changes of some variables, such as urban growth. These projections would further inform the strategies that should be used now to ensure that management activities can achieve ecosystem restoration goals.

## Conclusions

Scientific literature recommends the use of prescribed burning for restoration of the longleaf pine and other fire-dependent ecosystems using prescribed fire, and conservation organizations and government agencies have stated restoration as a goal. However, my results highlight the fact that despite this goal of restoring degraded sites, prescribed burning activities tend to focus on maintaining sites that are in good condition and have been burned regularly. This focus is probably because land managers tend to focus on sites where burning poses less risk. In particular, my results suggest that risks posed by proximity to development are important in determining whether degraded sites are burned. The more proximate causes of these risks – development patterns combined with fuel buildup – are important to overcome. However, finding ways to overcome the less proximate causes, including public perception of burning and risk-averse attitudes within management agencies, may be just as important for improving likelihood of restoration in the long term.

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## Tables

Table 5.1: Criteria for decisions about prescribed burning, and corresponding predictor variables used in this analysis.

| Criterion | Predictor variable | Source | Varies by yr |
|---|---|---|---|
| **Ecological:** | | | |
| Ecosystem health | % Canopy cover, 2001 | LiDAR (Breckheimer et al. unpublished) | |
| | % Midstory cover, 2001 | LiDAR (Breckheimer et al. unpublished) | |
| | Number of prescribed burns in 10 years prior | Prescribed burn records | X |
| Frequent presettlement fire | Soils that may have supported wet or mesic longleaf pine | Crosswalk of SSURGO soils (Frost and Costanza, unpublished) | |
| Red-cockaded Woodpeckers | Locations of active clusters (nesting areas), 2001 | NC Natural Heritage Program | |
| | Locations of inactive clusters (nesting areas), 2001 | NC Natural Heritage Program | |
| | Location of foraging habitat, 2001 | LiDAR (Breckheimer et al. unpublished) | |
| Threatened/ endangered species | Locations of threatened or endangered plants and animals that depend on fire | NC Natural Heritage Program; Invertebrates: Hall and Schafale (1999); Plants: Buchanan and Finnegan (2008) | |
| **Non-ecological:** | | | |
| Firebreaks | Road locations | NC Department of Transportation | |
| | Stream locations | NC Center for Geographic Info. and Analysis | |
| Firebreaks / proximity to other burned areas | Recently burned areas (within the last 5 years) | Prescribed burn records | X |
| Timber | Location of managed pine plantations, 2001 | Southeast Gap Analysis Project (2008) | |
| Time since last burn | Number of years since last burn | Prescribed burn records | X |
| Wildland-urban interface | Location of developed land, 2001 | National Land Cover Database (Homer et al. 2007) | |

Table 5.2: List of all variables included as predictors, and results of Wald tests for significance of variables used in three optimal multiple regression models[a]. The p-values indicate the significance of each predictor when it is added to a model containing all variables listed above it.

| | Ecological | | Non-ecological | | Both | |
|---|---|---|---|---|---|---|
| Predictor variables[b] | $X^2$ | *p* | $X^2$ | *p* | $X^2$ | *p* |
| Dist from active woodpecker clusters | 7.4 | 0.007 | | | 8.0 | 0.005 |
| Dist from inactive woodpecker clusters | 27.5 | < 0.001 | | | 24.7 | < 0.001 |
| Dist from T&E Species | 19.3 | < 0.001 | | | n.s. | |
| Midstory cover | 66.7 | < 0.001 | | | 78.1 | < 0.001 |
| Canopy cover | 20.8 | < 0.001 | | | 28.6 | < 0.001 |
| Dist from inactive woodpecker clusters^2 | 16.2 | < 0.001 | | | n.s. | |
| Prop. experiencing freq. presettle. fire | n.s. | | | | n.s. | |
| Prop. woodpecker foraging habitat | n.s. | | | | n.s. | |
| Number of burns in last 10 years | n.s. | | | | n.s. | |
| Area (ha) | | | 10.7 | 0.001 | 5.6 | 0.01 |
| Time since last burn[c] | | | 147.6 | < 0.001 | 62.6 | < 0.001 |
| Dist from road | | | 36.2 | < 0.001 | 39.6 | < 0.001 |
| Prop. In managed timber | | | 5.0 | 0.03 | 6.1 | < 0.001 |
| Prop. Never burned | | | 38.7 | < 0.001 | 15.6 | < 0.001 |
| Dist. From recent burn | | | 18.3 | < 0.001 | 17.2 | < 0.001 |
| Dist. From development | | | 12.3 | < 0.001 | 24.2 | < 0.001 |
| Dist. from develop. : Time since last burn[b] | | | 23.5 | < 0.001 | 20.8 | < 0.001 |
| Dist. from stream | | | n.s. | | n.s. | |

[a] "n.s." indicates the variable was included in the pool of possible predictors for a given model, but was not included in the optimal model.

[b] “Prop.” stands for proportion. “Dist.” stands for distance.

[c] Indicates a categorical variable.

Table 5.3: Area and percent of longleaf pine sites treated with prescribed burning by the six management agencies in the Onslow Bight, during each the four years of analysis.

| **Year** | **Area (ha)** | **Percent** |
|---|---|---|
| 2004 | 7423 | 14% |
| 2005 | 8134 | 16% |
| 2006 | 8433 | 16% |
| 2007 | 9035 | 17% |

Table 5.4: Confusion matrices for optimal models using only ecological, only non-ecological, or both sets of predictors.

**Ecological predictors: threshold = 0.16; sensitivity and specificity = 0.63**

| | Observed | | |
|---|---|---|---|
| Predicted | False | True | Total |
| False | 1505 | 151 | 1656 |
| True | 877 | 259 | 1136 |
| Total | 2382 | 410 | 2792 |

**Non-ecological predictors: threshold = 0.18, sensitivity and specificity = 0.64**

| | Observed | | |
|---|---|---|---|
| Predicted | False | True | Total |
| False | 1527 | 148 | 1675 |
| True | 855 | 262 | 1117 |
| Total | 2382 | 410 | 2792 |

**Both sets of predictors: threshold = 0.18, sensitivity and specificity = 0.67**

| | Observed | | |
|---|---|---|---|
| Predicted | False | True | Total |
| False | 1594 | 136 | 1730 |
| True | 788 | 274 | 1062 |
| Total | 2382 | 410 | 2792 |

## Figures

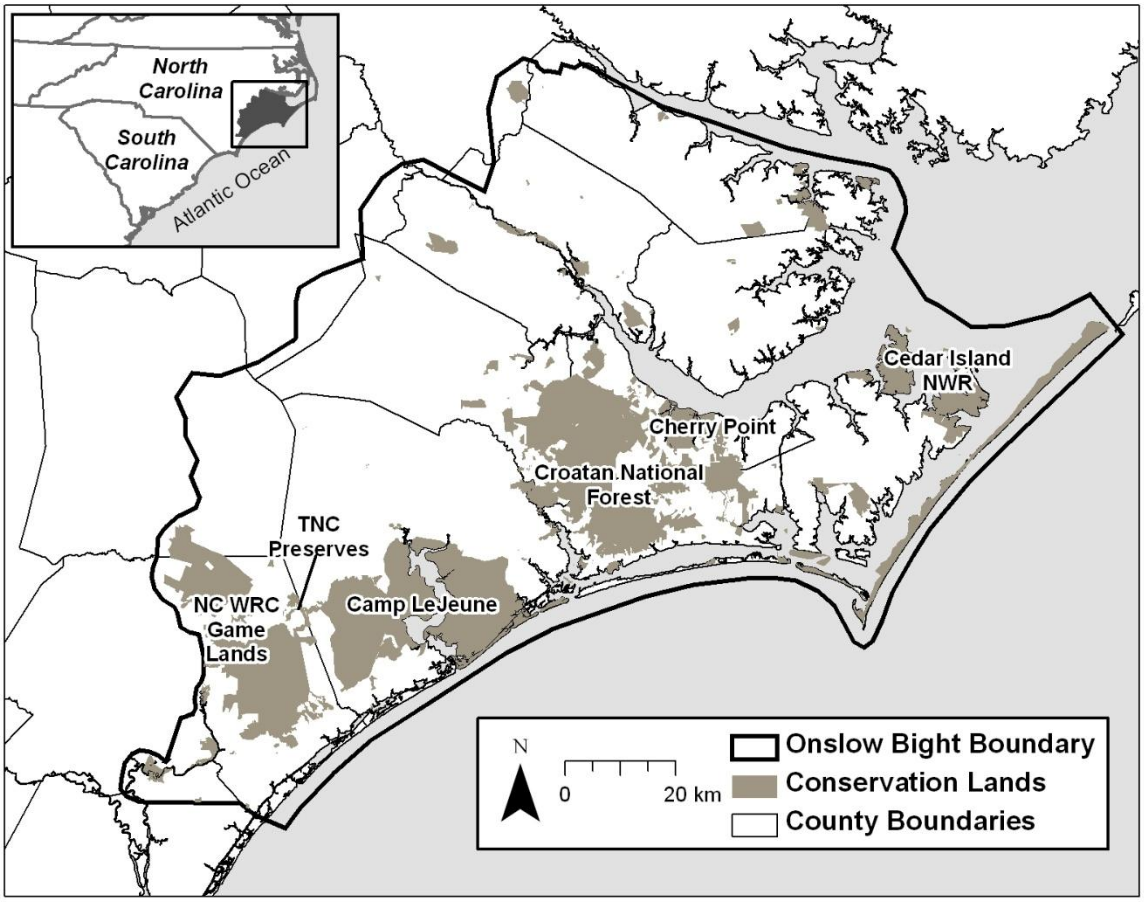


Figure 5.1: Onslow Bight study area, showing the locations of the six management agencies included in this study.

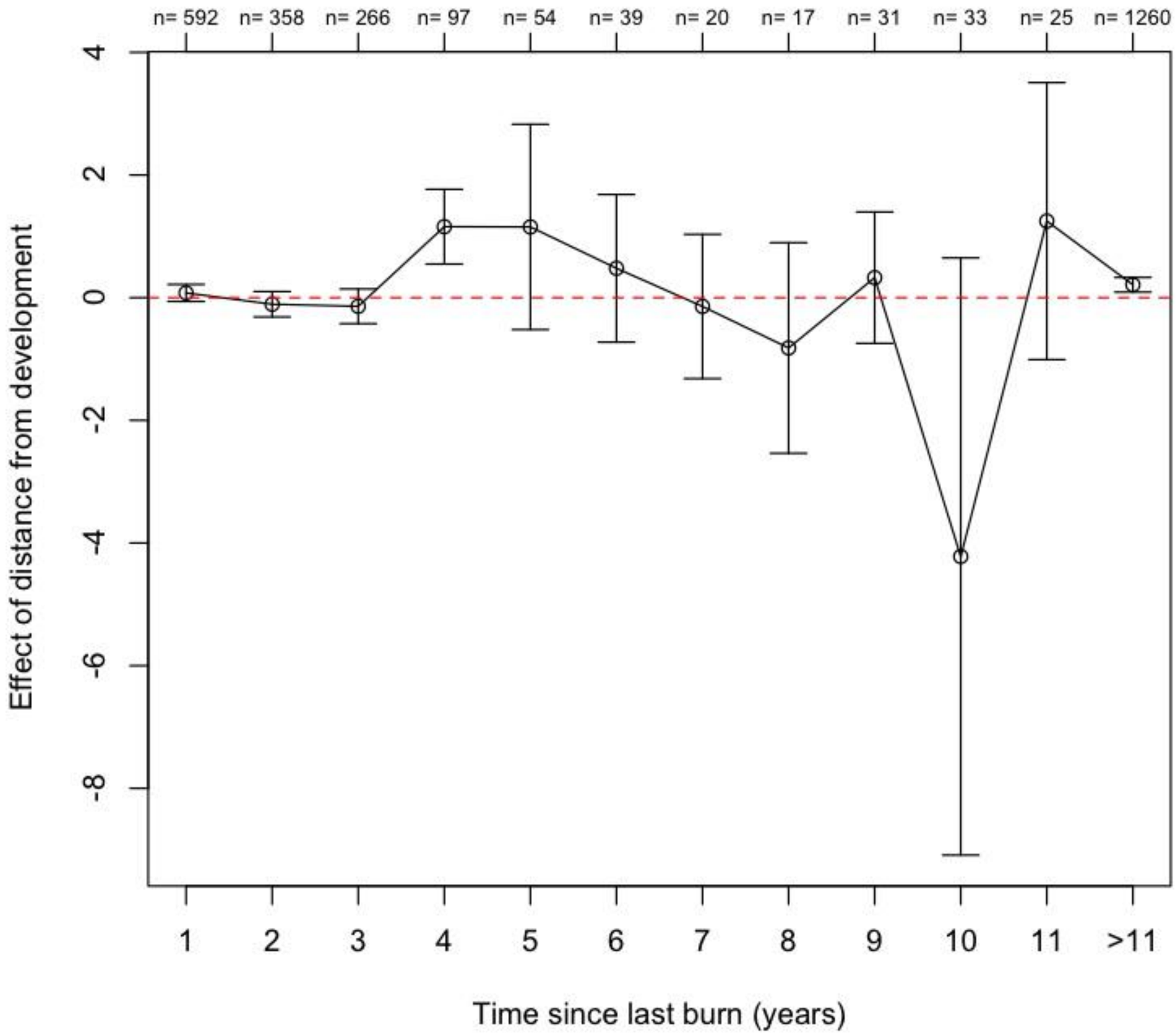


Figure 5.2: The effect of distance from development on the probability a site was burned, with increasing time since the last burn on a site.

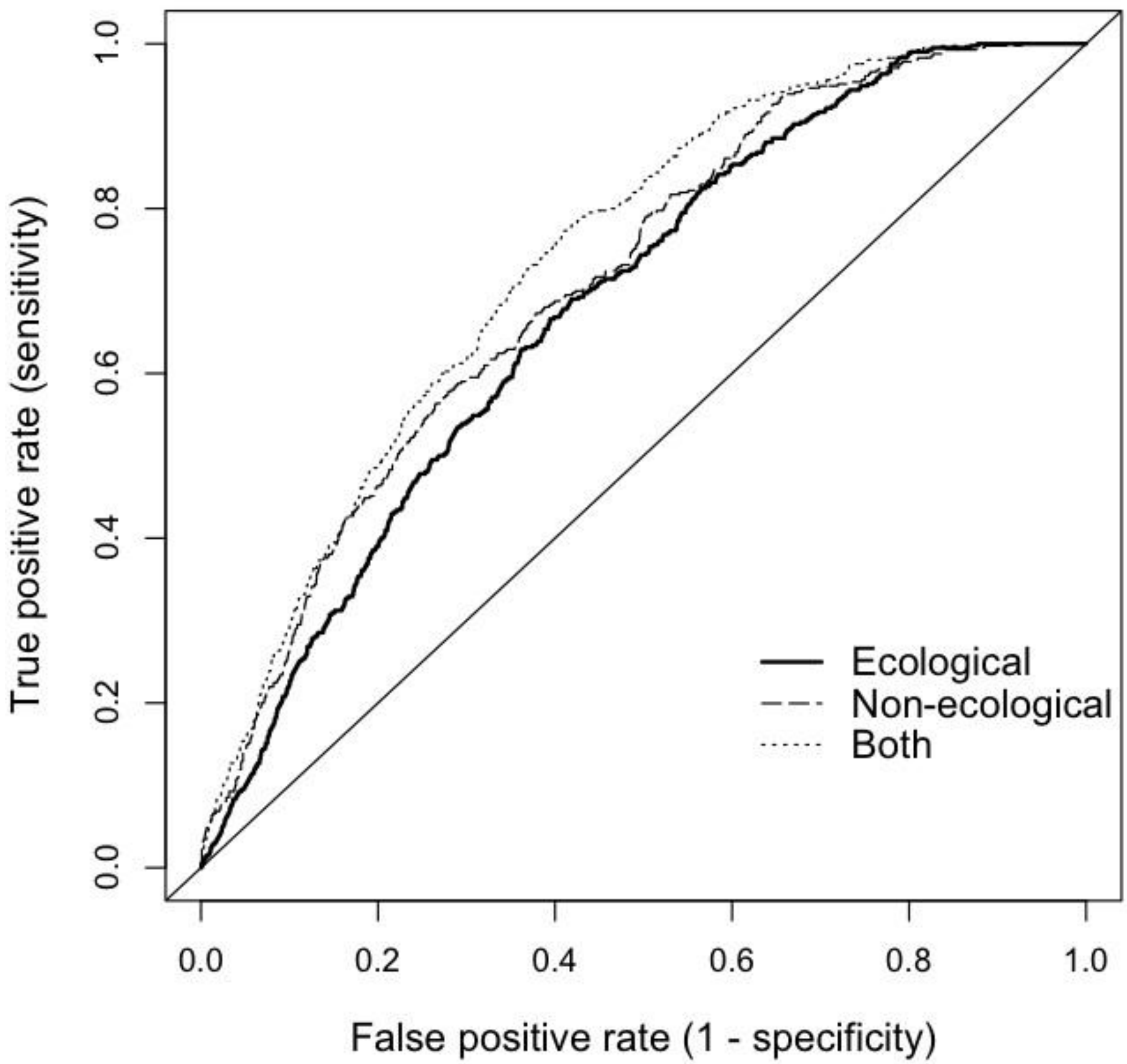


Figure 5.3: Receiver operating characteristic (ROC) curve for the optimal models using ecological predictors only, non-ecological predictors only, and both sets of predictors.

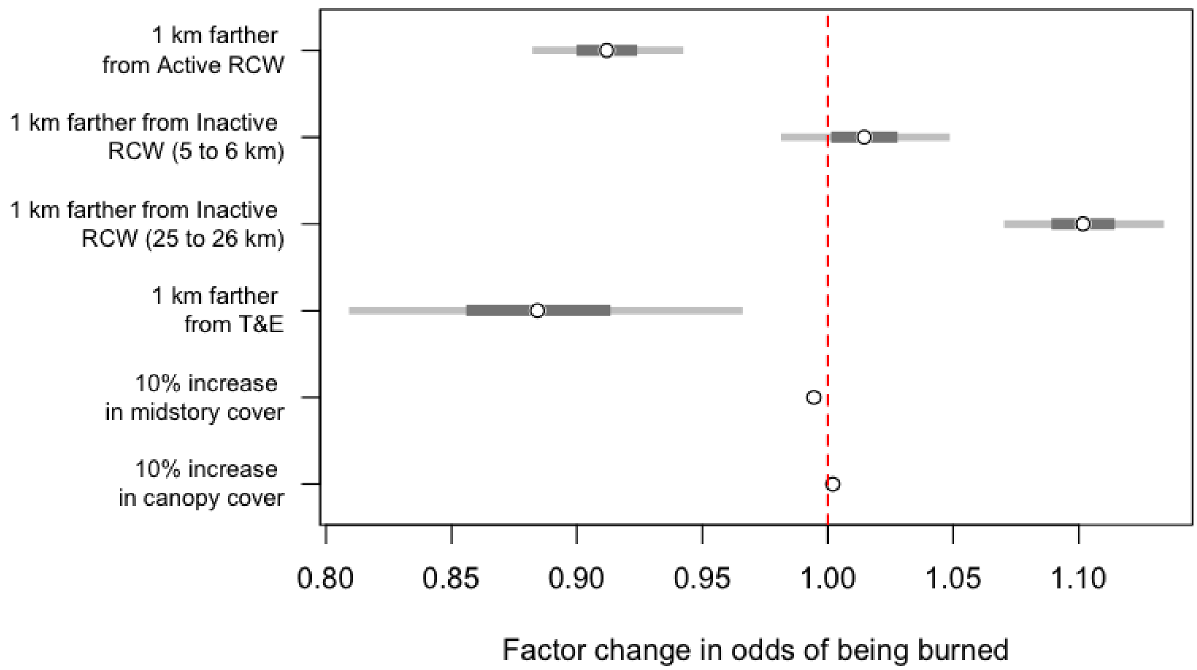


Figure 5.4: Odds ratios for the model with ecological predictors. Light gray bars indicate 95% confidence intervals. Dark gray bars indicate 50% confidence intervals. Values above 1.0 indicate an increase in odds of burning with the stated change in the given variable; values below 1.0 indicate a decrease in odds of burning. For percent midstory and canopy cover, confidence intervals are too small to be seen in the figure, but do not cross 1.0. RCW stands for Red-cockaded Woodpecker clusters.

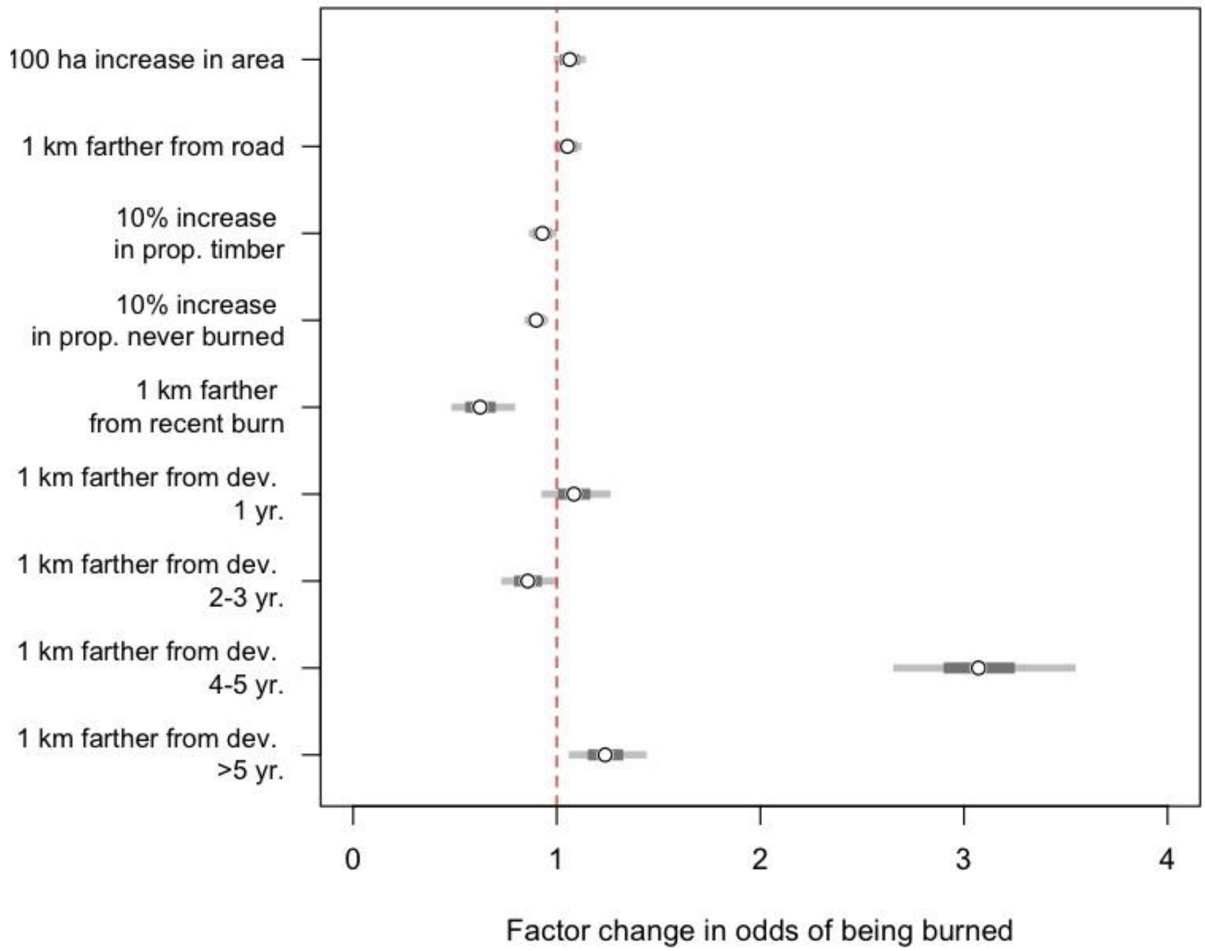


Figure 5.5: Odds ratios for the model with non-ecological predictors. Light gray bars indicate 95% confidence intervals. Dark gray bars indicate 50% confidence intervals. Values above 1.0 indicate an increase in odds of burning with the stated change in the given variable; values below 1.0 indicate a decrease in odds of burning.

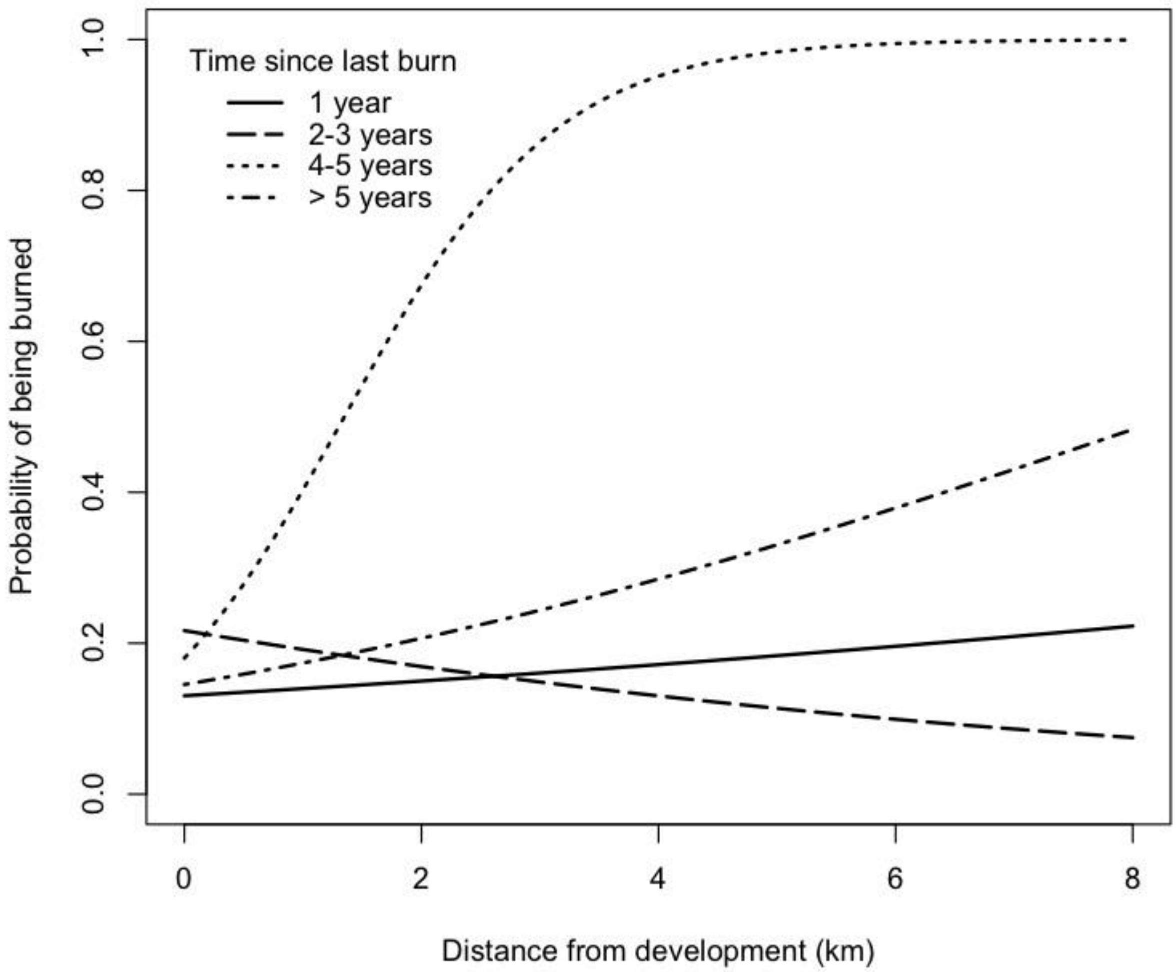


Figure 5.6: The effect of distance to development on the probability of a site being burned, for each category of time since sites were last burned. This figure shows the effect of the interaction of distance to development and the time since last burn in the model with non-ecological predictors. All other variables in the model were held constant. The effect of distance to development is significant for sites burned 4-5 years earlier.

# CHAPTER 6

# CONCLUSION

## Summary of major conclusions

My research investigated the relationships among local sites, their social and ecological contexts, and partnerships conducting ecosystem conservation. Using methods that spanned the social and natural sciences, I examined these relationships in the longleaf pine ecosystem of the US Southeast. Overall, my results demonstrate the importance of a focus on both local sites, as well as their ecological and social contexts when broad-scale ecosystem conservation is the goal. The conclusions from my research are:

1.The relationship between plant species richness and broad-scale ecological and social processes can be detected using data representing heterogeneity of elevation, plant productivity, and land use.

2. Conservation strategies that focus on both local sites and their landscape contexts have potential to ensure long-term ecosystem sustainability.

3. The characteristics of local sites, along with their social and ecological contexts, affect how stakeholders perceive risks associated with management, and therefore the likelihood of ecosystem restoration being accomplished.

**Fundamental contributions**

My research contributes to the field of conservation biology by expanding the body of work concerning how ecosystem management is accomplished. In particular, my research helps bridge the gap between ecosystem conservation as an overall goal for partnerships, and individual decisions made about management at individual sites. I show that even when conservation requires large-scale restoration, because management decisions at individual sites are affected by site condition and landscape context, these decisions can be biased against restoration. Therefore, the potential to restore sustainable ecosystems may be limited.

My work provides significant insights into the decision-making process in ecosystem management. Although theory suggests that management decisions may tend to be risk averse (Maguire and Albright 2005), my research is one of the first to provide empirical evidence for risk aversion by managers (but see Stankey et al. 2003 for a description of risk aversion and the Northwest Forest Plan). In particular, I have shown that various stakeholder groups perceive risk from prescribed burning differently, and that those conducting burning perceive greater risk than do other stakeholders. As a result of my research, recommendations can be made to collaborative conservation partnerships, policy makers, and public and private agencies about how to better accommodate risk in decision-making, and conduct more effective ecosystem management (see implications section below). In addition, my results point to the need for further research on the effects of fire on long-unburned sites.

My research further strengthens the link between human land use and conservation. Because urban areas are expanding near protected areas (Theobald

2005), understanding how it affects management and long-term conservation is crucial. There is much theory about how human land uses near protected areas affect ecological processes within protected areas, for example, via loss of wildlife habitat, water and air pollution (Alavalapati et al. 2005). My research demonstrates how the surrounding landscape, and particularly human development, directly affects the management decisions aimed at conserving these ecological processes.

My research also contributes to the body of knowledge regarding how landscape patterns affect local ecological processes. Although ecological theory predicts that heterogeneity across a variety of scales affects local species richness, there has been little work to determine how heterogeneity could be best incorporated into models of species richness. My work represents a comprehensive study of the relationship between heterogeneity and local richness, spanning multiple scales and environmental variables. Because I measured heterogeneity across a variety of ecologically meaningful scales, and incorporated a suite of environmental variables, my work can inform ecologists about how to measure heterogeneity, at what scales, and with which variables. These results will be useful for future efforts to model local species richness across large extents.

**Future directions**

The research I have done sheds light on how ecosystem conservation can be more effective at achieving large-scale conservation goals. I have shown that management decisions focus on maintaining sites in good condition, and I have synthesized the conservation strategies used by established conservation partnerships.

However, my research has measured the relationship between management and ecology indirectly. To directly connect my research with conservation goals, a major additional component is necessary: an analysis of how management decisions affect ecological processes and conservation targets. We still need an answer to the question: how does the aggregate of decisions made over time affect ecological processes that relate to conservation objectives? In addition, how does the effect of management on species richness compare with the effects of environmental variables?

A statistical analysis that relates management history and environmental variables to one or more important conservation targets at sites throughout the longleaf pine ecosystem would provide a valuable follow-up to the work I have done. In such an analysis for the longleaf pine ecosystem, conservation targets could include plant species richness, or locations of threatened or endangered species populations. Prescribed burn history could be used as a predictor variable, along with land ownership type (whether public or private), and other management history, such as timber management. In addition, results from chapter 2 results suggest that environmental variables at local as well as larger scales may be important to include as predictors. In the case of longleaf pine, local pH, soil texture, and woody basal area are useful predictors of species richness. Elevation, plant productivity and land use measured across larger extents also need to be included. Management-related variables such as burn history can also be included in such models. To explore the potential future effects of today's management regime on conservation targets, the results from such a study could be projected into the future using simulation modeling. Such a study would allow recommendations for management agencies about how to make decisions that maximize conservation benefits.

In addition to this recommended follow-up to my dissertation, there are many other questions arising from individual chapters, which should be addressed in the future. First, my results on the heterogeneity-richness relationship suggest that metrics of heterogeneity will be useful for incorporating into models of plant species richness. Future work should focus on whether these metrics actually add value to such models. A comparison of the predictive power of multivariate models including and without large-scale heterogeneity metrics would shed light on the value of these metrics. Furthermore, my results failed to find evidence for the ecological theory that local heterogeneity has a positive effect on local species richness (Chesson 2000). I postulated that this result was because samples came from sites that were assumed *a priori* to represent homogenous vegetation communities. However, would a relationship be found between local heterogeneity and local richness if a different set of vegetation plots were used, or if a different set of local-scale predictors was used? In addition to soil characteristics and basal area, measures of local heterogeneity could be expanded to include additional metrics, such as variability in vegetative cover.

My research on the strategies used by collaborative partnerships suggests pathways for successful long-term conservation. While partnerships can be effective in accomplishing conservation goals, there are both criticisms and challenges to sustaining the collaborative process. Additional work should be done to examine how partnerships can overcome these challenges. For example, some have argued that collaboration can lead to decision-making that represents the "least common denominator" when a consensus-based approach is used (GAO 2008). In addition, partnerships often have organizational challenges. If they focus their efforts too broadly, they can get mired in day-to-day activities and lose sight of big-picture goals because they have insufficient resources to accomplish their objectives (Bonnell and Koontz 2007). Are those claims justified? While research has shown some evidence for such claims (Bonnell and Koontz 2007), a comprehensive study of the drawbacks of collaboration in conservation has not yet been done. Such a study would shed light on whether partnerships are effective, and would involve a comparison of conservation accomplishments among landowners who participate in collaborative partnerships and those who do not.

In addition, my research included one type of partnership: formally established, public-private regional collaboratives. Incorporating a wider variety of partnerships within the longleaf pine ecosystem and in other ecosystems would shed more light on the relative effectiveness of partnerships of different types and in different settings. For example, comparing the accomplishments of formal partnerships with those that result from more ad-hoc collaboration would enable an exploration of the necessity of formal partnerships.

My research points to several areas for future study of prescribed burning decisions. A study that examines the priorities of individual landowners and compares them with other stakeholders will be essential for developing a better understanding of which areas are priorities for burning. Such a study would inform partnerships about how to better engage private landowners. In addition, using additional predictors in modeling prescribed burning decisions may improve those models. For example, incorporating weather conditions as predictors would help determine how these short-term constraints affect decisions to burn.

**Implications for collaborative partnerships**

My work has implications for understanding how conservation of resilient, sustainable ecosystems can be accomplished by collaborative partnerships. In chapter 3, I provide a set of strategies used by partnerships to accomplish conservation across broad extents. These strategies allow effective conservation because they aim for long-term sustainability of the partnership and of the ecosystem. However, the strategies that were mentioned by interview subjects as being important for long-term success have been most challenging to implement. Furthermore, while interview subjects from the three partnerships indicated that their ability to conduct prescribed burning has been improved as a result of collaboration, conducting burning on appropriate sites and at sufficient scales to achieve large-scale restoration continues to be a challenge. Overcoming the challenges associated with ecosystem conservation and management will be essential for improving restoration potential.

My research points to one major way that partnerships can be more effective at conservation and management: improved communication with local communities, including local governments and residents. My research on prescribed burning decisions indicates that sites near development were less likely to be burned. Prescribed burn practitioners indicated increased risks when development was nearby. While many interview subjects mentioned outreach to local governments and to the public as important strategies for ensuring long-term support for conservation, determining how best to communicate with these groups was also challenging. Interview subjects stated that establishing and maintaining communication with local governments allows partnerships as well as individual land managers to engage in dialog about promoting development patterns that are compatible with conservation, and prescribed burning in particular. In addition, by collaborating with local governments, partnerships can promote a balance between conservation objectives and regional economic objectives. Accepting economic growth, in a way that is compatible with conservation, is likely to lead to a wider base of public support for conservation in general. Initiating outreach efforts by targeting one or small number of landowners, government representatives, or other citizens who live or work near a core habitat area can be a valuable way to develop a clear, effective message about conservation or management efforts. Then, that initial experience can inform future, expanded outreach efforts by the partnership.  Landowners or residents with whom the partnership has successfully worked can be a voice to other citizens about the importance of conservation in the landscape.

My research also leads to several recommendations for helping land managers understand risk and uncertainty, and thus improving the likelihood that prescribed burning decisions will lead to restoration of degraded ecosystems. First, a better understanding of the effects of fire on long-unburned sites is essential.  While controlled experiments by researchers can investigate these effects, land managers can contribute to our understanding of fire effects as well. Improved monitoring following any prescribed burn or wildfire can provide useful information on fire effects.

In addition, clarifying risk can help partnerships and land managers acknowledge inherent uncertainty in ecological processes and management actions. An explicit acknowledgement of risk and uncertainty can come from implementing a more structured decision-making process, in which managers and agencies explicitly acknowledge priorities for burning and the rationales behind them. Such a process would likely help practitioners view prescribed burning decisions as part of an adaptive learning process, and may help overcome risk averse management decisions that have the potential to lead to further ecosystem degradation.

Finally, because I have been involved in the Onslow Bight Conservation Forum ("the Forum") and the Onslow Bight Fire Partnership ("the Fire Partnership") for the past five years, and because of my research focus on the Onslow Bight landscape, I am compelled to make specific recommendations to that partnership. The Onslow Bight Conservation Design Plan calls for increased land protection as well as improved adaptive management on existing protected lands (Onslow Bight Conservation Design Committee 2004). My research underscores the importance of improved adaptive management, especially prescribed burning, in the landscape. The Fire Partnership has been established to help land management agencies overcome barriers to prescribed burning in the region. While the Fire Partnership has made some progress by establishing an MOU for sharing resources, my research indicates that some barriers to prescribed burning for restoring the longleaf pine ecosystem are still in place.

While my above recommendations are applicable to the Onslow Bight, one strategy in particular would be effective in identifying and removing barriers to burning there. Members of the Fire Partnership should conduct a collaborative planning effort to determine their desired future condition in the landscape and identify priorities for prescribed burning that would lead to that condition. Priorities for burning should be related to ecological and conservation goals (for example: "burn sites that have potential to contribute to connectivity of Red-cockaded Woodpecker habitat). Thus, potential tracts could be identified whose need for fire is high. Then, the partnership could make use of the MOU to share resources to accomplish prescribed burning on high-priority tracts.

Both the general strategies above as well as the systematic planning I suggest for the Onslow Bight would be facilitated by better leveraging the unique strengths of partners in that landscape. Camp LeJeune is a member of the Fire Partnership that has access to significant funds for land conservation. In addition, Camp LeJeune is currently undertaking an assessment of potential Red-cockaded Woodpecker habitat across the Onslow Bight. Thus, they have an interest in regional conservation and restoration and would be instrumental in promoting improved land management in the Onslow Bight. The Nature Conservancy is also a partner in the Onslow Bight, with strength in ecoregional conservation planning, and access to tools and knowledge regarding planning across large extents. The North Carolina Wildlife Resources Commission has expertise in prescribed burning, and in particular how burning affects wildlife habitat. The Croatan National Forest has access to equipment that many other partners in the Onslow Bight do not have, including a helicopter and other resources for conducting burning in large tracts. Thus, the Onslow Bight partners are well equipped to plan and implement prescribed burning for broad-scale restoration of the longleaf pine ecosystem. I hope my research provides insights that help them be more successful.

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**APPENDIX 1**

## INTERVIEW GUIDE: COLLABORATIVE CONSERVATION PARTNERSHIPS IN THE LONGLEAF PINE ECOSYSTEM

### Introduction:

Thanks for taking the time to talk to me today. Like I wrote in my email, I am a graduate student at UNC-Chapel Hill, and I am studying the experiences of people who have participated in collaborative conservation partnerships in the longleaf pine ecosystem.

### Part I:

I'll start with some general questions about the purpose of your partnership and the strategies your partnership has used.

1. What is the purpose of your partnership, as you understand it?
2. Briefly, how would you describe your role in the partnership?
3. What is your definition of success for your partnership? Tell me about some ways in which your partnership has been successful.
4. Tell me about strategies you have used for collaboration in your partnership. What has worked, and what has not?
5. How important is actually achieving success in your partnership versus simply doing your best along the way? Is it the destination or the journey that matters most in this case?

### Part II:

Now, I'll ask some more specific questions about your partnership's efforts.

1. What has your partnership been able to achieve in terms of conserving the longleaf pine ecosystem?
   For example: *(Probes, as necessary)*
   a. Recovery of red-cockaded woodpecker or other species
   b. Land management, especially fire management
   c. Restoration of longleaf communities
2. Have you been able to increase public support for land conservation or management? In what ways?
3. Have you tried to increase communication with private landowners? What has that been like?
4. Has the capacity of individual partners improved as a result of the partnership? In what ways?
5. How have partners tried to share experiences and knowledge about conservation and management with other partners?

<u>For more information, use these prompting questions:</u>

*How important is that, relative to other accomplishments?*
*Why was your partnership able to achieve that?*

## APPENDIX 2

### ONLINE SURVEY: PRIORITIES FOR BURNING IN THE ONSLOW BIGHT, NORTH CAROLINA

Following are screenshots showing the survey that was administered online.

**Default Question Block**

**Onslow Bight Burn Priorities Survey**

**Jennifer Costanza – UNC-Chapel Hill**

Dr. Aaron Moody, Advisor

Thank you for agreeing to participate in this survey! It will contribute to my research on how priorities for restoration using prescribed burning are determined in longleaf pine communities in eastern North Carolina.

The survey will first ask you to indicate which factors are important in determining burning priorities, based on your knowledge and experience. Then, you will be asked a series of follow-up questions about the priorities you consider important. Finally, you will be asked a few questions about your background and experience.

This survey should take approximately 15-20 minutes to complete.

**University of North Carolina-Chapel Hill**
**Consent to Participate in a Research Study**
**Adult Participants**
**Social Behavioral Form**

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**IRB Study #07-1030**
**Consent Form Version Date: May 19, 2008**

**Title of Study: Collaborative priorities for restoration of the longleaf pine ecosystem in the Onslow Bight, NC**

**Principal Investigator: Jennifer Costanza**
**UNC-Chapel Hill Department: Curriculum in Ecology**
**UNC-Chapel Hill Phone number: 919-672-8601**
**Email Address: costanza@unc.edu**
**Faculty Advisor: Aaron Moody**
**UNC-Chapel Hill Department: Curriculum in Ecology**
**UNC-Chapel Hill Phone number: 919-962-5303**
**Email Address: aaronm@email.unc.edu**

**Study Contact telephone number: 919-672-8601**
**Study Contact email: costanza@unc.edu**

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**What are some general things you should know about research studies?**
**You are being asked to take part in a research study. To join the study is voluntary.**
**You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.**

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study.
You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
You are being asked to participate in a study about the ways in which people set priorities for restoration of ecological communities across landscapes. Because the Onslow Bight is established to conduct collaborative management efforts among agencies, it is an ideal place to explore priorities. Information gained as part of this survey regarding restoration priorities will add to our knowledge about restoration of the longleaf pine ecosystem.

You are being asked to be in the study because you have experience in, or knowledge about setting priorities for restoration.

How many people will take part in this study?
If you decide to be in this study, you will be one of approximately 140 people in this research study.

How long will your part in this study last?
This survey will take 15-20 minutes to complete. You may be contacted with follow-up questions about the survey at a later date. However, you are only agreeing to the focus group and survey now.

What will happen if you take part in the study?
This is a web-based survey that will ask you to answer questions about your background and experience. The goal is to determine what factors people use to determine burning priorities in the longleaf pine ecosystem, and why.

The survey will first ask you to indicate which factors are important in determining burning priorities, based on your knowledge and experience. Then, you will be asked a series of follow-up questions about the priorities you consider important. Finally, you will be asked a few questions about your background and experience.

What are the possible benefits from being in this study?
Research is designed to benefit society by gaining new knowledge You may also expect to benefit by participating in this study by informing the strategies used for conservation and restoration of longleaf pine on the Coastal Plain of North Carolina. Furthermore, at the end of the survey, there is a place to indicate whether you would like us to provide additional information to you regarding fire ecology, management, or other aspects of restoration on the coastal plain.

What are the possible risks or discomforts involved from being in this study?
You may feel uneasy about sharing your knowledge and experience; however, your answers are completely confidential, and providing your name is optional. Should you choose to provide your name, it will not be included in any publications, nor will it be made public in any way. You should report any problems you have with the survey to the researchers listed above.

**How will your privacy be protected?**
**The surveys and transcriptions will be stored on a secure network that can only be accessed via a password-protected account.**

**Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.**

**The survey data will be kept in a digital file on a computer that is on a secure network and password protected. You are not required to submit your name unless you want to.**

**Will you receive anything for being in this study?**
**You will not receive anything for taking part in this study. However, at the end of the survey, there is a place to indicate whether you would like us to provide additional information to you regarding fire ecology, management, or other aspects of restoration on the coastal plain.**

**Will it cost you anything to be in this study?**
**There will be no costs for being in the study.**

**What if you have questions about this study?**
**You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or concerns, you should contact the researchers listed above.**

**What if you have questions about your rights as a research participant?**
**All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.**

By clicking the “>>” button, you certify that you have read the information provided above and you voluntarily agree to participate in this research study.

What is your role in determining burning or restoration priorities currently? Please choose all that apply.

- ☐ I make day-to-day decisions about which sites get burned or restored.
- ☐ I advise others on which sites should get burned or restored.
- ☐ I approve burn plans.
- ☐ I am involved in setting agency policies regarding restoration or burning activities.

- [ ] I have no active role in determining priorities currently.
- [ ] I write burn plans.
- [ ] Other - please specify

During last year's burn season, approximately how many times did you take part in a burn? Please choose one.

- ( ) 0
- ( ) 1-10
- ( ) 11-20
- ( ) 21-30
- ( ) more than 30

In this survey, we are particularly interested in burning priorities in the Onslow Bight landscape. Please take a look at the map below.


Do you currently live or work in the Onslow Bight?

- ( ) Yes
- ( ) No

How long have you lived or worked in the Onslow Bight, as defined by the purple line on the map above? Please choose one.

- Less than one year
- 1-5 years
- 6-10 years
- 11 or more years

In this survey, we are interested in the characteristics of a site, such as a burn unit, that determine its priority for restoration using prescribed burning in the Onslow Bight. In particular, we are focused on burning in longleaf pine and other related vegetation types.

Important site characteristics may include the vegetation or species present, the condition of the vegetation, the time since the site was burned previously, or the qualities of the landscape surrounding the site.

**Which of the following characteristics are important in determining whether a site (such as a burn unit) has a high priority for burning?** Please check all that apply.
(Because the rest of the survey is based on your response to this question, checking at least one site characteristic here is required. All of the other questions in this survey are optional.)

- Presence of firebreaks or well-established fire lines at a site/burn unit
- Whether a site/burn unit is managed for timber
- Overall ecosystem health of a site/burn unit
- Presence of red-cockaded woodpeckers
- Presence of other threatened or endangered species
- Distance to developed or residential land (the wildland-urban interface)
- Time since the last burn at a site/burn unit
- Presence of undesired exotic or invasive plants
- Proximity of a site/burn unit to other burned areas
- Experienced frequent fire historically or during presettlement
- Other characteristic 1 - please specify:
- Other characteristic 2 - please specify:
- Other characteristic 3 - please specify:
- Other characteristic 4 - please specify:

Below are the characteristics that you indicated are important for determining burn priorities. Please rank them in order of importance, starting with **1** for the **most important** characteristic.

- [ ] » Whether a site/burn unit is managed for timber
- [ ] » Time since the last burn at a site/burn unit
- [ ] » Presence of undesired exotic or invasive plants
- [ ] » Presence of red-cockaded woodpeckers
- [ ] » Experienced frequent fire historically or during presettlement
- [ ] » Presence of firebreaks or well-established fire lines at a site/burn unit
- [ ] » Overall ecosystem health of a site/burn unit
- [ ] » Other characteristic 3 - please specify:
- [ ] » Proximity of a site/burn unit to other burned areas
- [ ] » Other characteristic 4 - please specify:
- [ ] » Other characteristic 1 - please specify:
- [ ] » Other characteristic 2 - please specify:
- [ ] » Presence of other threatened or endangered species
- [ ] » Distance to developed or residential land (the wildland-urban interface)

## Important Factors - Time Since Last Burn

You are being asked the following questions because you indicated that the time since last burn is one of the most important site characteristics for determining whether a site has high priority for burning.

In your opinion, what is the optimal fire return interval (time between burns) for longleaf pine sites? Please choose one.

- ○ 1 year
- ○ 2 years
- ○ 3 years
- ○ 4 years
- ○ 5 years

- More than 5 years
- Other - please specify

Please indicate whether the following statements are True or False, according to your knowledge or experience.

| | True | False |
|---|---|---|
| The optimal fire return interval varies depending on whether the site is in the wildland-urban interface. | | |
| The optimal fire return interval is generally fixed for all sites. | | |
| The optimal fire return interval varies depending on the site conditions. | | |
| The optimal fire return interval varies depending on the objectives of a burn. | | |

Please rate the following in terms of their priority for burning.

| | Lowest priority | Medium priority | Highest priority |
|---|---|---|---|
| Sites that have burned less than 1 year ago | | | |
| Sites that have burned 1-2 years ago | | | |
| Sites that have burned 2-3 years ago | | | |
| Sites that have burned 3-5 years ago | | | |
| Sites that have burned 5-10 years ago | | | |
| Sites that have burned 10-15 years ago | | | |
| Sites that have burned more than 15 years ago | | | |

Why do you consider the time since a site was last burned to be important for determining burn priorities? *Please choose all that apply.*

- There are more benefits to ecological health in sites that have not been recently burned.
- There are more benefits to ecological health when burning in recently-burned sites.
- Fire behavior is more predictable in recently-burned sites.
- Either I, or my agency, receives funding to burn sites based on the time since they were last burned.
- Smoke management is easier in recently-burned sites.
- Agency policies mandate that uncharacteristic sites be restored to a more "natural" state.

If there are any other reasons why time since last burn is important for determining burning priorities, please list them here.

**Important Factors - RCW**

You are being asked the following questions because you indicated that the presence of red-cockaded woodpeckers is one of the most important site characteristics for determining whether a site has high priority for burning.

Please rate the following in terms of their priority for burning.

| | Lowest priority | Medium priority | Highest priority |
|---|---|---|---|
| Sites that contain active woodpecker cavity trees | ○ | ○ | ○ |
| Sites that do not contain active cavity trees, but are woodpecker foraging areas | ○ | ○ | ○ |
| Sites that do not contain active cavity trees, but are near woodpecker nesting areas | ○ | ○ | ○ |
| Sites that have inactive woodpecker cavity trees, but no active woodpeckers | ○ | ○ | ○ |
| Sites that contain neither active nor inactive woodpecker clusters or foraging sites | ○ | ○ | ○ |

Why do you consider the presence of red-cockaded woodpeckers to be important for determining burn priorities? *Please choose all that apply.*

- ☐ Burning these sites ensures that their historic or "natural" character is preserved.
- ☐ The public cares about red-cockaded woodpeckers.
- ☐ Either I, or my agency, receives funding to manage for red-cockaded woodpeckers.
- ☐ Red-cockaded woodpeckers influence the ecological health of the longleaf pine ecosystem.
- ☐ Either my or my agency's primary goal is to conserve endangered species or wildlife.

If there are any other reasons why red-cockaded woodpeckers are important for determining burning priorities, please list them here.

**Important Factors - WUI**

You are being asked the following questions because you indicated that the distance to developed or residential land (the wildland-urban interface) is one of the most important site characteristics for determining whether a site has high priority for burning.

How close does a site need to be to homes or other structures for you to consider it in the wildland-urban interface? *Please choose one.*

- ○ Immediately adjacent to developed property
- ○ Within ½ mile
- ○ Within ½ to 1 mile
- ○ Within 1 to 5 miles
- ○ Could be more than 5 miles away
- ○ Distance is completely variable and/or depends on smoke dispersion on the day of a burn

Of the options below, which of the following has highest priority for burning? *Please choose one.*

- ○ Sites within the wildland-urban interface
- ○ Sites outside the wildland-urban interface

Why do you consider the distance to the wildland-urban interface is important for determining burn priorities? *Please choose all that apply.*

- ☐ Fuel buildup in wildland-urban interface areas increases risk of a wildfire that could damage surrounding homes or property.
- ☐ Smoke is difficult to manage properly in wildland-urban interface areas.
- ☐ Either I, or my agency, receives funding to burn in the wildland-urban interface.
- ☐ Either I, or my agency, is mandated to consider the wildland-urban interface.
- ☐ The public is concerned about fires in wildland-urban interface areas.

If there are any other reasons why the wildland-urban interface is important for determining burning priorities, please list them here.

### Important Factors - T&E Species

You are being asked the following questions because you indicated that the presence of other threatened or endangered species is one of the most important site characteristics for determining whether a site has high priority for burning.

Please enter the names of the threatened or endangered species you or your agency use to prioritize burning in the Onslow Bight, and indicate whether each is fire-dependent or not.

| | | Fire-dependent? | | |
|---|---|---|---|---|
| | Name | Yes, Fire-dependent | No, Not Fire-dependent | Not sure |
| Species 1 | | ○ | ○ | ○ |
| Species 2 | | ○ | ○ | ○ |
| Species 3 | | ○ | ○ | ○ |
| Species 4 | | ○ | ○ | ○ |
| Species 5 | | ○ | ○ | ○ |

Of the options below, which of the following are highest priority for burning? *Please choose one.*

- ○ Sites with threatened or endangered species
- ○ Sites without threatened or endangered species

Why do you consider the presence of threatened or endangered species to be important for determining burn priorities? *Please choose all that apply.*

- ☐ Either I, or my agency, is mandated to manage for these species.
- ☐ Managing for threatened or endangered species preserves the historic character of natural areas.
- ☐ The public cares about threatened and endangered species.
- ☐ Threatened or endangered species play an important role in the longleaf pine ecosystem.
- ☐ Either I, or my agency, receives funding to manage for these species.

If there are any other reasons why presence of threatened or endangered species is important for determining burning priorities, please list them here.

### Important Factors - Timber Management

You are being asked the following questions because you indicated that whether a site is managed for timber is one of the most important site characteristics for determining whether a site has high priority for burning.

Of the options below, which of the following has highest priority for burning? *Please choose one.*

- ○ Sites that are managed for timber
- ○ Sites that are not managed for timber

Why do you consider timber management to be important for determining burn priorities? *Please choose all that apply.*

- ☐ Either I, or my agency, is mandated to manage for timber.
- ☐ Burning at sites managed for timber also benefits endangered species or the overall ecosystem health of the site.
- ☐ Smoke management is easier in sites managed for timber than at other sites.
- ☐ Fire behavior is more predictable at sites managed for timber than at other sites.
- ☐ Either I, or my agency, receives revenue from timber sales.

If there are any other reasons why timber management is important for determining burning priorities, please list them here.

### Important Factors - Firebreaks

You are being asked the following questions because you indicated that the presence of firebreaks or well-established fire lines is one of the most important site characteristics for determining whether a site has high priority for burning.

Which of the following do you or your agency consider to be a firebreak or fire line? *Please choose all that apply.*

- ☐ A road
- ☐ A stream or river
- ☐ A hand-cut line
- ☐ A tractor or plow line
- ☐ A change in vegetation or fuels, such as the transition from open savanna to pocosin
- ☐ Other - please specify [ ]

Why do you consider the presence of firebreaks or well-established fire lines to be important for determining burn priorities? *Please choose all that apply.*

- ☐ Burns at sites with firebreaks/fire lines pose less risk to people, buildings, or property.
- ☐ Either I, or my agency, receives funding to burn sites based on whether they have firebreaks/fire lines.
- ☐ Burns at sites with firebreaks/fire lines require less time or money invested.
- ☐ Firebreaks/fire lines make it easier to introduce fire into previously unburned sites.
- ☐ Burns at sites with firebreaks/fire lines avoid the negative ecological impact of creating additional firebreaks .
- ☐ Burns at sites with firebreaks/fire lines are easier to control.
- ☐ Either I, or my agency, is mandated to burn sites with firebreaks/fire lines.

If there are any other reasons why firebreaks/fire lines are important for determining burning priorities, please list them here.

[ ]

**Important Factors - Ecosystem Health**

You are being asked the following questions because you indicated that a site's overall ecosystem health is one of the most important site characteristics for determining whether a site has high priority for burning.

Which of the following do you consider to be qualities of sites with good overall ecosystem health in longleaf pine communities in the Onslow Bight? *Please choose all that apply.*

- ☐ High species richness (large number of species) in the understory
- ☐ Presence of threatened or endangered species
- ☐ Low shrub fuel load/open midstory
- ☐ Open canopy
- ☐ Old-growth canopy/trees on a long rotation
- ☐ Frequently burned
- ☐ Aesthetically pleasing
- ☐ Other - please specify

Of the options below, which of the following has highest priority for burning? *Please check one.*

- ○ Sites that have good ecosystem health
- ○ Sites that have poor ecosystem health

Why do you consider the overall ecosystem health of a site to be important for determining burn priorities? *Please choose all that apply.*

- ☐ Focusing on sites with POOR ecosystem health ensures that burning results in ecological benefits.
- ☐ Smoke management is easier at sites with good ecosystem health than at other sites.
- ☐ Either I, or my agency, is mandated to focus on overall ecosystem health.
- ☐ The public cares about the ecosystem health of sites.
- ☐ Sites with good ecosystem health have lower fuel loads.
- ☐ Focusing on sites with GOOD ecosystem health ensures that burning results in ecological benefits.
- ☐ Fire behavior is more predictable at sites with good ecosystem health.
- ☐ Either I, or my agency, receives funding to focus on overall ecosystem health.

If there are any other reasons why ecosystem health is important for determining burning priorities, please list them here.

**Important Factors - Exotics**

You are being asked the following questions because you indicated that the presence of undesired exotic or invasive plants is one of the most important site characteristics for determining whether a site has high priority for burning.

Of the options below, which has highest priority for burning? *Please choose one.*

- ○ Sites that have undesired exotic or invasive plants
- ○ Sites that do not have undesired exotic or invasive plants

Why do you consider the presence of undesired exotic or invasive plants at a site to be important for determining burn priorities? *Please choose all that apply.*

- ☐ The public cares about burning sites with undesirable exotic or invasive plants.
- ☐ Either I, or my agency, receives funding to control undesirable exotic or invasive plants.
- ☐ Burning sites WITHOUT undesirable exotic or invasive plants makes smoke management easier on current burns.
- ☐ Burning sites WITHOUT undesirable exotic or invasive plants minimizes fire behavior on current burns.
- ☐ Burning sites with undesirable exotic or invasive plants makes it easier to eradicate these plants.
- ☐ Burning sites with undesirable exotic or invasive plants makes predicting fire behavior on future burns easier.
- ☐ Burning sites with undesirable exotic or invasive plants improves habitat for native plants and/or wildlife.
- ☐ Burning sites with undesirable exotic or invasive plants makes smoke management easier in the future.
- ☐ Either I, or my agency, is mandated to control undesirable exotic or invasive plants.

If there are any other reasons why the presence of undesired exotic or invasive plants is important for determining burning priorities, please list them here.

**Important Factors - Proximity**

You are being asked the following questions because you indicated that the proximity of a site to other burned sites is one of the most important site characteristics for determining whether a site has high priority for burning.

Of the options below, which has highest priority for burning? *Please choose one.*

- ○ Sites that are close to other burned sites
- ○ Sites that are not close to other burned sites

Why do you consider the proximity of a site to other burned sites to be important for determining burn priorities? *Please choose all that apply.*

- ☐ Either I, or my agency, is mandated to burn sites that are near other burned sites.
- ☐ Burning sites that are near other burned sites makes controlling fires easier.
- ☐ Smoke management is easier in sites that are near other burned sites.
- ☐ Burning sites that are near other burned sites makes planning ahead for future burns easier.
- ☐ Wildlife or plant populations benefit from restored habitat areas that are connected to, or near one another.
- ☐ Either I, or my agency, receives funding to burn sites that are near other burned sites.
- ☐ Fewer resources (money, equipment, or personnel) are required to burn sites that are close to other burned sites.

If there are any other reasons why proximity to other burned sites is important for determining burning priorities, please list them here.

**Important Factors - Presettlement**

You are being asked the following questions because you indicated that whether a site experienced frequent fire historically or during presettlement is one of the most important site characteristics for determining whether a site has high priority for burning.

Of the options below, which has highest priority for burning? *Please choose one.*

- Sites that experienced frequent fire historically
- Sites that did not experience frequent fire historically

Why do you consider the historic fire frequency of a site to be important for determining burn priorities? *Please choose all that apply.*

- Burning based on historic fire frequency helps maintain or restore threatened or endangered species.
- Either I, or my agency, receives funding to burn based on the historical or presettlement condition of sites.
- Smoke management is easier at sites that experienced frequent fire historically.
- Burning sites that have NOT experienced frequent fire historically results in more ecological benefits.
- The public cares about restoring the presettlement or "natural" condition of sites.
- Fire behavior is easier to predict at sites that experienced frequent fire historically.
- Either I, or my agency, is mandated to burn sites based on their historic fire frequency.
- Burning based on historic fire frequency helps improve wildlife or plant habitat.

If there are any other reasons why historic fire frequency is important for determining burning priorities, please list them here.

**Important Factors - Add'l Factor 1**

You are being asked the following questions because you indicated that an additional factor(s) is among the most important site characteristics for determining whether a site has high priority for burning.

Please describe why ${q://QID16/ChoiceTextEntryValue/11} is an important site characteristic for determining burning priorities.

**Important Factors - Add'l Factor 2**

Please describe why ${q://QID16/ChoiceTextEntryValue/12} is an important site characteristic for determining burning priorities.

**Important Factors - Add'l Factor 3**

Please describe why ${q://QID16/ChoiceTextEntryValue/13} is an important site characteristic for determining burning priorities.

**Important Factors - Add'l Factor 4**

Please describe why ${q://QID16/ChoiceTextEntryValue/14} is an important site characteristic for determining burning priorities.

**Ending Questions**

Do you have information on the historic, or presettlement condition of one or more sites in the Onslow Bight landscape?

- Yes
- No

Where did you get the historical information you have? *Please choose all that apply.*

- Historic maps
- Historic aerial photos

- [ ] Expert opinion
- [ ] Witness accounts
- [ ] Historical accounts such as newspapers or literature
- [ ] Maps specifically created to describe presettlement or "natural" conditions
- [ ] Land deeds or other public records
- [ ] Evidence from charcoal deposits
- [ ] Evidence from tree rings
- [ ] Evidence from historic fire scars
- [ ] Archaeological evidence such as artefacts from human settlements
- [ ] Other - please specify

Overall, how useful is the historical information you have? *Please choose one.*

- Very useful
- Somewhat useful
- Not very useful
- Not useful at all

Overall, how confident are you in the historic information you have? *Please choose one.*

- Very confident
- Somewhat confident
- Not very confident
- Not confident at all

If you had additional information on historical or presettlement conditions, do you think you would use it?

- Yes
- No

At the end of this survey, you will have the opportunity to provide your name and contact information if you would like us to send you references and/or data regarding presettlement conditions in eastern North Carolina.

Based on your experience or knowledge, how important do you think each of the following is in constraining burning activities currently?

| | Very Important | Somewhat Important | Unimportant |
|---|---|---|---|
| Agency policies that discourage risk-taking | ○ | ○ | ○ |
| Local ordinances that restrict burning | ○ | ○ | ○ |
| Size of the site to be burned | ○ | ○ | ○ |
| Shortage of resources, including money or equipment | ○ | ○ | ○ |
| Landowners do not want to burn | ○ | ○ | ○ |
| Inappropriate weather conditions | ○ | ○ | ○ |
| Public perceptions of burning | ○ | ○ | ○ |
| High fuel loads | ○ | ○ | ○ |
| Smoke management regulations | ○ | ○ | ○ |
| Shortage of trained personnel | ○ | ○ | ○ |
| Residential or other development in or near areas to be burned | ○ | ○ | ○ |

If there are any other factors that constrain burning activities, please list them.

Over the <u>next 5 years</u>, do you think these factors will become more or less important in constraining burning activities, as compared to <u>today</u>?

| | More Important | Unchanged | Less Important |
|---|---|---|---|
| Landowners do not want to burn | ○ | ○ | ○ |
| High fuel loads | ○ | ○ | ○ |
| Smoke management regulations | ○ | ○ | ○ |
| Shortage of resources, including money or equipment | ○ | ○ | ○ |
| Agency policies that discourage risk-taking | ○ | ○ | ○ |

| | | | |
|---|---|---|---|
| Public perceptions of burning | ○ | ○ | ○ |
| Local ordinances that restrict burning | ○ | ○ | ○ |
| Shortage of trained personnel | ○ | ○ | ○ |
| Residential or other development in or near areas to be burned | ○ | ○ | ○ |
| Inappropriate weather conditions | ○ | ○ | ○ |
| Size of the site to be burned | ○ | ○ | ○ |

Over the next 10 years, do you think these factors will become more or less important in constraining burning activities, as compared to today?

| | More Important | Unchanged | Less Important |
|---|---|---|---|
| Agency policies that discourage risk-taking | ○ | ○ | ○ |
| Inappropriate weather conditions | ○ | ○ | ○ |
| Public perceptions of burning | ○ | ○ | ○ |
| Shortage of resources, including money or equipment | ○ | ○ | ○ |
| Shortage of trained personnel | ○ | ○ | ○ |
| Landowners do not want to burn | ○ | ○ | ○ |
| Size of the site to be burned | ○ | ○ | ○ |
| Residential or other development in or near areas to be burned | ○ | ○ | ○ |
| High fuel loads | ○ | ○ | ○ |
| Smoke management regulations | ○ | ○ | ○ |
| Local ordinances that restrict burning | ○ | ○ | ○ |

Based on your knowledge or experience, what is the probability that a major wildfire will occur in the Onslow Bight in the **Next Year, Next 5 Years, and Next 10 Years**? *Assume that a major wildfire is one that requires resources to be brought in from outside the area, and which threatens property.*

| | 0% - definitely will not occur | Between 1% and 25% | Between 26% and 50% | Between 51% and 75 % | Between 76% and 100% | 100% - definitely will occur |
|---|---|---|---|---|---|---|
| Next Year | ○ | ○ | ○ | ○ | ○ | ○ |
| Next 5 Years | ○ | ○ | ○ | ○ | ○ | ○ |
| Next 10 Years | ○ | ○ | ○ | ○ | ○ | ○ |

Please provide any additional comments regarding burning priorities in the Onslow Bight.

This survey will conclude with a few questions about you and your background.

What is your primary area of expertise? Please choose all that apply.

- ☐ Botany or plant ecology
- ☐ City/county planning
- ☐ Fire management or fire ecology
- ☐ Forestry or forest ecology
- ☐ Land conservation
- ☐ Wildlife management or wildlife ecology
- ☐ Other - please specify

How would you characterize yourself? Please choose one.

- ○ Fire/Restoration or other land manager
- ○ Non land management
- ○ Individual landowner with interest in burning/restoration
- ○ Other - please specify

How would you characterize your employer? Please choose one.

- ○ Independent/self-employed
- ○ Private agency/nonprofit
- ○ Public federal agency
- ○ Public state agency
- ○ Public local agency

- ○ Other public agency
- ○ University or college
- ○ Currently unemployed
- ○ Other - please specify [ ]

Please help my study by providing the names and email addresses of up to four other people you know, who have knowledge or experience regarding burning priorities in the Onslow Bight. These people will only receive an email asking them if they wish to participate. They will be under no obligation to complete a survey.

| | Name | Email Address |
|---|---|---|
| Additional Contact 1 | | |
| Additional Contact 2 | | |
| Additional Contact 3 | | |
| Additional Contact 4 | | |

Optionally, please provide your name below.

Providing your name ensures that we will be able to contact you if we want to clarify your responses or need more information, since this survey does not automattically associate your name with your responses. If you provide your name, it will not be published, nor will it be made public in any other way.

First Name [ ]

Last Name [ ]

Are you interested in any of the following?

- ☐ Maps/spatial data showing potential conditions of the Onslow Bight prior to European settlement
- ☐ Data on ecologically-appropriate fire regimes in the Onslow Bight
- ☐ Information on fire management effects on rare wildlife
- ☐ Would like to be added to the Onslow Bight Fire Partnership email list
- ☐ Other - please specify: [ ]

If you would like any of the items listed above, please provide your email address here, so that we may get in touch with you.

Email

## APPENDIX 3

### VARIABLES USED IN MODELING RECENT PRESCRIBED BURNING ACTIVITIES

Variables used in model selection, along with coefficient estimates[a] and standard errors for parameters in three optimal multiple regression models. Asterisk indicates significant parameters ($p<0.05$), according to Wald test.

| | Ecological | | Non-ecological | | Both | |
|---|---|---|---|---|---|---|
| Variables[b] | Value | S.E. | Value | S.E. | Value | S.E. |
| Intercept[c] | -1.064* | 0.112 | -1.598* | 0.130 | -1.799* | 0.183 |
| Dist from active woodpecker clusters | -0.092* | 0.016 | | | -0.056* | 0.012 |
| Dist from inactive woodpecker clusters | -0.017 | 0.022 | | | 0.051* | 0.009 |
| Dist from inactive woodpecker clusters^2 | 0.002* | 0.001 | | | n.s. | |
| Dist from T&E Species | -0.123* | 0.044 | | | n.s. | |
| Midstory cover | -0.056* | 0.006 | | | -0.037* | 0.006 |
| Canopy cover | 0.020* | 0.003 | | | 0.014* | 0.004 |
| Prop. experiencing frequent presettlement fire | n.s. | | | | n.s. | |
| Prop. woodpecker foraging habitat | n.s. | | | | n.s. | |
| Number of burns in last 10 years | n.s. | | | | n.s. | |
| Area (ha) | | | 0.001* | 0.000 | 0.001* | 0.000 |
| 2-3 years since burn | | | -0.986* | 0.111 | -1.153* | 0.155 |
| 4-5 years since burn | | | -1.216 | 0.242 | -1.426 | 0.284 |
| > 5 years since burn | | | -1.473 | 0.192 | -1.641 | 0.234 |
| Dist from road | | | 0.052* | 0.024 | 0.056* | 0.028 |
| Prop. In managed timber | | | -0.732* | 0.270 | -0.824* | 0.288 |
| Prop. Never burned | | | -1.065* | 0.229 | -0.661* | 0.241 |
| Distance from recent burn | | | -0.472* | 0.112 | -0.447* | 0.108 |
| Dist from development: 1 year since burn | | | 0.081 | 0.071 | 0.139 | 0.076 |
| Dist from development: 2-3 years since burn | | | -0.154 | 0.087 | -0.034 | 0.079 |
| Dist from development: 4-5 years since burn | | | 1.122* | 0.313 | 1.345* | 0.360 |
| Dist from development: > 5 years since burn | | | 0.213 | 0.059 | 0.250 | 0.059 |
| Distance from stream | | | n.s. | | n.s. | |

[a] "n.s." indicates the variable was included in the pool of possible predictors, but was not included in the optimal model.

[b] "Prop." stands for proportion. "Dist." stands for distance.

[c] For models with non-ecological predictors only, or both sets of predictors, the Intercept represents the coefficient estimate for sites that were burned 1 year prior.