PRESCRIBED BURNING ACTIVITY IN REMNANT LONGLEAF PINE (*Pinus palustris*) ECOSYSTEMS OF NORTH AND SOUTH CAROLINA: PATTERNS, INFLUENCING FACTORS, AND POLICY RECOMMENDATIONS

by
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ABSTRACT

MARK DAVID KNOTT: Prescribed burning activity in remnant longleaf pine (*Pinus palustris*) ecosystems of North and South Carolina: patterns, influencing factors, and policy recommendations
(Under the direction of Robert K. Peet)

Remnant longleaf pine ecosystems of North and South Carolina face continued imperilment due to fire suppression. Without active, committed management with prescribed fire, the biological potential of these historically species-rich systems cannot be achieved. I surveyed managers of 1000+ acres of remnant longleaf pine forest in North and South Carolina. Fifty-three respondents completed surveys (63% response rate). They manage approximately 472,000 acres of longleaf, 76% of the resource remaining in the Carolinas. Path analysis shows that respondent behavior is most influenced by forest management objectives whereas constraints due to proximity to the wildland-urban interface most impact behavioral preferences. The risks and challenges of burning in a populated landscape force land managers to manage many sites with longer than preferred prescribed burn rotations. Thus, expanding prescribed burning requires alleviation of constraints for those with currently active programs and the creation of well-informed incentive programs to motivate managers with less active programs.

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INTRODUCTION

Open, park-like longleaf pine (*Pinus palustris*, Miller) savannas native to the Atlantic and Gulf Coastal Plains of the Southeastern United States are among the world's most endangered ecosystems (Noss, LaRoe, and Scott 1995). Once occupying ninety-two million acres of land from southeastern Virginia to east Texas, only 674,000 acres resemble the original ecosystems, a 99.3% reduction in area (Frost 1993). These well-managed remnants of longleaf pine habitat are not only home to hundreds of rare, threatened, and endangered species (Hardin and White 1989; Walker 1993) but also a significant portion of the South's biological diversity (Dodd 1995; Hardin and White 1989; Noss 1989; Noss, LaRoe, and Scott 1995; Walker 1993; Walker and Peet 1983). However, it seems unlikely that these frequently burned patches of longleaf will be sufficient to provide the area necessary to keep native Southeastern species that require open, park-like upland pine habitats for declining or becoming extinct (Brennan et al. 1998). Thus, preserving these acres and restoring the estimated 2.3 million acres of degraded remnant longleaf pine ecosystems (Outcalt and Sheffield 1996) is a top conservation priority (Johnson 1996; Landers 1995; Means 1996; Means 1985; Walker 1999).

The regular occurrence of fire is necessary for the survival and rehabilitation of longleaf pine ecosystems (Frost 1993; Harper 1913; Wahlenberg 1946). In the presettlement landscape low intensity, lightning-ignited surface fires swept across the Southeastern Coastal Plains every 2 to 8 years (Abrahamson and Hartnett 1990; Frost 1993), profoundly impacting the structure and species composition of Southern ecosystems (Christensen 1993a; Christensen 1993b; Christensen 2000). Fires limited the extent and importance of fast growing, but fire susceptible hardwoods, shrubs and mesophytic pines while favoring plant species adapted to survive regular fire (e.g., longleaf pine seedlings and perennial herbs and grasses), which dominated upland sites (Wahlenberg 1946). Recurring fires successfully arrest natural successional processes, control competition among plant species, maintain sites for seed germination, and prepare mineral seedbeds. Longleaf pine and its grassy associates were intimately linked to this vegetation-fire cycle that ensured their continued dominance (Christensen 1993a; Christensen 1993b; Christensen 2000).

Alterations of the South's native fire ecology have contributed significantly to the decline and degradation of longleaf pine ecosystems (Abrahamson and Hartnett 1990; Abrahamson. and Abrahamson 1996; Brennan et al. 1998; Frost 1993; Gilliam 1999; Wahlenberg 1946). In today's highly fragmented landscape, lightning-ignited fires are neither sufficiently extensive nor frequent to maintain native longleaf communities and ecosystems (Johnson and Gjerstad 1998; Simberloff 1993). Natural successional processes set in motion by fire exclusion (Christensen 1993a; Christensen 1993b; Christensen 2000) allow highly competitive mesophytic pine, hardwood, and shrub species to invade longleaf habitat. Due to their inability to survive deep shade, longleaf pine seedlings and their herbaceous associates succumb to these invasions within a few years of fire exclusion on all but the driest sites (Frost 1993).

The high quality longleaf sites that remain the South today exist because of concerted human efforts to maintain open, grassy longleaf habitat (Frost 1993; Komarek 1974; Rosene 1969). Frequent prescribed, or controlled, burning (e.g., several times a decade) effectively controls competing vegetation on most sites, is associated with species diversity unparalleled in North America, (Walker and Peet 1983), and has been successfully used in longleaf pine ecosystem restoration efforts (Brockway 1998; Kush 1999; Kush, Meldahl, and Varner 1998). Thus, longleaf pine ecosystem preservation and restoration are predicated on the ability and willingness of land managers to implement dedicated burning programs as part of ecologically sound longleaf management (Abrahamson. and Abrahamson 1996; Brockway 1997; Glitzenstein 1995; Hiers, Wyatt, and Mitchell 2000; Jacqmain 1999; Platt 1988a; Robbins and Myers 1992; Streng 1993).

Bolstering currently active burn programs, expanding prescribed burning in less active programs, and increasing the use of growing season burns (April to September) are essential parts of sustaining a great portion of the South's biological diversity (Frost 1993; Johnson 1996; Johnson and Gjerstad 1998)]. In order to accomplish these goals in remnant longleaf pine ecosystems of North and South Carolina a comprehensive understanding of land manager use of fire and the development of public policies that support burning as part of ecologically-sound forest management are required. Currently, public policies that reflect longleaf's imperiled status, its fire dependent nature, and an understanding of land manager behavior do not exist. However, neither do data showing how much remnant longleaf is (1) occasionally burned, (2) frequently burned, (3) burned during the growing season, (4) managed with longer than preferred burn intervals, and (5) not burned at all. Furthermore, we do not have an adequate understanding of the factors the actually affect land manager behavior. Thus, characterization of the longleaf pine problem as a function of prescribed burning activity may be too uncertain for public policy makers to take preemptive action to stave the well documented, historical decline of longleaf systems in the Carolinas.

Previous studies examining prescribed burning activity in the South and the variables that influence it lack explicit theoretical frameworks and fail to explore the interplay between factors potentially influencing land manager behavior and land manager behavior, *per se* (Cleaves and Haines 1995; Cleaves, Martinez, and Haines 2000; Haines and Cleaves 1999; Wade 1993; Wade and Lunsford 1989). Researchers who explored the motivations for forest management, objectives for conducting prescribed burns, and barriers to prescribed burning activity show myriad variables as potential influences of land manager behavior but do not test how these factors actually impact behavior. Other researchers have examined prescribed fire activity in North and South Carolina longleaf systems (Cely and Ferral 1995; Frost 1993), but do not consider underlying causes of land manager behavior. Frost (1993) notes that only 23 of 91 North Carolina longleaf sites he surveyed were managed with regular fire; the rest were in transition to other forest types. Cely and Ferral (1995) suggest that hardwood encroachment, the result of fire exclusion, was the leading cause of red-cockaded woodpecker loss in South Carolina longleaf systems between 1977 and 1989. Also, none of these researchers has examined seasonal use of prescribed fire in longleaf systems, a potentially critical part of longleaf preservation and restoration (Abrahamson. and Abrahamson 1996; Brockway 1997; Glitzenstein 1995; Platt 1988a; Streng 1993). I viewed the updating and expanding of this information base as an essential starting for a landscape-scale assessment of prescribed fire usage in remnant longleaf ecosystems of North and South Carolina.

The research described below addresses four primary objectives: (1) quantify and describe prescribed burning activity throughout remnant North and South Carolina longleaf pine ecosystems, (2) develop a detailed understanding of factors that impact prescribed burning activity by the managers of public and private longleaf lands, (3) quantify and describe patterns of seasonal prescribed fire usage and explore variables that influence these patterns, and (4) explore policy scenarios designed to make the prescribed burning environment of the Carolinas more hospitable.

To address these research objectives, I attempted to census the managers of ≥ 1000 acres of North and South Carolina longleaf pine forest by developing and implementing a self-administered, mail survey. With this tool I asked members of the survey population to consider their use of prescribed fire between 1996 and 2000; their motivations for longleaf forest management; their objectives for conducting prescribed burns; various social, legal, and economic barriers to prescribed burning; and to identify which policies they feel would make the prescribed burning environment in the Carolinas more hospitable. I used path analysis, a multiple regression tool, to explore the factors that affected the amount of longleaf burned in North and South Carolina between 1996 and 2000. After defining the prescribed burning problem in the Carolinas and analyzing those factors that affect prescribed burning activity, I proceed to analyze government programs that survey respondents favor to help them expand prescribed burning in remnant longleaf ecosystems.

BACKGROUND

Ecology of longleaf pine and longleaf pine ecosystems: climate, fire, and vegetation

When Europeans arrived in what would become the Southeastern United States, the ecosystems they found represented 10,000 years of development following the retreat of the Wisconsonian Ice Age glaciers, which had profoundly influenced the climate of the ice-free South (Delcourt et al. 1993). Following the Quaternary Period, climate patterns in the Southeast changed bringing increased summer warmth, moisture, and storm activity as well as increased drought severity and frequency of lightning strikes (Delcourt et al. 1993). These changes culminated around 4 ka in long growing seasons, high primary productivity, and the occurrence of widespread fire throughout the Southeast (Christensen 2000; Delcourt et al. 1993). The latter factor favored the expansion of fire-tolerant species, contributing to the growing frequency of low-intensity surface fires (Platt 1988b), which encouraged further expansion and overall dominance of southern pine, herbs, and grasses in the Southeast (Delcourt et al. 1993). By European settlement a forest intimately linked to the vegetation-fire cycle and dominated by a longleaf pine (*Pinus palustris* Miller) overstory and an herbaceous understory, dominated more than 60% of the Southeastern Coastal Plain and stretched into the Piedmont and sometimes the mountainous regions of what would become the Carolinas, Georgia, and Alabama (Frost 1993; Ware, Frost, and Doerr 1993).

Characteristics of regularly burned longleaf ecosystems favor the return of frequent fire (Frost 1993; Gilliam 1999; Glitzenstein 1995; Platt 1988b). Longleaf's heavy annual needle cast provides quickly dried, fine fuel, which, given its abundance and resin content, rapidly convert lightning strikes to low-intensity, widespread surface fires (Platt 1988b). Frequent fire also favors perennial grass species including wiregrasses (*Aristida* spp., *Sporobolous pinetorum*), bluestem grasses (*Andropogon* spp., *Schizachyrium scoparium*), Indian grasses (*Sorghastrum* spp.), and panic grasses (*Dichanthelium* spp., *Panicum* spp.) (Frost 1993; Peet and Allard 1993; Walker 1993; Walker and Peet 1983). These grasses provided a continuous fine fuel matrix across much of the Southeast and also intercepted cast longleaf needles, keeping them off the ground, easy to dry, and quick to burn (Clewell 1989). In the presettlement landscape the accumulation of dried plant parts allowed low intensity surface fires to burn throughout the Southeast on a 2- to 8-year cycle (Abrahamson and Hartnett 1990; Christensen 1993a; Christensen 1993b; Christensen 2000; Frost 1993). Fires that recur over such short intervals are known to favor grasses and herbs over woody species and longleaf pine over all other Southeastern tree species (Christensen 1993a; Christensen 1993b; Christensen 2000).

Short fire return intervals contributed to longleaf's dominance by opening and maintaining recruitment sites for seedlings (Brockway and Outcalt 1998; Glitzenstein 1995; Platt 1988b). Longleaf seedlings, like those of other southern pine, require a mineral seedbed for germination and are extremely intolerant of shade (Platt 1988b). Thus, successful recruitment of pine seedlings in a landscape characterized by long growing seasons and high primary productivity depends upon disturbance as a means of opening up sites with sufficient sunlight and soil resources and of controlling competing vegetation (Brockway and Outcalt 1998; Platt 1988b). The seedlings of *Pinus taeda*, *P. elliottii*, and *P. echinata* (southern pines) overcome the ephemeral nature of unoccupied sites by initiating height growth soon after germination enabling them to successfully compete for limiting resources in areas protected from fire. In contrast, longleaf seedlings, adapted to survive in a fire prone environment, enter the "grass stage" within six months of germination by sprouting a tuft of long, slender, drooping needles and then allocating carbohydrate resources to roots rather than shoots. This strategy, similar to that of many fire-adapted species, enables them not only to resprout needles quickly if the seedling is defoliated during a fire, but also protects the terminal bud during fire. In addition underground reserves enable longleaf seedlings to bolt from the grass stage when the carbohydrate-rich taproot becomes sufficiently large to propel the terminal bud above flame lengths in the span of a few years (Platt 1988b). In the absence of frequent fire, longleaf seedlings cannot compete with faster growing mesophytic pine and hardwood seedlings. Regeneration of longleaf and the herbaceous groundcover is eliminated within a few years of fire exclusion on all but the driest sites due to invasion of highly competitive species (Frost 1993). Without fire, longleaf ecosystems cannot survive intact.

The Southeastern landscape and humans: the effects of culture on fire ecology

In the presettlement Southeastern landscape, low intensity surface fires burned throughout longleaf's range on a 2-to 8-year cycle (Abrahamson and Hartnett 1990; Christensen 1993a; Christensen 1993b; Christensen 2000; Frost 1993). On the Atlantic and Gulf Coastal Plains, which contained large fire compartments uninterrupted by bodies of water or topographic variation, widespread, lightning-ignited fire occurred frequently enough to ensure longleaf ecosystem dominance of the uplands (Frost 1993; Ware, Frost, and Doerr 1993). However, in areas of the Coastal Plain, Piedmont, and southern Appalachians dissected by streams and steep slopes, longleaf ecosystems grew in small fire compartments that were probably protected from widespread, lightning ignited fires during most years. Burning by Native Americans on these sites may have facilitated the persistence of longleaf ecosystems by shortening the fire return interval (Frost 1993; Ware, Frost, and Doerr 1993). Natives used fire in the fall and winter to drive game, open the woods to ease travel, prepare land for agriculture, control insects, and increase the abundance of desirable plants (Cronon 1983; Johnson and Gjerstad 1998)

European settlers also made extensive use of fire (Komarek 1974; Ware, Frost, and Doerr 1993) both adopting Native practices and importing practices from Europe (Pyne 1997). Like Native Americans, they used fire to open up the woods, control insect pests, and improve wildlife habitat and hunting (Johnson and Gjerstad 1998). Settlers also used fire to provide forage for livestock and protect "orchards" of pine they tapped for the production of naval stores (Frost 1993; Johnson and Gjerstad 1998; Rosene 1969). The widespread and generally indiscriminate use of fire by Europeans (Wahlenberg 1946) lasted until the advent of forestry following the Civil War (Komarek 1974) and the passage of stock laws in the 1940s, which ended open grazing throughout the South (Rosene 1969).

Inhabitants of the Southeast have long extracted resources from their forested environments and in many cases radically changed ecological processes of the Southeast (Cronon 1983; Komarek 1974; Rosene 1969). Within the range of longleaf Native Americans cleared small patches of forest for small-scale subsistence agriculture (Cronon 1983; Komarek 1974) that supplemented the diet collected from hunting, fishing, and gathering. But their widespread use of fire probably more than offset the small area of longleaf forest they cleared. Early in the Colonial Period settlers also cleared land for small-scale agriculture and farm development, a process limited by labor supply, animal power, and distance to markets. However, as a consequence of the Industrial Revolution, the introduction of the railroad, a growing settler population, and a growing U.S. economy, nearly all longleaf stands optimally suited for agriculture were in production by the end of the Civil War, and by 1900 nearly 1/4 of the original longleaf forest had been cleared for crops (Ware, Frost, and Doerr 1993).

Use of the longleaf pine resource for its economic potential began in 1604 at the original Jamestown with the processing of a few barrels of naval stores (Frost 1993; Ware, Frost, and Doerr 1993). The production of pitch, rosin, turpentine, and tar was at first inefficient and therefore limited in scope. Settlers collected large quantities of raw materials by burning longleaf branches in earthen pits and collecting the tar that oozed out of the branches, or by "boxing" mature longleaf pines to collect crude gum for turpentine. These raw materials, generally filled with impurities, were then shipped to English seaside ports for processing (Frost 1993; Pomeroy and Yoho 1964). Upon the introduction of the copper whiskey still to naval stores industry around 1834, turpentiners could refine their product in the woods and ship the finished goods to commercial ports, easing transportation problems and increasing the profitably of their operations. The process became highly efficient and exploitation of longleaf widespread. By 1894, W.W. Ashe estimated that only 56,000 acres of untapped longleaf pine timber and 700,000 acres of "abandoned orchards" remained out of forests that once covered four to five million acres of the North Carolina Coastal Plain. Following the exhaustion of longleaf in North Carolina, the boom-bust economy of naval stores production moved south into South Carolina, Georgia, and other southern states (Pomeroy and Yoho 1964).

The impact of settlers outside North Carolina and Virginia on the longleaf forest was relatively minor up through the 1870s and the end of the Civil War. Between 1607 and the mid-1730s, logging was done by hand, using horses and mules to drag logs to streams where the sawn timber could be transported to ports. Milled boards were mostly used locally as they were laboriously sawed by hand. Water-powered sawmills were introduced in the 1730s and increasing the efficiency of milling so that by 1880 all commercial timber had been removed from lands within a few miles of navigable streams. After the Civil War, however, timber companies initiated the large-scale exploitation of the longleaf resource by applying steam technology to logging, enabling them to harvest formerly untouched, interior, virgin stands of longleaf by laying railroads and employing efficient steam skidders and steam-powered sawmills. The pace of intensive, commercial logging was so great that between 1880 and 1930, virtually all of the remaining virgin longleaf forest, an estimated 1.2 *trillion* board feet of merchantable lumber, was harvested (Ware, Frost, and Doerr 1993).

In addition to agriculture, naval stores, and logging devastating the longleaf resource throughout its range, longleaf forests did not replace themselves following exploitation. Three factors are considered primary contributors. First, the absence of seed-bearing adults (Wahlenberg 1946) and the inherently low restocking of longleaf stands under a natural fire regime might require 300 years for a stand to fully recover following logging (Ware, Frost, and Doerr 1993). Second, free ranging livestock, especially feral hogs (Wahlenberg 1946), exhibit an extraordinary fondness for grass stage longleaf seedlings and have been observed to eat up to 400 in a single day. Given that longleaf seedlings may stay in the grass stage for nearly a decade and that feral hog populations once approached saturation densities in the Southeastern woods, whole cohorts of potential longleaf recruits left following logging were eaten in matter of years (Frost 1993; Outcalt 2000; Wahlenberg 1946; Ware, Frost, and Doerr 1993). Third, the era of modern fire suppression beginning with the passage of state fire laws around 1920, extirpated longleaf seedlings and their herb counterparts from all but the driest harvested sites as they could no longer compete with mesophytic pines, hardwoods and shrubs that inevitably invaded after only a few years of fire exclusion (Wahlenberg 1946; Ware, Frost, and Doerr 1993).

The roles of fire suppression and forestry in the decline of longleaf pine ecosystems

Although logging and naval stores affected a greater percentage of the Southeastern land base than agriculture, the intensive nature of farming, the growth of weeds, and the low reproductive rates of the perennial herbs and grasses that dominated longleaf ecosystems essentially eliminated the ability of these species and longleaf seedlings to reinvade lost area. Logging and naval stores activity reduced longleaf's area but tended to leave most of the groundcover intact (Clewell 1989; Noss 1989; Noss 1990; Noss, LaRoe, and Scott 1995; Wahlenberg 1946). As long as lightning- and resident-ignited fires burned through the landscape the herbaceous component of many longleaf ecosystems would hypothetically remain and where seed sources remained, longleaf would eventually come to replace much of the area it lost to exploitation (Frost 1993; Rosene 1969; Wahlenberg 1946). In the eyes of foresters, however, frequent burning prevented the establishment of the forest to replace the ravaged, primeval one, and so they sought to protect all lands from fire (Johnson 1996; Pyne 1997; Wahlenberg 1946).

Forestry and forest management first came to the South around 1920 (Johnson 1996). The virgin longleaf forest was harvested so quickly that much of the Southeastern landscape was at that time devoid of trees (Wahlenberg 1946). Newly trained forestry professionals, who saw the widespread and indiscriminate use of fire as the main barrier preventing the re-establishment of the forest, advocated strict fire suppression and prevention (Dahl et al. 1981;

Pyne 1997; Rosene 1969). Foresters, most of whom had been trained in Europe and the Northern United States and studied forests that function under very different ecological processes, saw all fire as unnatural and destructive and its use counter productive and primitive (Pyne 1997; Wahlenberg 1946). These conclusions motivated them to end all burning regardless of purpose (Komarek 1974). The U.S. Forest Service, with support from the conservation movement of President Theodore Roosevelt and his advisor Gifford Pinchot, furthered this effort by starting a propaganda campaign aimed at convincing the public that fire was unnecessarily destructive and unnatural especially to wildlife (Komarek 1974).

The fire protection policies initiated by scientists, government officials, and foresters succeeded in regenerating a second forest, but not one that resembled its predecessor. While the effects of fire exclusion varied along a hydrologic gradient (drier sites remained more stable in species composition while wetter sites underwent significant change) the resulting change in the forests of the Southeastern was unmistakable (Christensen 2000; Plocher 1999). The dominance of longleaf pine and perennial herbs in the Southeast plummeted while the importance of loblolly pine (*Pinus taeda*) and hardwoods in the forest canopy and woody shrubs in the understory, species once restricted to areas protected from frequent fire, exploded by seeding into abandoned fields and cutover forestlands (Ware, Frost, and Doerr 1993). Fire suppression eliminated the chances of longleaf pine regeneration and extirpated the vast majority of the herb layer that remained following logging (Clewell 1989; Frost 1993; Gilliam 1999). The efforts of fire suppression were so successful, in fact, that of the 2.95 million acres of longleaf that remain in the South today (Outcalt and Sheffield 1996) less than 674,000 acres (0.7% of the original area) truly resemble the original forest that dominated nearly 92 million acres (Frost 1993).

Fire suppression also made plantation forestry of fast growing but fire susceptible pines feasible and profitable (Pyne 1997), which led to the further decline of longleaf ecosystems. By the 1940s fire protection and the cessation of indiscriminate woods burning protected plantation investments that otherwise would have had a high probability of being destroyed by fires. Plantation forestry become so profitable that by the end of World War II, the large timber companies that favored second growth longleaf for its high quality logs and poles were acquired by pulp and paper companies that considered the initially faster growing and easily established loblolly (*Pinus taeda*) and slash pines (*P. elliottii*) better trees than longleaf to maximize short term finances (Landers 1995). The conditions of plantation forestry (tight stocking, fire protection, and mechanical site preparation) eliminated longleaf regeneration as well as any remnants of the native herbaceous component present (Wahlenberg 1946). Furthermore, its profitability has turned some 31 million acres of the Southeastern landscape into blocks of plantation pines (Sheffield and Dickson 1998), which generally support very little native species diversity (Guldin and Wigley 1998).

<u>Prescribed fire: history, usage, and effectiveness</u>

Despite the efforts of the U.S. Forest Service to eradicate fire from the landscape and the support the effort enjoyed with the general public, early in the twentieth century a few researchers came to realize the virtues of regular burning [e.g., Harper, 1913 #66; Wahlenberg, 1946 #98; Rosene, 1969 #181; Komarek, 1974 #176]. Harper noted in 1913: "it can be safely asserted that there is not and never has been a long-leaf pine forest in the

United States ... which did not show evidence of fire, such as charred bark near the bases of the trees; and furthermore, if it were possible to prevent forest fires absolutely the long-leaf pine—our most useful tree—would soon become extinct." H.H. Chapman began experimental work in 1923 on the use of fire and the management of longleaf pine. S.W. Green, who worked in animal husbandry, proved that cattle grazed on burned land gained more weight than those grazed on unburned pasture. Beginning in 1924 the work of Herbert L. Stoddard and the Cooperative Quail Study Investigation demonstrated that fire protection resulted in the elimination of food and nesting sites for bobwhite quail (*Colinus virginianus*) whereas regular fire maintained and enhanced these necessities (Komarek 1974).

The efforts of Stoddard, in particular, demonstrated that the regular, careful use of fire could enhance site quality and species diversity to the benefit of wildlife. Stoddard's methods of regular, planned burning were demonstrably effective and were incorporated into the management procedures of many private quail hunting preserves from North Carolina to Arkansas (Komarek 1974). Supplementary work by Rosene (1969) also demonstrated the link between fire, habitat, and the abundance of desired, native species. The legacy of Stoddard and Rosene's work lives on as some the highest quality longleaf sites that remain today exist because the managers of private quail hunting preserves adopted their techniques. A few prime examples are: the Wade Tract near Tallahassee, Florida (Komarek 1974); the Ichauway Preserve in Baker Country, Georgia (Drew 1998); Okeetee Club, near Ridgeland, South Carolina; and Groton Plantation, near Estill, South Carolina (Rosene 1969).

The effectiveness of prescribed burning to meet management objectives keeps fire burning through many parts of the Southeast, but on a limited basis. Lightning and human carelessness may ignite thousands of wildfires annually, but in most years the extent of these burns do not exceed 4 million acres in the entire United States in a highly fragmented landscape with limited fuel continuity and highly mobile fire-fighting crews. In contrast, many forestland managers and landowners set fires intentionally to meet a variety of land management objectives (Wade and Lunsford 1989). Prescription burning is a cost effective means of reducing hazardous fuel loads, preparing sites for seeding and planting, disposing of logging debris, improving wildlife habitat, managing competing vegetation, controlling disease, enhancing aesthetics, improving woodland access, perpetuating fire-dependent species, and managing endangered species. Land managers annually burn roughly 8 million acres in the South, a small but growing percentage of Southeastern land base (Wade and Lunsford 1989). Furthermore, prescribed burning is the only tool available to maintain and rehabilitate longleaf ecosystem remnants that can no longer rely on sufficiently frequent lightning ignition (Brennan et al. 1998; Johnson and Gjerstad 1998).

Most prescribed burning is conducted during the dormant season (October to March), yet fires naturally occurred during the growing season (April to September), especially in the early growing season. Researchers have hypothesized that the timing of fire may be critical to the maintenance of native species diversity (Abrahamson. and Abrahamson 1996; Brockway 1997; Glitzenstein 1995; Hiers, Wyatt, and Mitchell 2000; Jacqmain 1999; Platt 1988a; Robbins and Myers 1992; Streng 1993). Regular dormant season fires may maintain open, grassy understories by successfully controlling competing species, but dormant season burns may alter the flowering and reproductive success of many native plant species (Clewell 1989; Platt 1988a), which may affect insect pollinators and cascade into higher trophic levels (Hiers, Wyatt, and Mitchell 2000). Growing season fires, on the other hand, may be a better conservation tool because the pyrophytic species inhabiting longleaf systems evolved with growing season burns as a selective force (Christensen 1993b). Despite these ideas seasonal burning seems to have little effect on species diversity indicating that frequency of burning is more important to biodiversity than season (Platt 1988a; Platt and Rathburn 1993; Robbins and Myers 1992; Streng 1993). Nonetheless, growing season burns may be the most conservative approach toward maintaining and enhancing species diversity.

Prescribed fire: barriers to burning activity

Those land managers who use prescribed fire to meet their management objectives put themselves at potentially serious social, economic, and legal risk (Cleaves and Haines 1995; Cleaves, Martinez, and Haines 2000; Haines and Cleaves 1999; Wade and Outcalt 1999). If a fire escapes its intended boundaries endangering nearby residences, shifting winds blow smoke onto a nearby roadway or smoke sensitive structure, or local residents are forced to stay indoors because of temporarily poor air quality, land managers and public agencies run the risk of losing public support for burning efforts and/or being sued for damages (Haines and Cleaves 1999; Wade and Outcalt 1999). These risks and other limiting factors may reduce the willingness of longleaf managers, both public and private, to use prescribed burning (Cleaves and Haines 1995; Cleaves, Martinez, and Haines 2000; Haines and Cleaves 1999).

The state legislatures of North and South Carolina have recently recognized the personal risks of using prescribed fire and the importance of fire as a management tool as well as its benefits to public safety, forest and wildlife resources, the environment, and state economies (North Carolina Prescribed Burning Act, 1999). Each state has passed laws designed to "*encourage* prescribed burning in forests by forest landowners" (North Carolina

Prescribed Burning Act, 1999) [italics added] by protecting those willing to be certified by the state. As long as these "certified burners" follow specific standards while burning, their legal liability is partially reduced, which it is hoped will encourage the expanded and responsible use of prescribed fire (see South Carolina Prescribed Fire Act, 1994 and North Carolina Prescribed Burning Act, 1999).

Although these Acts may give confidence to some forest landowners and managers who have interests in prescribed fire, protecting them from legal liability is only a part of *encouraging* prescribed burning (Bonnie 1997; Cleaves and Haines 1995; Cleaves, Martinez, and Haines 2000; Haines and Cleaves 1999; Wade and Outcalt 1999). In the National Forest System, forest managers may have their burn programs restricted by air quality and smoke management regulations, narrow burn windows, funding problems, and agency risk reduction policies (Cleaves, Martinez, and Haines 2000). Industrial forest landowners may burn less than management objectives might otherwise dictate because of concerns about site productivity and tree growth, insurance costs (Haines and Cleaves 1999), and the difficulties of complying with internal, state, and federal policies that regulate burning (Wade and Outcalt 1999). Non-industrial private forest landowners may limit their burning due to increasing costs of burn crews and insurance, increased regulation, smoke management regulations (Cleaves and Haines 1995), and fear of restriction from the Endangered Species Act (Bonnie 1997; Costa 1995a; Costa 1995b). The many barriers not addressed by the "certified burner" laws of North and South Carolina suggest that policy makers may not be fully cognizant of the factors that limit prescribed burning, which, in turn, limits its ecological and social benefits.

Direct conflicts between federal environmental acts may also hamper the use of prescribed fire. The ecosystem management efforts of federal agencies (Estill 1999) and §7(a)(1) of the Endangered Species Act explicitly promote the use of prescribed fire to aid longleaf ecosystem and endangered species recovery, respectively. However, other federal legislation directly compromises these goals. The Clean Air Act regulates, as one of six criteria pollutants, particulate matter, the primary pollutant from the burning of vegetation. As a result, regulation of prescribed burning to meet national and regional air quality goals, may adversely affect prescribed burning programs (Hauenstein and Siegel 1980), ecosystem management, endangered species recovery, and longleaf ecosystem survival.

Major policies affecting today's longleaf pine ecosystems and the use of prescribed fire:

Recent trends suggest that management of federally owned lands may be advancing longleaf pine ecosystem recovery efforts (Brennan et al. 1998). Funding for prescribed burning among the federal land management agencies who report to the National Interagency Fire Center (NIFC) (e.g., Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, National Park Service, and the USDA Forest Service) increased nearly five-fold from 1995 to 1999 ($20,446,000 in 1995 to $99,104,000 in 1999) according to NIFC figures. [The $99,104,000 invested in prescribed burning during 1999 pales in comparison to the $523,468,000 spent on fire suppression costs by the federal agencies.] And area burned doubled between 1995 and 1999 (918,300 acres in 1995 to 1,843,456 acres in 1999) (http://www.nifc.gov/stats/prescribedfirestats.html). Given that roughly one-third of the prescribed fires ignited (1,800 of 5,937) and fully half the area burned by these fires (938,578 acres of 1,843,456 total acres) in the entire United States occurred in the Southern region, the future prospects for longleaf on federally owned lands might be improving (http://www.nifc.gov/fireinfo/1999/hilites.html).

Longleaf conservation has also become a top priority for the federal land management agencies and Department of Defense installations (Estill 1999). The USDA Forest Service and the Department of Defense, which together manage the largest remaining area of publicly owned longleaf pine forests, are devoting a significant amount of resources to red-cockaded woodpecker (RCW) recovery efforts. RCW, a federally protected species, favors old-growth longleaf pine stands free of a woody underbrush for foraging and nesting. The land management agencies are working to enhance and restore RCW habitat by burning existing longleaf stands, creating nesting cavities in young longleaf pines, and removing off-site pines to replant these areas with longleaf seedlings (Cely and Ferral 1995; Costa 1995b; Ortego, Krueger, and Barron 1995).

In contrast to longleaf ecosystem management by federal agencies, longleaf management on state, county, and private lands throughout the South is much more troubling. Although state and county land managers generally assist in endangered species recovery efforts and have done a considerable amount of longleaf pine ecosystem restoration, strained budgets and lack of personnel may hamper their ability to burn, and thus their ecosystem management goals (Cely and Ferral 1995). Longleaf habitat loss and degradation is even more pervasive on privately owned than publicly owned lands (Bean 1998; Cely and Ferral 1995; Costa 1995a; Ortego, Krueger, and Barron 1995; Outcalt 1997) perhaps partially due to the lack of incentives to actively use prescribed fire (Bean 1998; Bonnie 1999; Costa 1995a). Unless management objectives (e.g., wildlife management or aesthetic enjoyment) otherwise require it, the use of regular prescribed burning by private land managers may increase their management expenses unnecessarily (Wilcove and Chen 1998). Section 9 of the Endangered Species Act (ESA), which prohibits the "taking" of protected species, may deter many landowners and land managers from using regular burning. From the property owner's point of view, sound stewardship may not only attract endangered wildlife species, but also federal regulators, land use restriction, and legal liability (Bonnie 1999). These factors contribute to the erosion of the longleaf resource on private lands, which is especially significant given that private landowners control some 90% of the Southeastern land base.

The U.S. Fish and Wildlife Service (USFWS), the agency largely responsible for enforcing the mandates of the Endangered Species Act, has stepped in to help improve the situation for longleaf ecosystems and endangered species recovery on non-federal lands. Safe Harbor Agreements for RCW are available to all landowners in South Carolina as well as landowners in the North Carolina Sandhills. Program participants enter into a cooperative agreement with USFWS or a state agency to enhance habitat for existing populations of endangered species. Enrollment in the program relieves landowners of the responsibility to protect any additional RCW that may be attracted by the improved habitat. As part of the agreement landowners who participate in the Safe Harbor Program develop a Habitat Conservation Plan not only to maintain existing RCW habitat but also create new habitat for RCW. USFWS hopes that this program will protect original habitat and encourage landowners to maintain most newly created habitat in exchange for assurance that no future regulatory restrictions will be imposed if management activities do attract endangered species. One unfortunate aspect of this program for longleaf pine *ecosystem* recovery is that one can provide habitat for RCW without burning or protecting native ground cover.

Other federal environmental legislation impacts prescribed burning. The Clean Air Act of 1970 and its 1977 and 1990 Amendments charge each state in the country with the responsibility of meeting National Ambient Air Quality Standards (NAAQS) and preventing the significant deterioration of air quality. NAAQS require states to limit the amount of particulate matter (PM), and five other criteria pollutants, in the ambient air in order to maintain compliance with the Clean Air Act. These regulations are designed to provide respiratory protection for vulnerable populations such as asthmatics, the very young and very old. If cities, counties, or states violate NAAQS, they are deemed non-attainment areas, which can carry a number of statutory penalties.

In order to maintain compliance with NAAQS, states regulate prescribed burning activity through smoke management guidelines. These rules affect all burners, public and private. To regulate burning, the state forestry agencies require notification of burning activity, collecting information on the area to be burned, fuel loading, weather conditions, height of dispersal winds, wind direction, and other factors. Basing their decisions on weather conditions (temperature, humidity, wind direction), the agencies then determine if a given burn can go forward as planned, needs to be reduced in area, or may not proceed. Based on weather conditions and location to smoke sensitive structures, these regulations may significantly reduce the area of longleaf pine forest burned each year.

Population growth and subsequent local development also have a significant effect on burning. Between 1970 and 1998, the population of the South (VA, NC, SC, GA, FL, AL, MS, AR, LA, TX, and OK) grew from 56 million to 86 million, a 54% increase in just 28 years. Perhaps more significantly for longleaf management, portions of the Southeastern Coastal Plain of South Carolina, Georgia, and Florida grew the fastest at 87.3% (Cordell et al. 1998). Cordell, et. al. (1998) state that "*population growth* is and will continue to be THE most significant factor influencing what natural resource managers do, might think about doing or can do" as they seek to carry out their missions. Population growth makes burning and general resource management more difficult, which can contribute to the qualitative degradation of fire-dependent communities and ecosystems. Population growth also results in quantitative degradation of longleaf ecosystems: average patch size decreases as population density increases (Wear, Abt, and Mangold 1998). As patches of longleaf and other forest types decrease in size, not only do the marginal costs and risks of burning increase, but forest fragmentation also reduces the ecological value of forest remnants (Simberloff 1993).

Even for remnant longleaf systems that undergo no further fragmentation, population growth makes managing the side effects of burning (e.g., smoke emission, particulate matter emissions, liability risks) increasingly difficult (Cordell et al. 1998). Smoke from prescribed burns may inadvertently interfere with smoke sensitive structures like schools, hospitals, and roadways potentially raising the liability risks of a burner (Achtemeier et al. 1998). And as areas near longleaf sites are developed, weather conditions (e.g., temperature, humidity, and wind direction and smoke dispersal heights especially) may become more limiting, reducing the amount of longleaf burned annually.

Local development policies may have serious, negative consequences for longleaf management for several reasons: 1) Decisions governing land-use change occur almost exclusively at the local level; therefore, they are made a different times and locations (Theobald et al. 2000). 2) Local jurisdictions have nearly exclusive control over land use on the land in the Southeast not in federal ownership (Crist, Kohley, and Oakleaf 2000). 3)

Biodiversity is rarely a serious component of local government planning and regulation of land use (Crist, Kohley, and Oakleaf 2000). 4) Local governments are the primary planning and regulatory authority for the low-elevation, highly-productivity, and most threatened ecosystems (Noss, LaRoe, and Scott 1995).

Conservation priorities: reasons to restore longleaf

Although the area of fire-maintained longleaf systems throughout the Southeast has declined steadily and dramatically since European settlement, public support for longleaf conservation only recently received attention (Johnson 1996). The formation of organizations like the Longleaf Alliance at Auburn University, Alabama has helped to inform the public about the unique biological, ecological, cultural, and economic values of longleaf forests. Many of the values associated with longleaf ecosystems include:

1 Fire-maintained longleaf ecosystems have been shown to support species diversity unparalleled in North America. In an annually burned, mesic, longleaf pine-wiregrass savanna found in the Green Swamp of North Carolina, Walker and Peet (1983) found up to 42 species/0.25 m^2 and 84 species/625 m^2. And of the 290 species of herpetofauna native to the Southeast, 170 (74 amphibian, 96 reptiles) may be found in remnant longleaf pine ecosystems (Dodd 1995). Longleaf systems also support hundreds of avian and mammalian species (Engstrom 1993).

2 Fire-maintained longleaf ecosystem remnants support 389 rare plant taxa, of which an estimated 187 (48%) are considered vulnerable to extinction due to severe habitat reduction and fire suppression (Walker 1993). The U.S. Fish

and Wildlife Service (USFWS) has given 84 of these taxa status under the Endangered Species Act (Hardin and White 1989).

3 Colonies of the federally endangered red-cockaded woodpecker favor, for both nesting and foraging, mature stands of longleaf pine free of a woody midstory. Other longleaf pine ecosystem residents given status or currently candidates for listing by USFWS include: the gopher tortoise (*Gopherus polyphemus*), the flatwoods salamander (*Ambystoma cingulatum*), striped newt (*Notophthalmus perstriatus*), Carolina and dusky gopher frogs (*Rana capito capito* an *R. c. sevosa*), eastern indigo snake (*Drymarchon corais couperi*), and Florida pine snake (*Pituophis melanoleucus mugitus*).

4 Many natural longleaf pine ecosystems are critically endangered due to habitat loss and degradation (Noss, LaRoe, and Scott 1995) and are threatened by continued fire suppression.

5 Longleaf pine and wiregrass served as the keystone species in a complex of fire-dependent Southeastern ecosystems (Clewell 1989; Noss 1989; Outcalt 2000). These species grow across a range of hydrologic gradients (from xeric sandhills to wet savannas) and carry fires not only across longleaf-wiregrass ecosystems (Peet and Allard 1993), but also into neighboring communities (Abrahamson and Hartnett 1990; Outcalt 1999; Stout and Marion 1993). Many of these species are critically imperiled due to fire suppression and fragmentation of the landscape (Frost 1993; Noss, LaRoe, and Scott 1995).

METHODS

The Conceptual Framework

This study describes and analyzes patterns in prescribed burning activity among the managers of ≥ 1000 acres of North and South Carolina longleaf pine forest. I use a conceptual model, following the rationale of Kurtz and Lewis (1981), to examine the associations among (1) demographic variables (e.g., ownership, enrollment in Safe Harbor Program), (2) motivations for longleaf pine forest management, (3) objectives for using prescribed fire, (4) constraints that limit prescribed burning activity, and (5) land manager behavior (i.e., prescribed burning activity). To explore the relative impact of demographics, motivations, objectives, and constraints on behavior I employed path analysis. This technique, which uses ordinary least squares regression to decompose bivariate correlations, is appropriate for examining hypothesized patterns of causation among the set factors believed to influence land manager behavior (Kingsolver and Schemske 1991; Pedhazur 1982). I also asked respondents to consider programs that might help to make the prescribed burning environment of the Carolinas more hospitable.

Previous studies examining prescribed burning activity and the variables that influence it lack an explicit theoretical framework and fail to explore the interplay between factors potentially influencing land manager behavior and land manager behavior, *per se*. I drew upon literature on forestland *owner* decision-making (Hyberg and Holthausen 1989; Kurtz and Lewis 1981; Megalos 1999; Royer 1987; Sampson and DeCoster 1997) and factors influencing forestland *manager* behavior (Bonnie 1999; Cleaves and Haines 1995; Cleaves, Martinez, and Haines 2000; Haines and Cleaves 1999; Wade 1993; Wade and Outcalt 1999; Wade and Lunsford 1989), to develop my conceptual framework.

Research Approach

I surveyed the managers of 1000 acres or more of North and South Carolina longleaf pine forest (at least 60% longleaf pine overstory) because this group manages the vast majority (ca. 80%) of the Carolinas' remnant longleaf (E. C. Franklin, personal communication). Thus, with a small sample (I believe that fewer than 100 people manage 1000 or more acres of longleaf in the Carolinas), one can efficiently and thoroughly assess prescribed burning activity on a landscape-scale. Furthermore it is the annual decision-making and behaviors of these few individuals that directly affect the ecological well-being and future prospects for most of the Carolinas' remnant longleaf pine ecosystems.

I did not survey the managers and owners of smaller longleaf tracts for a variety of sociological, biological, and practical reasons. (1) It is believed that managers of large tracts (several hundred acres) are more likely to burn than the managers and owners of smaller, more fragmented tracts. (2) Small holders are less likely to manage forests for any purposes, even profit-oriented ones (Megalos 1999), and tend to be risk averse (Bliss et al. 1994; Cordell et al. 1998; Hyberg and Holthausen 1989; Megalos 1999; Pomeroy and Yoho 1964; Royer 1987). (3) Small-time holders do not receive economy-of-scale benefits, so the costs of burning per unit area are greater than for large holders. (4) Fragmented tracts may be more difficult and more risky to burn than large ones, especially those occupying the wildland-urban interface (Winter and Fried 2000) where costs of burning are noticeably greater (Cleaves and Haines 1995; Haines and Cleaves 1999; Larson 1978; Roussopoulos 1998; Wade 1993). (5) In a landscape characterized by fragmentation, large tracts are presumably of greater biological value than small tracts (Simberloff 1993). (6) Identifying even a portion of small holders of remnant longleaf systems seems beyond the scope and time constraints of this work. It should be noted, however, that some small longleaf tracts are regularly burned by small holders and are of greater biological value than large tracts that have not been regularly burned or have been converted to other land uses.

Survey Methods

To address the factors impacting the use of prescribed fire by those who manage longleaf pine forests in North and South Carolina, I developed and implemented a self-administered survey—"Longleaf Pine Management in the Carolinas: A Survey of Land Managers"—following the Tailored Design Method (Dillman 2000). See Appendix B

Sample Selection:

The survey population consisted of individuals who manage at least 1000 acres of longleaf pine forest (at least 60% longleaf) in the Carolinas. This minimum area need not have been contiguous and could have been scattered across several ownerships or habitat types. Members of the survey populations include the managers of non-industrial private forestlands (e.g., consulting foresters, hunt club managers, and non-government organization lands), forest industry lands, and public lands (e.g., National Forest, state park, National Wildlife Refuge, and Heritage Program lands).

To identify members of the survey population, several sources of information were required. Initially, lists of longleaf sites were obtained from Dr. Robert K. Peet of the University of North Carolina and Patrick McMillan of the North Carolina Museum of Natural Sciences. These lists included site location, land manager names, and, often, contact information. Information regarding the identity of other longleaf pine managers was obtained through email and telephone contacts with employees of the U.S. Fish and Wildlife Service, the U.S. Forest Service, the South Carolina Forestry Commission, the North Carolina Division of Forest Resources, the North Carolina Wildlife Resources Commission, the North Carolina Department of Agriculture, the Sandhills Area Land Trust, the North and South Carolina chapters of the Nature Conservancy, the Coastal Land Trust, Ducks Unlimited, Clemson University, North Carolina State University, and consulting forestry firms. These telephone contacts usually provided names and telephone numbers of potential members of the survey population.

Once names and telephone numbers were gathered, I contacted each potential member of the survey population for three primary reasons. I wished to determine (1) whether a contact did in deed manage ≥ 1000 acres of longleaf in the Carolinas, (2) if so, whether he or she would participate in a survey of longleaf pine management in the Carolinas, and (3) if so, to confirm or obtain an accurate mailing address to which to send the survey. Approximately 70 of 84 potential survey respondents were contacted in this manner. The other 14 were mailed an introductory letter and survey packet without prior telephone contact.

Study Design

The 7-page survey and follow-up questionnaire contained 24 separate questions relating to management goals, prescribed burning objectives, constraints that limit land manager willingness to conduct prescription burns, behavior, and various demographic variables. The survey was peer reviewed by 20 researchers with expertise in longleaf management, longleaf ecology and conservation, economics, the Endangered Species Act, and forestry. The Academic Affairs Institutional Review Board at the University of North Carolina at Chapel Hill then reviewed and approved the survey (AA-IRB Request Number: IRSS 2000-010, submitted 18 July 2000). The survey was pilot tested prior to distribution by a group that consisted of three members of the survey population who individually completed the survey. No style or editorial changes were recommended or incorporated into the final survey. Between July and September 2000, 84 copies of a self-administered survey were mailed to the managers of ≥ 1000 acres of North and South Carolina longleaf pine forest (at least 60% longleaf pine overstory). The questionnaire and related correspondence can be found in Appendix A.

Closer examination of data collected regarding land manager behavior proved both inadequate and difficult to analyze. To correct these problems, I developed a brief follow-up survey in which I asked only respondents to the original questionnaire to consider their use of prescribed fire between 1996 and 2000. Respondents were asked to provide information about (1) the area of longleaf they burned once between 1996 and 2000 and (2) the area of longleaf they burned *more than* once between 1996 and 2000. Approximately 40 of the 64 original respondents were contacted by telephone. Each of the respondents I failed to contact by telephone was sent a brief introductory letter and postcard that addressed the same questions (see Appendix A). Contact of these individuals was made between November and December 2000.

Survey Administration

Rather than conduct a random survey of longleaf pine management, I attempted to census all managers of at least 1000 acres of longleaf pine forest so as to provide a landscape-scale assessment of longleaf management. Participants received an initial survey followed by a thank you/reminder post card two weeks later. A second survey was sent to all non-respondents after two months. Undeliverable surveys were discarded. The overall response rate was 76% (64 of 84 potential respondents), remarkably high in comparison to previous attempts to survey this group (Robert M. Franklin, personal communication). Non-response to follow-up questions decreased the useable response rate to 63% (53 of 84 potential respondents). Data were analyzed using the SPSS 10.0 (1999) statistical software package.

Measures

The measures used in the investigation of land manager behavior consist of self-reported ratings of preferences and opinions and estimations of area managed and area burned. Five sets of measures were used. They include:

1. Demographic variables (a) public or any of five private ownership types, (b) enrollment of longleaf site(s) in Safe Harbor Program, and (c) state certification under "certified burner" laws.
2. Motivations for longleaf forest management (i.e., desired management outcomes). Motivations were determined by response to 8 variables, each rated on a 5-point Likert scale ranging from "not at all important" to "extremely important."
3. Objectives for conducting prescribed burns. Response to 14 variables, each rated on a 5-point Likert scale ranging from "not at all important" to "extremely important."

4. Constraints (i.e., variables that limit willingness to conduct prescribed burns). Variables constraining respondents were determined by response to 17 variables, each rated on a 5-point Likert scale ranging from “not at all limiting” to “extremely limiting.”
5. Land manager behavior. Aspects of manager behavior determined were measures of the area of longleaf burned as a fraction of total longleaf area managed. Specifically, response variables I used included (1) longleaf area burned between 1996 and 2000 divided by area of longleaf managed and (2) longleaf area burned more than once between 1996 and 2000 divided by area of longleaf managed. Respondents also indicated in a separate question (3) the percentage of longleaf area they manage with longer than preferred prescribed burn rotations (see above).

Variable selection

The large number of different individual variables that describe motivations, objectives, and constraints makes quantitative analysis of land manager behavior difficult. Furthermore, the small number of respondents who returned completed surveys (n = 53) limits the complexity of models that could be used to explore land manager behavior. Therefore, reducing the large list of individual variables describing (1) essential demographic features, (2) motivations for forest management, (3) objectives for conducting prescribed burns, and (4) constraints to conducting prescribed burns is necessary.

To determine the existence of statistically significant relationships between land manager behavior and any of the selected demographic variables (e.g., ownership, enrollment in the Safe Harbor Program, and State certification under the “certified burner” laws) I ran Pearson’s correlation analysis. I used Principal Components Analysis (PCA) to simplify the observed data describing motivations, objectives, and constraints prior to selection for and inclusion in the path model. Specifically, I used PCA to reduce a large set of measured, or observed, intercorrelated variables into a small suite of independent axes that optimally summarize key information in terms of linear combination of the observed variables.

All individual measures of motivations, objectives, and constraints whose average score among all respondents was 2 or greater were included in the PCA. This step provides insight into the underlying variables affecting each of these primary factors. The factor loadings extracted from PCA for each respondent and each primary factor are included in both bivariate and multivariate analyses in the sections that follow.

Analysis of latent variables

Principal Components Analysis was followed by bivariate correlation analysis and multivariate analysis of the path model. Bivariate analysis shows the correlations between two variables whereas multivariate path analysis gives one the ability to differentiate between direct, indirect, and spurious effects between variables. If the assumed model is true, for example, then the indirect effect of C by A will be the product of the correlation between A and B and the correlation between B and C. The direct effects can be established by the path coefficients, estimated using an ordinary least squares regression approach (Pedhazur 1982).

Bivariate Analyses

A Pearson's correlation coefficient is estimated between the independent variables (e.g., demographics, motivations, objectives, and constraints) and the dependent variable of greatest concern (i.e., behavior). The overall correlation (*r*) between two variables provides the basis for causal analysis of the path model.

Multivariate Analyses

Three variations of a multiple regression model were used to test the relationships between the independent factors included in the model (i.e., demographics, motivations, objectives, and constraints) and the three measured aspects of land manager behavior: (1) area of longleaf burned once between 1996 and 2000, (2) area of longleaf burned *more than* once between 1996 and 2000, and (3) area of longleaf managed with longer than preferred prescribed burn rotation.

Path analysis models are useful for studying patterns of causation among a set of variables and for identifying the factors affecting behavior (Pedhazur 1982). In complex systems, like land manager decision-making and behavior, it can be difficult to isolate causes and effects because each component can potentially influence many others through networks of direct and indirect interactions. Basically, path analysis decomposes the overall correlation between two variables into the direct effects of one on the other, indirect effects mediated by other variables, and spurious effects due to common causes (Pedhazur 1982; Smith, Brown, and Valone 1997). The computed path coefficients indicate the amount of change expected in the dependent variable due to a unit change in the independent variable (Smith, Brown, and Valone 1997).

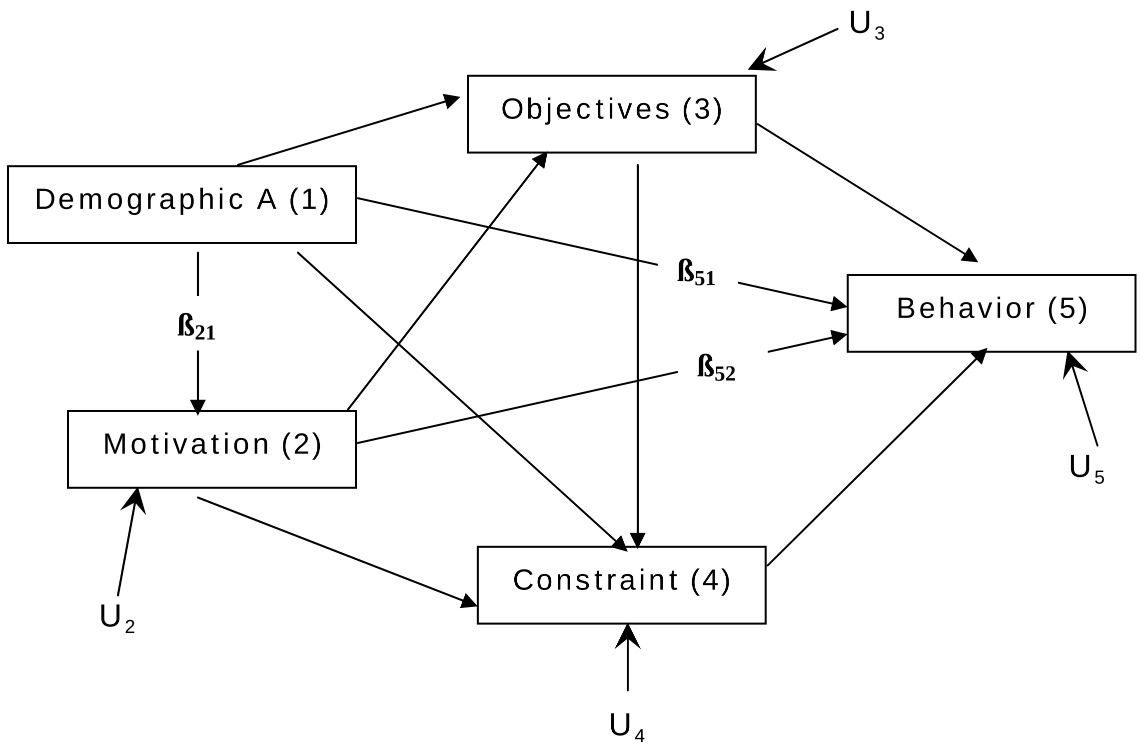
Figure 1 is a conceptual representation of the path analysis model used in this research. In it demographic variables (e.g., ownership, enrollment in Safe Harbor, and state certification), motivations for forestland management, objectives for prescribed burning, and constraints to prescribed burning are hypothesized to influence specific attributes of land manager behavior between 1996 and 2000. Like other regression models, path analysis assumes that the relationships among the factors in the path model are linear and additive and that the residuals are not correlated (Kingsolver and Schemske 1991; Pedhazur 1982; Smith, Brown, and Valone 1997). In addition, with the model shown in Figure 1 we assume that the effects of each factor included in the model are unidirectional (i.e., recursive without feedback loops).

In the path diagram below, a straight, single-headed arrow between two variables reflects a causal relationship. For measured variables, path coefficients are standardized partial-regression coefficients (ß), which were obtained from a multiple regression on standardized variables for each dependent variable in the path diagram. For example the path coefficient $ß_{51}$ in the diagram represents the direct effect of demographic variable A on land manager behavior with all other variables held constant. An indirect effect is simply the product of the path coefficients representing multiple causal paths (e.g., $ß_{21} * ß_{52}$). The sum of the direct effect ($ß_{51}$) and indirect effects (e.g., $ß_{21} * ß_{52}$) is the effect coefficient, and represents the change in a given dependent variable due to change in the one of its causal variables (Kingsolver and Schemske 1991; Pedhazur 1982; Smith, Brown, and Valone 1997).

In the diagram, the paths 15 (read "one-to-five" and so on), 25, 35, and 45 represent the direct effects of the independent variables 1, 2, 3, and 4 on 5 (land manager behavior), and the paths 125 (read "one-to-two-to-five" and so on), 1235, and 12345 are the indirect effects of demographic variable A (1) on behavior (5). The residual variables U_2, U_3, U_4, and U_5 include all unmeasured variables that affect the dependent variables 2, 3, 4, and 5, respectively. The path coefficient for a given residual variable is calculated as $\sqrt{(1-R^2)}$ where R^2 is the proportion of the variation in the dependent variable that is explained by the model.

Path analysis models are far from rigid and offer only hypothesized relationships among variables (Kingsolver and Schemske 1991; Pedhazur 1982; Smith, Brown, and Valone 1997). My goal has been to develop a model that effectively describes land manager behavior and reflects the underlying patterns of the data collected from the survey described above and included in Appendix A. These initial steps in understanding land manager behavior were highly exploratory, so I was not hesitant to deviate from the model shown in Figure 1 when it proved inadequate or individual factors were shown to exhibit a high degree of collinearity, a problem that plagues many path models in the literature by undermining one's ability to accurately assess the patterns of causation (Petraitis, Dunham, and Niewiarowski 1996).

Figure 1. ***Path diagram of hypothesized interactions among demographic variables, motivations for forest management, objectives for prescribed burning, and constraints to conducting burns on land manager behavior (prescribed burning activity).*** *In this model, each one-headed arrow denotes a causal relationship from a causal variable to an effect. While the path diagram demonstrates causal relationships between variables, no true causal relationship can be proven. Furthermore, the model presented may fit the data, but there may also be other models that fit just as well, if not better (Pedhazur 1982). This is a fully recursive model; all relationships are presumed to be unidirectional with no feedback loops.*



Where:

1) Demographics include
    a. Ownership (public or private)
    b. Enrollment of longleaf sites in the Safe Harbor Program
    c. State certification under the North or South Carolina “certified burner” laws
2) Motivations for longleaf forest management
3) Objectives for conducting prescribed burns
4) Constraints to conducting prescribed burns
5) Behavior is land manager behavior, or prescribed fire usage:
    a. Area burned once between 1996 and 2000
    b. Area burned *more than* once between 1996 and 2000
    c. Area managed with longer than preferred prescribed burn rotation
6) U_x are residual path coefficients

Other measures of behavior: the case of seasonal burning

The measures used in this investigation of land manager behavior consist of self-reported ratings of preferences and opinions and estimations of number of prescribed burns conducted during the growing season. Three measures were used:

1. The number of burns conducted during the growing season, as a percentage of total burns conducted.
2. The benefits of conducting growing season burns. Six variables rated on a 5-point scale ranging from "not at all important" to "extremely important"
3. The benefits of conducting dormant season burns. Seven variables rated on a 5-point scale ranging from "not at all important" to "extremely important"

Analysis of results

Bivariate correlation analysis was run comparing ownership, enrollment in the Safe Harbor Program, and certification status under the North and South Carolina "certified burner" laws and burning activity. Those demographic variables shown to have a significant correlation with seasonal burning were used to help understand growing season burn activity and serve as a useful means of comparison. I employed comparison of means (ANOVA) to determine statistical differences between the mean responses of the demographic groups.

Developing better prescribed burning policy

Gathering information regarding policy change from those who not only conduct burns but who also have the most direct effect upon the ecology and future prospects of remnant longleaf ecosystems may help public policy makers to create a more hospitable prescribed burning environment in the Carolinas. Policy well grounded in the realities of conducting prescription burns will most certainly help land managers expand their use of prescribed burning.

Preferred programs (i.e., policies that would make prescribed burning environment in the Carolinas more hospitable) were determined by response to 13 variables. Each rated on a 5-point Likert scale ranging from “not at all effective” to “extremely effective.” I employed comparison of means (ANOVA) to determine statistical differences between public and private responses.

RESULTS

Objective 1. Quantify and describe prescribed burning activity throughout remnant North and South Carolina longleaf pine ecosystems

1.1 General characteristics of survey respondents with discussion of non-response bias

Land managers were surveyed to ascertain their use of prescribed fire between 1996 and 2000 in the longleaf pine stands they manage. Behaviors addressed included: (1) area of longleaf burned between 1996 and 2000; (2) area of longleaf burned more than once between 1996 and 2000; and (3) area managed with longer than preferred burn intervals. Discussion of seasonal use of prescription burns is included in a later section.

Fifty-three (53) survey respondents reportedly manage 3,414,173 acres of forestland in the Carolinas, including 472,550 acres of longleaf pine forest—76% of the resource remaining in the Carolinas (Outcalt and Sheffield 1996). The median age among respondents is 49 (born 1952) and 90% have at least a college education. Eleven respondents to the original survey did not complete the follow-up questionnaire and, therefore, did not provide information regarding their use of prescribed fire. Because I am working to establish a baseline for burning as well as understand factors that affect it, the data collected from these individuals are not included in this study.

Establishing a profile of non-respondents as a group and as individuals is more or less a conjectural exercise. However, several demographic variables are associated with those who responded. All but one identified manager of ≥ 1000 acres of publicly owned longleaf pine forest responded to the survey. Those private land managers with portions of their longleaf site(s) enrolled in the Safe Harbor program seemed more willing to respond than those not participating in this cooperative program. The survey may also have had underlying biases that encouraged members of the survey population with active burn programs to respond (e.g., the managers of well known private quail plantations) while discouraging those with less interest in conducting prescription burns from responding (e.g., those who manage their longleaf sites primarily for pinestraw). Those members of the survey population with whom I spoke directly seemed more likely to respond than those with whom I had only written contact. Respondents who manage large contiguous acres of longleaf were more likely to respond than those who manage smaller, fragmented areas. Response from consulting foresters and the managers of forest industry lands was better than 70%. I also have strong evidence that six or more surveys were lost in transit from these respondents to my home address following the relocation of my family to the Pacific Northwest, USA. The identity of these individuals is not known so I cannot make generalizations about them.

1.2 Demographic variables correlated with prescribed burning

Bivariate correlation analysis was used to determine which demographic variables (e.g., ownership, enrollment in the Safe Harbor Program, state certification under the "certified burner" laws of North and South Carolina) are significantly correlated with the three measures of burn behavior employed: (1) area burned once between 1996 and 2000, (2) area burned *more than* once between 1996 and 2000, and (3) area managed with longer than preferred prescribed burn intervals. Results are shown in Table 1

Table 1

Correlations and significance levels between select demographic variables and aspects of prescribed burning activity in longleaf pine forests

Demographic variable	% Longleaf area burned once[1]	% Longleaf area burned > once	% Managed with long burn rotations
Ownership[2]	**-0.265 (p=0.028)**	-0.201 (p=0.074)[†]	-0.073 (p=0.301)
Safe Harbor enrollment[3]	0.066 (p=0.351)	0.100 (p=0.280)	-0.034 (p=0.421)
Certified burn boss[4]	0.042 (p=0.384)	0.123 (p=0.191)	-0.077 (p=0.291)

[1] Period of interest is 1996 to 2000
[2] Where 1 is public and 2 is private
[3] For private land managers where 1 is enrollment in the program and 2 is not enrolled
[4] Where 1 is state certified burn boss (NC) or certified prescribed fire manager (SC) and 2 is non-certified burn boss or prescribed fire manager
Bold type indicates significant correlation (p<0.05), 1-tail
[†] Indicates significant correlation (p<0.1), 1-tail

Ownership is the only demographic variable included in this study significantly related to burn behavior. Managers of publicly owned longleaf pine forests seemed to burn a greater percentage of their longleaf sites between 1996 and 2000 than their private counterparts. However, ownership appears independent of the area of longleaf managed with longer than preferred burn rotations. I also failed to reject the hypothesis that government programs designed to (1) encourage responsible prescribed burning by reducing liability risk for those willing to complete state certification programs (e.g., "certified burner" laws) or (2) reduce the perceived risks of ecologically sound longleaf management (e.g., the Safe Harbor Program) have no effect on behavior.

1.3 Prescribed burning activity in remnant longleaf ecosystems of North and South Carolina between 1996 and 2000

Between 1996 and 2000, 50 respondents reported conducting prescription burns on 315,295 acres of longleaf pine forest in the Carolinas (67% of longleaf area managed by respondents). Three managers responsible for a total of 7500 acres of privately owned longleaf forest do not use prescribed fire. During this same five-year time period 196,107 acres (42% of total longleaf area managed by respondents and 62% of area burned between 1996 and 2000) were burned more than once. Respondents also estimated that they were unable to burn 184,293 acres of longleaf (39% of longleaf area managed by respondents) as frequently as they would like (Table 2).

Table 2

Reported longleaf area managed and prescribed burning activity on North and South Carolina longleaf pine sites (1996 to 2000)

Ownership	N	Longleaf area (acres)	Burned once ’96-‘00 (acres)	Burned > once ’96-’00 (acres)	Longer than preferred burn intervals (acres)
Public	17	360,500	256,270	153,947	139,823
Private	36	112,050	59,025	42,160	44,470
Totals	**53**	**472,550**	**315,295**	**196,107**	**184,293**

The public land managers who responded to the survey burned a greater percentage of their longleaf holdings between 1996 and 2000 than their private land manager counterparts. Public land managers as a group burned 71% of their longleaf sites at least once during the time period whereas private land managers as a group burned 53%. When examining the area burned more than once between 1996 and 2000 there is a smaller reported difference between the ownership groups. Public land managers burned 43% of their longleaf holdings more than once and private land managers similarly burned 38% of their longleaf holdings. However, of the area burned between 1996 and 2000, private land managers burned 71% more than once, whereas public land managers burned 60% frequently. The two groups also feel a similar degree of unintended fire exclusion. Public land managers were unable to burn 39% of their longleaf sites as frequently as they prefer whereas private land managers manage 40% of their longleaf sites with a longer than preferred prescribed burn rotation.

This general comparison of public and private land managers may either emphasize or downplay the behavior of individual land managers and their contributions to burning. To more closely examine land manager behavior, I further decomposed public and private respondents into two groups defined by behavior: (1) those who burned more than 50% of their longleaf sites repeatedly between 1996 and 2000 and (2) those who burned less than 50% of their longleaf sites repeatedly. Results are shown in the Tables 3, 4, and 5 below.

Table 3

Comparison of prescribed burning activity by those with active and less active burn programs on North and South Carolina longleaf pine sites (1996 to 2000)

% Longleaf area burned repeatedly	Longleaf area managed	Area burned between '96 and '00	Area burned repeatedly	Area with longer burn rotations
< 50% (n=34)	187,950	63,215	14,145	102,805
> 50% (n=19)	284,600	252,080	181,962	81,488
Total (n=53)	**472,550**	**315,295**	**196,107**	**184,293**

The 34 who burned less than 50% of their longleaf acreage repeatedly between 1996 and 2000 manage 39.8% of the longleaf area included in the survey, but account for only 20% of the area burned between 1996 and 2000 and less than 8% of the area burned repeatedly over this time span. They also indicated managing about 56% of their total longleaf area with longer than preferred prescribed burning rotations. This group does not actively burn large areas of longleaf, but it appears as if they would like to burn more longleaf, more frequently.

The 19 who repeatedly burned at least 50% of their longleaf acreage between 1996 and 2000 manage 60.2% of the longleaf area included in this survey. Moreover, they account for 80% of the area burned between 1996 and 2000 and 92.8% of the area burned frequently. This group expressed a lesser degree of unintended fire exclusion than the previously described group; managing 44.2% of their longleaf area with longer than preferred prescribed burning intervals.

Tables 4 and 5 show the assignment of members of the ownership groups into behavioral categories. Table 4 shows behavioral differences of public land managers who burn large percentages of their longleaf tracts repeatedly v. those public land managers who burn smaller percentages of their longleaf tracts repeatedly. Table 5 shows the resolution of private land managers into these groups.

Table 4

Comparison of prescribed burning activity between public land managers with active burn programs and public land managers with less active burn programs

% Longleaf area burned repeatedly	Longleaf area managed	Area burned between '96 and '00	Area burned repeatedly	Area with longer burn rotations
< 50% (n=8)	117,500	44,290	8,375	64,733
> 50% (n=9)	243,000	211,980	145,572	75,090
Total (n=17)	**360,500**	**256,270**	**153,947**	**139,823**

The eight public land managers who burned less than 50% of their longleaf acreage repeatedly between 1996 and 2000 manage 32.6% of the public longleaf area included in the survey, but account for only 17.3% of the area burned between 1996 and 2000 and less than 5.5% of the area burned repeatedly over this time span. Their preferences for burning also accounted for 46.3% the total longleaf area managed with longer than ideal prescribed burning rotations.

The nine who repeatedly burned at least 50% of their longleaf acreage between 1996 and 2000 manage 67.4% of the public longleaf area included in the survey. More importantly, they account for 82.7% of the area burned between 1996 and 2000 and nearly 95% of the area burned frequently. This group also expressed a greater feeling of unintended fire exclusion than the other group of public respondents; managing 53.7% of their longleaf area with longer than preferred prescribed burning rotations.

Table 5

Comparison of prescribed burning activity between private land managers with active burn programs and private land managers with less active burn programs

% Longleaf area burned repeatedly	Longleaf area managed	Area burned between '96 and '00	Area burned repeatedly	Area with longer burn rotations
< 50% (n=26)	70,450	18,925	5,770	38,072
> 50% (n=10)	41,600	40,100	36,390	6,398
Total (n=36)	**112,050**	**59,025**	**42,160**	**44,470**

The 26 who burned less than 50% of their longleaf acreage repeatedly between 1996 and 2000 manage the majority of the private longleaf area included in this survey, 62.9 percent. However, they account for only 32% of the area burned between 1996 and 2000 and less than 13.7% of the area burned repeatedly over this time span. Demand for burning is not being met by this group as their preferences for burning accounted for 85.6% the total longleaf area managed with longer than ideal prescribed burning rotations. This group would like to burn nearly 40,000 acres of longleaf more frequently.

The ten who repeatedly burned at least 50% of their longleaf acreage between 1996 and 2000 manage 37.1% of the private longleaf area included in this survey. Additionally, they account for 67.9% of the private area burned between 1996 and 2000 and 86.3% of the area burned frequently. This group is also very close to meeting their demand for burning; less than 6000 acres would like to be burned more frequently.

Objective 2. Develop a detailed understanding of factors that impact prescribed burning activity in longleaf pine forests: The effects of ownership, motivations for forest management, prescribed burning objectives, and constraints to burning on prescribed burning activity.

2.1 Overview

The following section is structured to reflect the step-wise nature of path analysis (i.e., data is reduced to latent variables before bivariate and multivariate analysis). The results of Principal Components Analysis (PCA) are discussed first, followed by the results of bivariate correlation analyses and multivariate path analyses. These results provide insight into three aspects of burn behavior examined in this study: (1) longleaf area burned once between 1996 and 2000, (2) longleaf area burned frequently between 1996 and 2000, and (3) area managed with longer than preferred prescribed burn rotations. Seasonal use of prescription burns and variables influencing its use are analyzed in the subsequent section (Objective 3).

2.2 Reduction of observed variables to latent variables: results of Principal Components Analysis (PCA)

Principal Components Analysis was used to simplify the variation observed across multiple variables to one or two composite factors representing motivations, objectives, and constraints. Exploration of motivations included all eight variables rated by respondents and all fourteen measures of objectives for burning. Ten of seventeen variables explaining constraints were included in the analysis. Seven variables that land managers overwhelmingly indicated little effect on their willingness to conduct prescribed burns (mean score in parentheses) were not included in this analysis: 1. Don't know about using prescribed burns (1.09), 2. Want to let nature take its course (1.15), 3. Don't like the look of a burned area (1.15), 4. Landowner does NOT want to burn more (1.50), 5. Agency management policies that discourage risk taking (1.64), 6. High cost of planning and implementing burns (1.66), and 7. May harm game populations (1.74).

Motivations for longleaf management were factor analyzed using PCA with VARIMAX rotation. Rotation of the extracted axes, makes the underlying variables more interpretable. VARIMAX, which yields uncorrelated (orthogonal) factors, is the most popular rotational method and has been used extensively in the forestry literature (McFarlane and Boxall 2000). Three factors were extracted before the eigenvalue fell below 1.0. These components can be interpreted as (1) the importance of managing longleaf for biological preservation (e.g., endangered species habitat), (2) the importance of managing longleaf for recreational values (e.g., hunting), and (3) the importance of managing longleaf for merchantable products (e.g., timber and pinestraw) and explained 66.4% of the total variance in the data (see Table 6).

Table 6

Rotated component matrix (Motivations for longleaf forest management)

	Rescaled Component		
Observed Motivating Variable	**1**	**2**	**3**
Wood products	-0.230	-0.040	**0.776**
Pinestraw	-0.108	-0.116	**0.909**
Game habitat	0.095	**0.687**	0.313
Non-game habitat	**0.742**	0.353	-0.138
Endangered species	**0.925**	-0.138	-0.092
Recreation	0.079	**0.855**	-0.194
Aesthetics	0.145	**0.590**	-0.251
Preservation for future	**0.549**	0.304	-0.227
% Variance explained	**32.2**	**19.0**	**15.3**

Extraction Method: Principal Components Analysis

Rotation Method: VARIMAX with Kaiser Normalization

Objectives for conducting prescribed burns were factor analyzed using PCA with VARIMAX rotation. Four components were extracted before the eigenvalue fell below 1.0. These components can be interpreted as (1) the importance of burning for its biological values (e.g., to perpetuate fire dependent species), (2) the importance of burning for maintaining recreational opportunities (e.g., provide game habitat), (3) the importance of burning for protecting forestry investments (e.g., remove ladder fuels and make suppression easier), and (4) the importance of burning for pinestraw collection and explained 65.9% of the total variance in the data (see Table 7).

Table 7

Rotated component matrix (Objectives for conducting prescribed burns)

	Rescaled component			
Observed objective	**1**	**2**	**3**	**4**
Manage fuel loads	0.054	0.005	**0.680**	-0.038
Make suppression easier	0.198	0.218	**0.735**	0.123
Provide clean pinestraw	-0.245	-0.282	0.263	**0.798**
Open woods for easier hunting	0.071	**0.898**	-0.223	0.146
Perpetuate fire dependent species	**0.787**	-0.039	-0.074	-0.164
Enhance aesthetic value	**0.623**	0.419	0.158	0.017
Provide habitat for game	0.005	**0.880**	0.112	-0.118
Habitat for non-game wildlife	**0.608**	0.330	0.181	-0.432
Habitat for endangered species	0.327	-0.288	0.198	**-0.618**
Control pest outbreaks	0.496	0.317	0.104	**0.560**
Prepare seedbeds	-0.049	-0.168	**0.362**	0.001
Enhance species diversity	**0.737**	-0.052	-0.182	-0.316
Preservation	**0.838**	-0.085	0.214	0.080
Keep costs down	-0.032	**0.609**	**0.613**	0.098
% Variance explained	**25.0**	**18.4**	**13.3**	**9.15**

Extraction Method: Principal Components Analysis
Rotation Method: VARIMAX with Kaiser Normalization

Constraints to conducting prescribed burns were factor analyzed using PCA with VARIMAX rotation. Three components were extracted before the eigenvalue fell below 1.0. These components can be interpreted as (1) level of perceived constraint due to proximity to the wildland-urban interface (e.g., lack of suitable weather), (2) the importance of avoiding the risks associated with burning (e.g., local ordinances that restrict open burning), and (3) level of perceived constraint due to personnel shortages and explained 58.4% of the total variance in the data (see Table 8).

Table 8

Rotated component matrix (Constraints to conducting prescribed burns)

	Rescaled component		
Observed constraint	**1**	**2**	**3**
Public opinion and acceptance	**0.535**	0.454	0.234
Losses of forest products	-0.305	**0.537**	0.464
Smoke management and air quality concerns	**0.414**	0.345	0.229
Local ordinances that restrict burning	0.171	**0.755**	0.011
Liability risk	**0.578**	0.419	0.460
Lack of suitable weather	**0.814**	-0.068	-0.042
Heavy fuel loads	**0.571**	0.236	0.341
Lower risk alternatives to burning	0.148	**0.809**	0.042
Nearby residential development	**0.822**	0.212	0.234
Personnel shortages	0.132	-0.072	**0.863**
% Variance explained	**37.0**	**12.5**	**8.8**

Extraction Method: Principal Components Analysis
Rotation Method: VARIMAX with Kaiser Normalization

Principals Components Analysis reveals the multi-dimensional nature of motivations for forest management, objectives for conducting prescribed burns, and constraints to burning. Perhaps more importantly, however, these results indicate that the path model shown in Figure 1 and used to develop the survey instrument excessively oversimplifies the relationships between the hypothesized factors that influence prescribed burning activity. To employ the path model as shown in Figure 1 only the first factor extracted from PCA could be included, given the number of paths shown. This step would seemingly result in a path model with little predictive value due to the limited amount of variance explained by the first PCA component for motivations, objectives, and constraints. For motivations only 22.6% of variance is included in the first PCA component, 25% of variance in objectives is explained by the first PCA component, and 37% of the variance in constraints is explained by the first PCA component. These concerns must also be balanced with the need to minimize the number of causal relationships among the variables included in any path model, especially when the sample size is as small as that included in this study.

To reconcile the need to limit the number of paths and include a sufficient amount of explained variance, I adopted a new strategy for analysis of the path model. First, the same underlying factors (e.g., burning is a necessary part of managing longleaf forests for certain game animals) are represented in both the motivations component and the objectives component under consideration. As above, PCA extracted from motivations three factors with may represent (1) a preservation index, (2) a recreation index, and (3) a forest products index. Principal Components of objectives were interpreted to be (1) a preservation index, (2) a recreation index, (3) forest products investment protection index, and (4) a pinestraw index. The similarities between these two sets of extracted factors indicate that I essentially measured the same factors with both motivations and objectives. Based on this finding, I decided to fully integrate the variables explaining motivations for longleaf forest management and objectives for conducting prescribed burns by running another PCA with VARIMAX rotation with all measured variables that explained each of these two factors. (The new factor is called management objectives.)

This analysis extracted four components that explained 64.1% of the total variance in the data (see Table 9). The first clarifies the importance of longleaf for preservation values on the positive end of the axis and the importance of longleaf for merchantable products on the negative end of the spectrum. The second component explains the importance of longleaf for recreation values (e.g., hunting). The third and fourth components make clear the importance of wood products and pinestraw, respectively. These results are very similar to those described above when motivations and objectives were considered as separate factors. By combining motivations and objectives, thereby creating the new management objectives factor, I also eliminated any collinearity problems presented by the high degree of correlation between these two factors. This step does not fundamentally change the path model; rather it changes its appearance. Constraints were not affected by such combining.

Table 9

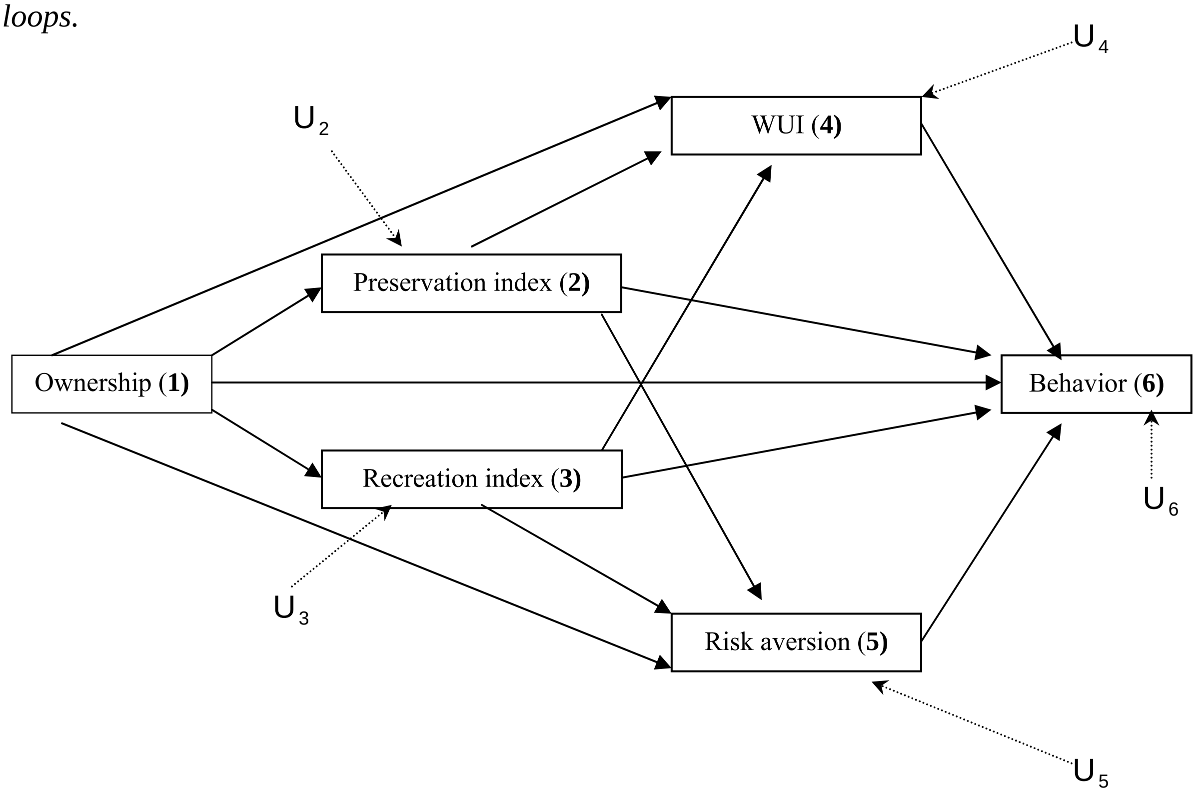
Rotated component matrix: combining motivations and objectives

	Component			
Observed motivation	**1**	**2**	**3**	**4**
Wood products	-0.575	0.085	**0.553**	0.266
Pinestraw	-0.326	-0.336	0.355	**0.698**
Game habitat	0.007	**0.862**	-0.135	0.179
Non-game habitat	**0.527**	0.285	-0.220	-0.220
Endangered species	**0.438**	-0.030	-0.134	-0.566
Recreation	0.302	**0.613**	-0.370	0.235
Aesthetics	**0.725**	0.477	0.078	0.145
Preservation for future	**0.548**	0.036	-0.034	0.047
Observed objectives				
Manage fuel loads	0.032	-0.068	**0.501**	0.085
Make suppression easier	0.290	0.123	**0.468**	0.021
Provide clean pinestraw	-0.263	-0.335	0.355	**0.765**
Open woods for easier hunting	0.034	**0.826**	-0.161	0.204
Perpetuate fire dependent species	**0.600**	0.063	0.050	-0.066
Enhance aesthetic value	**0.676**	0.346	-0.033	0.181
Provide habitat for game	-0.031	**0.901**	0.145	-0.063
Habitat for non-game wildlife	**0.450**	0.358	0.291	-0.442
Habitat for endangered species	**0.527**	-0.195	-0.238	-0.552
Control pest outbreaks	**0.660**	0.242	-0.232	0.332
Prepare seedbeds	-0.032	-0.123	**0.549**	-0.069
Enhance species diversity	**0.547**	0.045	-0.362	-0.143
Preservation	**0.793**	-0.058	0.108	0.236
Keep costs down	0.078	**0.628**	0.535	0.160
% Variance explained	**26.7**	**21.3**	**8.5**	**7.63**

Extraction Method: Principal Components Analysis
Rotation Method: VARIMAX with Kaiser Normalization

Secondly, to manage the number of paths included in the path model, I used the first two axes extracted from the new management objectives data factor and the first two from the constraints data set. For management objectives, these axes represented (1) the importance of managing longleaf for preservation values v. managing longleaf for merchantable products and (2) the importance of managing longleaf primarily for recreational values v. managing longleaf for a mix of values and explained 48% of the variance in the data. For constraints, the first two PCA axes represent, as above, (1) the level of perceived constraint due to WUI (e.g., public opinion), (2) the level of constraint due to risk aversion (e.g., local ordinances that restrict open burning) and explained 51.8% of the variance in the constraints data. The path model below (Figure 2) shows the hypothesized relationships between ownership, each of these four composite factors, and land manager behavior (longleaf burned as a percentage of longleaf area managed).

Figure 2. Revised Path Model. *Path diagram of hypothesized interactions among demographic variables, management objectives for longleaf management, and constraints to conducting burns on land manager behavior (prescribed burning activity). In this model, each one-headed arrow denotes a causal relationship from a causal variable to an effect. While the path diagram demonstrates causal relationships between variables, no true causal relationship can be proven. Furthermore, the model presented may fit the data, but there may also be other models that fit just as well, if not better [Pedhazur, 1982 #200]. This is a fully recursive model; all relationships are presumed to be unidirectional with no feedback loops.*



1) **Ownership** (public or private)
2) **Preservation index** (relative importance of maximizing preservation value of remnant longleaf stands)
3) **Recreation index** (relative importance of maximizing recreational value of remnant longleaf stands, especially as hunting lands)
4) **WUI constraint** (constraint due to proximity to wildland-urban interface)
5) **Risk aversion constraint** (constraint due to risk aversion)
6) **Behavior** is land manager behavior, or prescribed fire usage:
    a. Area burned once between 1996 and 2000
    b. Area burned *more than* once between 1996 and 2000
    c. Area managed with longer than preferred prescribed burn rotation
7) U_x are residual path coefficients

2.3 Integrating ownership, management objectives, and constraints: factors influencing the area of remnant longleaf burned between 1996 and 2000

Pearson's correlation analysis and decomposition of these values with path analysis helps to integrate ownership, forest management objectives, and constraints to burning with land manager behavior, the area of longleaf burned between 1996 and 2000. Table 10 reports the correlations among variables and the standardized path coefficients along with indirect, spurious, and total effect coefficients. Figure 3 shows the hypothesized interactions among the six factors in the model and the standardized regression coefficients (ß in Table 10), or the direct effect between the indicated factors.

Table 10

Correlations and path coefficients:
Area of longleaf burned once between 1996 and 2000.

Interaction (i→j)	***ß***	***IE***	***S***	**T**	***r***
Ownership→preservation	**-0.358**			-0.358	**-0.358**
Ownership→recreation	0.228			0.228	**0.228**
Ownership→WUI	0.058	-0.047		0.011	0.011
Preservation→WUI	0.061		-0.012	0.061	0.040
Recreation→WUI	-0.111	-0.022	0.013	-0.133	-0.097
Ownership→risk aversion	0.279†	0.070		0.349	**0.349**
Preservation→risk aversion	-0.160		-0.104	-0.160	**-0.259**
Recreation→risk aversion	0.054		0.077	0.054	0.117
Ownership→behavior	-0.241	-0.024		-0.265	**-0.265**
Preservation→behavior	0.121	0.023	0.076	0.144	**0.243**
Recreation→behavior	**0.300**	-0.008	-0.021	0.292	**0.229**
WUI→ behavior	0.003		-0.027	0.003	-0.024
Risk aversion→behavior	-0.141		-0.080	-0.141	-0.221†

Area of longleaf burned once between 1996 and 2000. Here ***ß*** represents the standardized path coefficients and is the direct effect of factor *i* on factor *j*. ***IE*** represents the indirect effect of *i* on *j*, and ***S*** represents the spurious effect, due to common causes, of *i* on *j*. ***T*** is the effect coefficient and is used to compare the relative, overall effects of interactions. Also, ***r*** represents the correlation between the indicated factors; bold type indicates probabilities of somewhat 0.05; † indicates probability of somewhat 0.1. See Appendix B for complete regression equations.

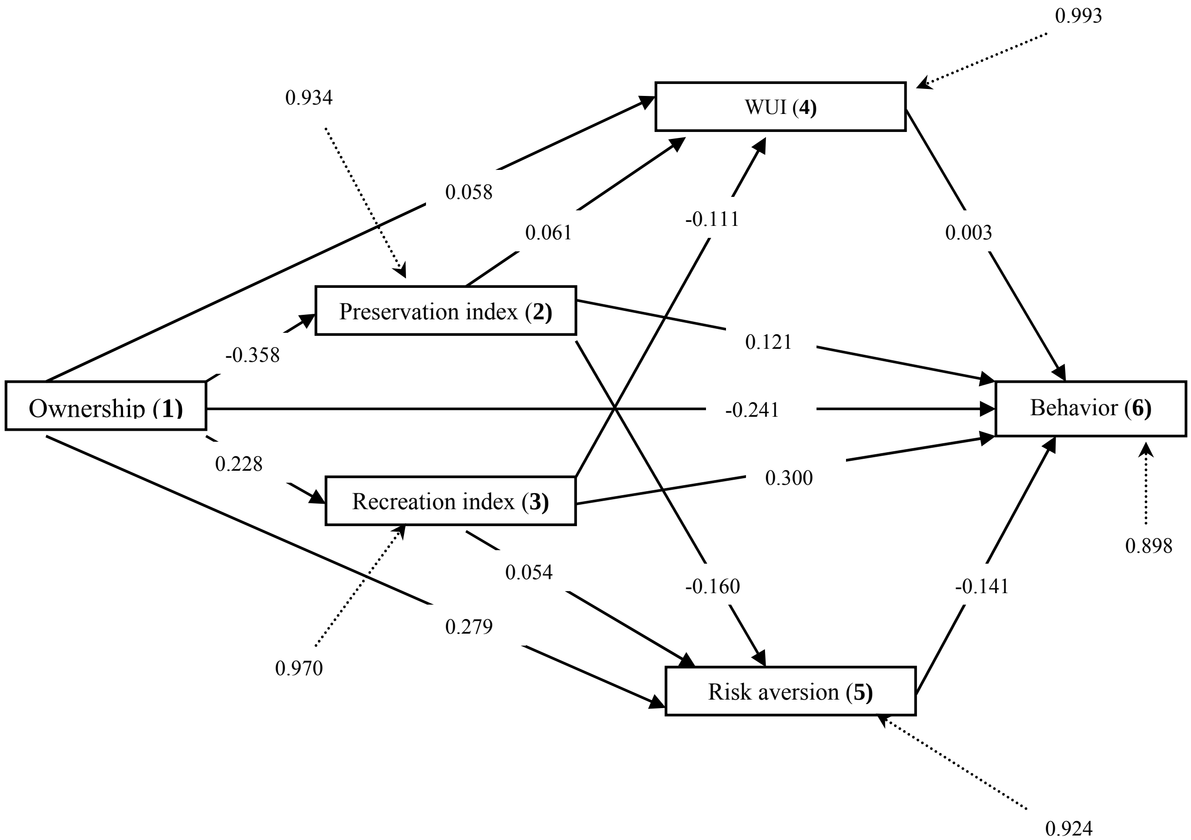


Figure 3—Path diagram of hypothesized interactions among ownership, forest management objectives, constraints to conducting burns, and the area of longleaf burned in the Carolinas between 1996 and 2000. Each path is intersected by a path coefficient (partial regression coefficient, ß) that represents the direct effect of the first component (tail) on another (head). Dashed lines are residual path coefficients and calculated by $\sqrt{(1-R^2)}$. This is a fully recursive model; all relationships are assumed to be unidirectional with no feedback loops.

Path Analysis: Area of longleaf burned once between 1996 and 2000

When applied to data related to the area of longleaf burned once between 1996 and 2000, path analysis results show the complex relationships among factors that influence prescribed burning activity. Decomposition of correlation coefficients illustrates that public land managers likely manage their longleaf sites for preservation values, whereas private land managers likely manage their longleaf for merchantable products ($ß_{21}$ = -0.358) or recreation ($ß_{31}$ = 0.228). These results divide survey respondents into three primary groups, one public, those who manage longleaf forests as nature preserves ($ß_{21}$ = -0.358), and two private, (1) those who manage longleaf as private hunting reserves ($ß_{31}$ = 0.228) and (2) those who manage longleaf as timberlands for merchantable forest products ($ß_{21}$ = -0.358).

The model also provides insight into the relationship between these three different management groups and their perception of constraint (variables that limit a respondent's willingness to burn). Here, private land managers seem more likely to be risk averse than their public colleagues ($ß_{51}$ = 0.279; T_{51} = 0.349). However, risk aversion is not a characteristic of all private land managers. Those who manage longleaf for merchantable products are more likely to be risk averse ($ß_{52}$ = -0.160) than those who manage longleaf for recreation ($ß_{53}$ = 0.054). Ownership has very little direct ($ß_{41}$ = 0.058) or total effect (T_{41} = 0.011) on the constraints of WUI, but those who manage longleaf for recreational values do seem less likely to be affected by these constraints ($ß_{43}$ = -0.111; T_{43} = -0.133) than public land managers ($ß_{41}$ = 0.058) or those who manage longleaf for merchantable products ($ß_{42}$ = 0.061).

Path analysis explains 19.3% of the variance in land manager *behavior* ($F = 2.245$, $p<0.1$). Forest management objectives and ownership affected the proportion of longleaf burned between 1996 and 2000 more than the constraints of the WUI or risk aversion. Management of longleaf lands for recreation is associated with most extensive amounts of burning between 1996 and 2000 (T_{63} = 0.300). That is, this group burned a greater percentage of the total longleaf forest area they manage between 1996 and 2000 than the other groups. Public land managers burned second most extensively (T_{61} = 0.265), largely due their interests in managing longleaf for preservation values (T_{62} = 0.144). The constraints of the WUI had little effect on burning (ß64 = 0.003) whereas those who are risk averse burned the least extensive amounts of longleaf between 1996 and 2000 (ß65 = -0.141).

Thus, it appears that for some groups and individuals, burning is essential to achieving management objectives (e.g., providing habitat for game animals, fire dependent species, or rare, threatened and endangered species), despite any perceived constraints of the WUI or risk aversion. For these individuals the benefits of burning outweigh the difficulties of maintaining compliance with air quality regulations, smoke management, liability risks, etc.

Although managing longleaf forests for recreation or preservation prompted some survey respondents to burn, the management objectives and general risk aversion led to little burning by others. Those private land managers interested in managing longleaf forests for merchantable products did not burn extensively between 1996 and 2000, presumably because management objectives can be achieved without extensive burning. Furthermore, this group tends to express a considerable amount of risk aversion. Even if the profitability of longleaf management might be improved, these benefits may not outweigh the risks of using prescription burning.

2.4 Factors influencing percentage of longleaf area burned *more than* once between 1996 and 2000.

To explore the second aspect of land manager behavior included in this study, factors influencing repeated burning during 1996-2000, correlation and path analyses were run to integrate the factors included in the model. Results are shown in Table 11 and direct effect (standardized regression coefficients ß) of each relationship are diagrammatically shown in

Figure 4. Note in Table 11 that only the impact of 1) ownership, 2) importance of managing longleaf for preservation values 3) importance of managing longleaf for recreational values, 4) constraints of WUI, and 5) constraints of risk aversion on behavior are included. Discussion of the interactions among these factors is included in section 2.3.

Table 11

Correlations and Path Coefficients:
Area of longleaf burned *more than* once between 1996 and 2000.

Interaction (i→j)	***ß***	***IE***	***S***	**T**	***r***
Ownership→behavior	-0.198	-0.003		-0.201	-0.201
Preservation→behavior	0.155	0.018	0.050	0.173	**0.258**
Recreation→behavior	**0.431**	-0.003	-0.023	0.428	**0.375**
WUI→ behavior	-0.041		0.556	-0.041	-0.079
Risk aversion→behavior	-0.131		-0.096	-0.131	-0.190†

Area of longleaf burned *more than* once between 1996 and 2000. Here ***ß*** represents the standardized path coefficients and is the direct effect of factor *i* on factor *j*. ***IE*** represents the indirect effect of *i* on *j*, and ***S*** represents the spurious effect, due to common causes, of *i* on *j*. ***T*** is the effect coefficient and is used to compare the relative, overall effects of interactions. Also, ***r*** represents the correlation between the indicated factors; bold type indicates probabilities of somewhat 0.05; † indicates probability of somewhat 0.1. See Appendix B for complete regression equations.

Note: See Table 10 for other interactions included in the path model that remain constant through the variations on the model.

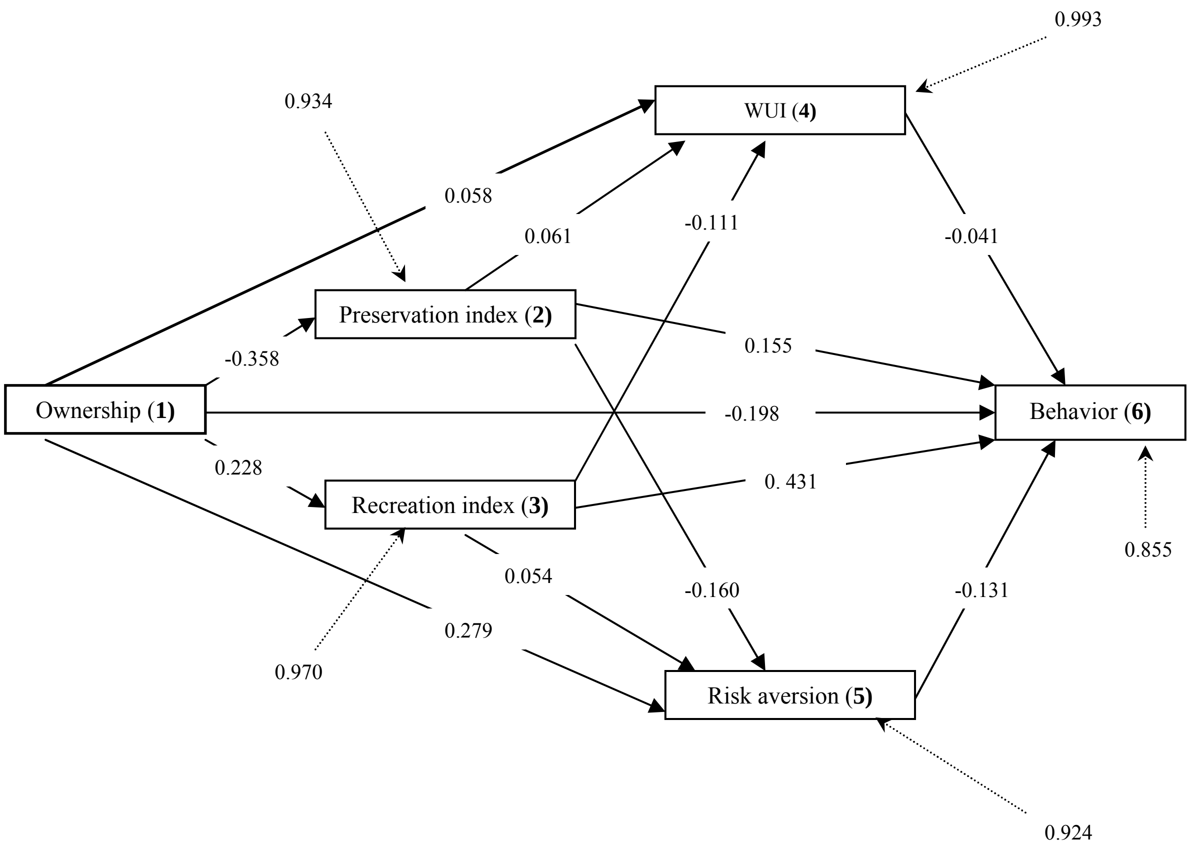


Figure 4—Path diagram of hypothesized interactions among ownership, forest management objectives, constraints to conducting burns, and the area of longleaf in the Carolinas burned *more than* once between 1996 and 2000. Each path is intersected by a path coefficient (partial regression coefficient, ß) that represents the direct effect of the first component (tail) on another (head). Dashed lines are residual path coefficients and calculated by $\sqrt{(1-R^2)}$. This is a fully recursive model; all relationships are assumed to be unidirectional with no feedback loops.

Path Analysis: Area of longleaf burned <u>more than</u> *once between 1996 and 2000*

Path analysis explains 26.9% of the variance in land manager *behavior* ($F = 3.464$, $p<0.05$). Overall, the relative influence of ownership, management objectives, and constraints changed little from the previous analysis. As in previous discussion, respondents who manage longleaf for recreation ($T_{52} = 0.428$) and, secondly, manage public lands ($T_{51} = -0.201$) tended to burn greater proportions of their longleaf sites frequently between 1996 and 2000 than those who manage their longleaf for merchantable products. Those who manage longleaf for recreation, who generally manage private lands ($ß_{31}$ = 0.228), burned a greater percentage of their longleaf holdings more frequently ($ß_{63}$ = 0.431) than public land managers ($ß_{61}$ = -0.198) between 1996 and 2000. Again, constraints due to the WUI (T_{64} = -0.041) and risk aversion (T_{65} = -0.131) had little affect on the behavior of these groups. Private land managers who manage longleaf for wood products neither burned extensively (as above) nor frequently. Presumably this is due to their ability to meet management objectives without active burn programs and general aversion to the risks of burning.

2.5 Factors influencing area of longleaf managed with longer than preferred prescribed burn intervals or rotations (length of time between consecutive burns)

To explore the third aspect of land manager behavior included in this study, factors influencing the amount of longleaf managed with longer than preferred prescribed burn intervals, correlation and path analyses were run to integrate the factors included in the model. Results are shown in Table 12 and direct effect (standardized regression coefficients ß) of each relationship are diagrammatically shown in Figure 5. Note in Table 12 only the impact of 1) ownership, 2) motivations, 3) objectives, and 4) constraints on 5) behavior are included. Discussion of the interactions among these factors is included above in section 2.3.

Table 12

Correlations and Path Coefficients:
Area of longleaf managed with longer than preferred burn rotations.

Interaction (i→j)	***ß***	***IE***	***S***	**T**	***r***
Ownership→behavior	-0.081	0.007		-0.074	-0.073
Preservation→behavior	**-0.241**	0.035	0.053	-0.206	-0.184†
Recreation→behavior	**-0.321**	-0.057	0.021	-0.378	**-0.391**
WUI→ behavior	**0.494**		0.021	0.494	**0.515**
Risk aversion→behavior	-0.032		-0.003	-0.032	-0.035

Area of longleaf burned *more than* once between 1996 and 2000. Here ***ß*** represents the standardized path coefficients and is the direct effect of factor *i* on factor *j*. ***IE*** represents the indirect effect of *i* on *j*, and ***S*** represents the spurious effect, due to common causes, of *i* on *j*. ***T*** is the effect coefficient and is used to compare the relative, overall effects of interactions. Also, ***r*** represents the correlation between the indicated factors; bold type indicates probabilities of somewhat 0.05; † indicates probability of somewhat 0.1. See Appendix B for complete regression equations.

Note: See Table 10 for other interactions included in the path model that remain constant through the variations on the model.

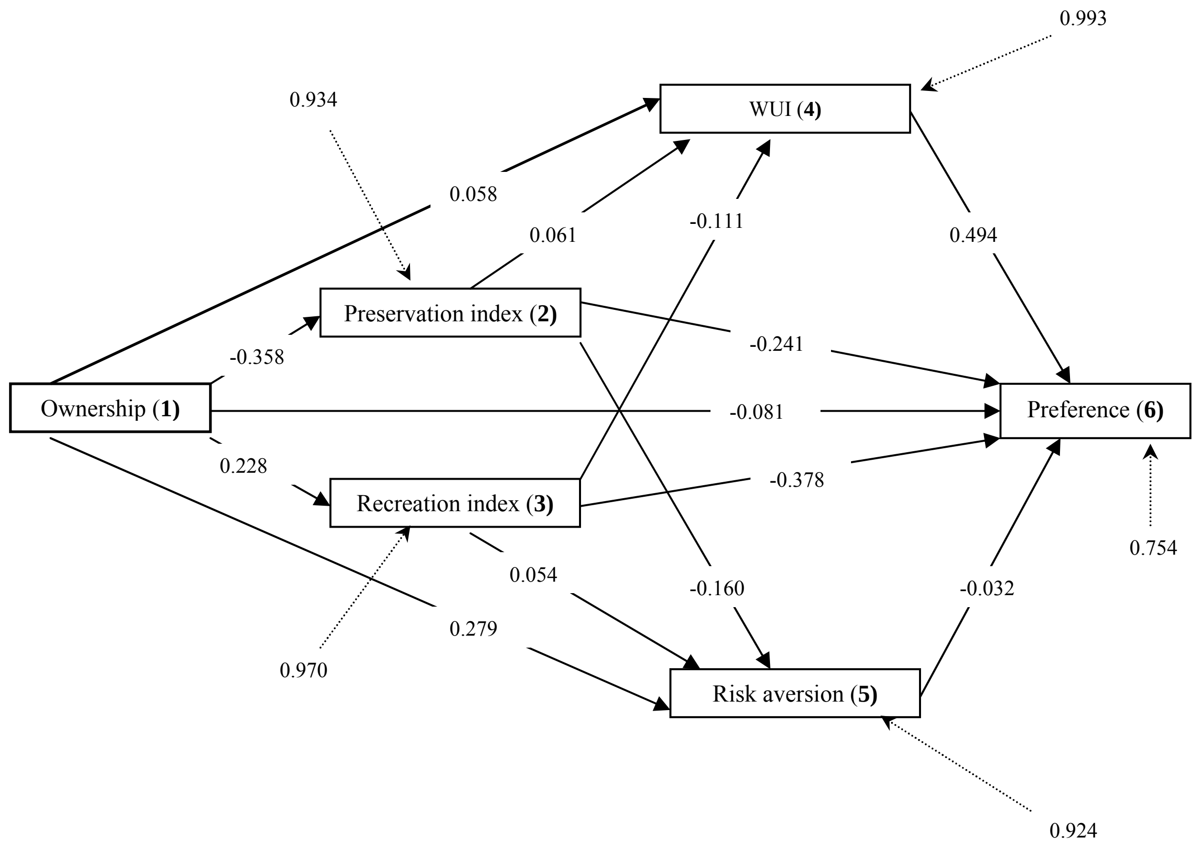


Figure 5—Path diagram of hypothesized interactions among ownership, objectives for longleaf management, constraints to conducting burns, and the area of longleaf in the Carolinas managed with longer than preferred prescribed burn rotations. Each path is intersected by a path coefficient (partial regression coefficient, ß) that represents the direct effect of the first component (tail) on another (head). Dashed lines are residual path coefficients and calculated by $\sqrt{(1-R^2)}$. This is a fully recursive model; all relationships are assumed to be unidirectional with no feedback loops.

Path Analysis: Area of longleaf managed with longer than preferred burn rotations

Path analysis explains 43.1% of the variance in land manager *behavioral preferences* ($F = 7.119$, $p<0.001$). Overall, constraints of the WUI most significantly affected the area of longleaf managed with longer than preferred burn rotations ($ß_{54} = 0.494$). As an individual's level of perceived social constraint increases (due to public opinion, smoke management and air quality concerns, liability risk, lack of appropriate weather, heavy fuel loads, and nearby residential development), so does unintended fire exclusion. Unfortunately, there is no clear association showing which groups are more affected by the constraints of WUI, rather it seems that the effect of this suite of constraints varies for each survey respondent based on their geographic location. Secondarily, management objectives for longleaf forest management have negative relationships with behavioral preferences. As the importance of longleaf for its recreational (T_{63} = -0.378) and preservation (T_{62} = -0.206) values increases, the area of longleaf managed with longer than preferred burn rotations decreases. Ownership (T_{61} = -0.074) and constraints due to risk aversion (T_{65} = -0.032) are largely independent of area managed with longer than preferred burn intervals. Consequently, it appears that area managed with longer than preferred burn rotations is affected not only by individual forest management objectives (e.g., those managing longleaf as nature preserves are likely to burn extensively and frequently) but also the size and location of specific longleaf tracts where the difficulties of managing smoke and air quality concerns, liability risk, public opinion, etc. are great. In other words, the greater the area of longleaf proximal to smoke sensitive structures (e.g., roads, hospitals, schools, and homes), the greater the extent not burned as frequently as desired, as a function of forest management objectives.

In summary, constraints of WUI and management objectives greatly affect the area of longleaf not burned as frequently as land managers would like. That is, constraints force land managers to unintentionally exclude fire from specific areas of their longleaf holdings, especially those areas near residential development where managing smoke, liability risk and public opinion would seem rather difficult. However, those with active burns programs, those who manage longleaf for recreation and preservation values, appeared able to manage more of their land with desired burn rotations than those with less active burn programs (e.g., those who manage longleaf primarily for wood products).

Objective 3. Quantify and describe patterns of seasonal prescribed fire usage and explore variables that influence these patterns

3.1 Patterns of seasonal prescribed fire usage

Throughout the range of longleaf in the Carolinas, dormant-season (October to March) burning continues to predominate, although 64% of respondents (34 of 53) do conduct at least a minor portion of their burns during the growing season. Table 13 shows the area of longleaf burned in the growing-season (April to September) and the dormant-season (October to March).

Table 13

Area of longleaf burned at least once between 1996 and 2000 during the growing-season (April to September) and dormant-season (October to March)

Ownership	Area burned in growing season '96 to '00 (acres)	Area burned in dormant season '96 to '00 (acres)	Total
Public (n=12)	105,525	150,745	**256,270**
Private (n=22)	8,533	50,492	**59,025**
Total	**114,058**	**201,237**	**315,295**

Twelve public land managers burned a much larger percentage of the longleaf sites they burned between 1996 and 2000 during the growing season (41%) than their twenty-two private colleagues (14%). Private land managers heavily favor burning during the dormant season (October to March) whereas public land managers only express a moderate seasonal preference.

3.2 Variables influencing season in which burns are conducted

Although season of burning was not considered in the path model, exploring the variables that influence seasonal burning may help policy makers better understand this facet of land manager behavior. In this section I show and explain the results of questions addressing the reasons for conducting growing season (April to September) burns and dormant season burns (October to March). Responses of public and private land managers were explored by comparing means using F-tests.

3.3 Comparison of means: objectives for conducting growing season (April to September) burns

Thirty-one respondents rated the importance of six variables associated with burning during the growing season (April to September). Table 14 displays respondent ratings in descending order of importance. Mean values and F-statistics for each variable are also shown.

Table 14

Reasons for burning during the growing season (April to September)

Reasons for growing season burns	Mean	Mean importance by ownership[1]		F-statistic	Significance (1-tail)
		Public (n=12)	Private (n=22)		
1) Eliminate woody understory (n=31)	**4.61**	4.50	4.68	0.552	0.463
2) Approximate natural fire regime	**3.52**	4.00	3.21	2.944	0.097†
3) Promote fire dependent elements	**3.48**	4.08	3.11	4.189	**0.050**
4) Stimulate height growth of longleaf seedlings	**3.00**	3.00	3.00	0.000	1.000
5) Consumes less pinestraw	**1.65**	1.58	1.68	0.128	0.724
6) Tradition	**1.52**	1.33	1.63	1.450	0.238

[1] on a scale of 1 to 5, where 1 is "not at all important" and 5 is "extremely important"
Bold type indicates that means are significantly different (P<0.05)
† indicates that means are significantly different (P<0.1)

Land managers from both groups conduct growing season burns primarily to reduce understory competition by eliminating the woody understory from their longleaf sites. This finding probably indicates a combined proactive strategy (e.g., control hardwoods while they are preemergent or recently emerged) and reactive/restoration strategy (e.g., restore grassy vegetation and park-like structure to currently overgrown areas) for conducting growing season burns. Public land managers indicate that growing season burns allow them to meet a few ecosystem management goals: (1) better approximate the natural fire regime of longleaf systems and (2) promote elements of fire dependent ecosystems (e.g., flowering).

F-tests revealed no significant differences between other reasons for burning during the growing season. Among the survey respondents, differences between ownership in tradition of burning during the growing season and the effect of growing season burns on pinestraw harvests are inconsequential. Of further note, several land managers wrote that they conduct growing season burns simply because they cannot accomplish all of their burning during the dormant season.

3.4 Comparison of means: objectives for conducting dormant season (October to March) burns

Fifty survey respondents addressed their thoughts on dormant season burns, or, why burning during the dormant season is more advantageous than burning during the growing season. Table 15 displays respondent ratings in descending order of importance. Mean values and F-statistics for each variable are also shown.

Table 15

Reasons for burning during the dormant season (October to March)

Reasons for dormant season burns	Mean	Mean importance by ownership[1]		F-statistic	Significance (1-tail)
		Public (n=17)	Private (n=33)		
1) More predictable weather (n=50)	**3.42**	2.94	3.67	3.621	0.063†
2) Less damage to quail nests	**3.36**	2.59	3.76	10.203	**0.002**
3) Kills fewer seedlings	**3.12**	2.41	3.48	8.340	**0.006**
4) Tradition	**2.78**	1.94	3.21	11.088	**0.002**
5) Leaves some hardwood cover	**2.08**	2.13	2.06	0.041	0.841
6) Easier to obtain permit	**2.06**	1.76	2.21	1.841	0.181
6) Consumes less pinestraw	**2.06**	1.35	2.44	9.938	**0.003**

[1] on a scale of 1 to 5, where 1 is "not at all important" and 5 is "extremely important"
Bold type indicates that means are significantly different (P<0.05)
† indicates that means are significantly different (P<0.1)

Overall, private land managers seemed to have much stronger preferences for attributes of dormant season burns than did public land managers suggesting that growing season burns may interfere with aspects of private forest management plans. Private land managers indicated that dormant season burns were more advantageous than growing season burns because (1) they do less damage to quail nests, (2) weather is more amenable to burning than growing season weather, (3) they kill fewer seedlings, (4) private land managers have a tradition of burning during the dormant season, and (5) dormant season burns consume less pinestraw than growing season burns. These findings indicate that parties interested in promoting growing season burns by private land managers may be met with limited success.

Objective 4. Explore policy scenarios designed to make the prescribed burning environment of the Carolinas more hospitable

Fifty-three respondents rated the potential effectiveness of thirteen programs designed to either reduce the regulation of burning or provide incentive for its regular use. This step not only serves to collect opinions from part of the group that would be affected by changes in explicit (e.g., reduced particulate matter standards for those who conduct prescribed burning) or *de facto* (e.g., zoning restrictions) prescribed fire policy, but also provides an opportunity to narrow the number of public policy options that might be most efficacious. Table 16 displays respondent ratings in descending order of importance. Table 17 illustrates respondent ratings to programs that would be offered only to private land managers. Mean values and F-statistics for each variable are also shown.

Table 16

Program scenarios to encourage expanded use of prescribed fire

Program	**Mean**	**Mean importance by ownership[1]**		**F-statistic**	**Significance (1-tail)**
		Public (n=17)	**Private (n=36)**		
1) Ease particulate matter standards for prescribed burning	**4.17**	4.24	4.17	0.155	0.696
2) Greater liability protection from state legislatures	**4.02**	3.41	4.31	7.154	**0.010**
3) No land use restriction if endangered species	**3.68**	2.94	4.03	8.093	**0.006**
4) Zoning restrictions to control residential development	**3.72**	3.35	3.89	2.027	0.161
5) Endangered species mitigation bank	**3.51**	2.59	3.94	14.636	0.001
6) Cost-sharing of	**3.28**	2.41	3.69	8.670	**0.005**

prescribed burning expenses					
7) Conservation recognition and protection	**3.23**	2.94	3.36	1.026	0.316
8) Greater funding of fuel reduction efforts	**3.06**	2.76	3.06	1.059	0.308
9) Technical assistance	**2.96**	3.24	2.83	1.012	0.319

[1] on a scale of 1 to 5, where 1 is "not at all important" and 5 is "extremely important"
Bold type indicates that means are significantly different (P<0.05)
[†] indicates that means are significantly different (P<0.1)

Table 17

Programs useful to private land managers only

Government program	Mean[1]
1) Tax incentives for endangered species managers	4.22
2) Deductible burning expenses	4.08
3) Reimbursement for lost income	3.72
4) Government subsidized insurance	2.83

[1] on a scale of 1 to 5, where 1 is "not at all important" and 5 is "extremely important"

Public land managers strongly favor programs that offer other than financial assistance: 1) the easing of particulate matter standards for those who conduct prescribed burns, but also indicate that 2) greater liability protection from state legislatures, 3) zoning restrictions that control development, and 4) technical assistance will make the prescribed burning environment more hospitable. Private land managers favor programs that have legal, technical, and economic undertones. According to respondents who manage private longleaf forests 1) greater liability protection from state legislatures, 2) tax incentives for those who manage for endangered species, 3) eased particulate matter standards for those who conduct prescribed burns, 4) tax deductible burning expenses, and 5) a weakened Endangered Species Act would help them to more easily meet their management objectives with prescribed fire.

DISCUSSION

Long-term commitment to active prescribed burning programs is critical for the maintenance and restoration of open, park-like longleaf pine savannas, which are among the most endangered ecosystems in North America (Noss, LaRoe, and Scott 1995). In the presettlement landscape fires burned throughout the Atlantic and Gulf Coastal Plains of the Southeastern United States every 2 to 8 years creating and maintaining both the structure and composition of these grassy upland ecosystems (Abrahamson and Hartnett 1990; Christensen 1993a; Christensen 1993b; Christensen 2000). Due to habitat fragmentation and land use change, these lightning-ignited fires do not burn extensively enough or frequently enough to maintain the native, fire dependent species of longleaf pine ecosystems (Frost 1993; Johnson and Gjerstad 1998). Thus, the biological future of remnant longleaf pine ecosystems depends on the ability and willingness of landowners and land managers to intentionally set fire to their longleaf tracts several times a decade. Paradoxically, it might seem, intensive human management is now required to maintain native longleaf pine ecosystems and the numerous fire dependent species living therein.

Based on our knowledge of longleaf pine ecosystem requirements and the need to restore degraded ecosystems to open, park-like longleaf savannas for the now rare species that require such habitat, I undertook a study to (1) quantify and describe patterns in prescribed fire usage in remnant longleaf pine ecosystems of North and South Carolina, (2) understand the relative importance of the factors included in the longleaf manager decision-making framework (motivations for forest management, objectives for prescribed burning, constraints to prescribed burning), (3) quantify the amount of longleaf burned in the growing season (April to September) and assess the reasons for its use, and (4) make recommendations to policy makers suggesting how best to encourage prescribed burning by longleaf pine managers in North and South Carolina, a crucial part of restoring the once great pine savannas of the South.

Area burned and area burned frequently between 1996 and 2000

One essential part of improving longleaf pine management throughout the Carolinas is to increase the area burned repeatedly so that longleaf tracts are burned every 2 to 4 years. Burning once every 5 to 10 years or more may actually lead to increased sprouting and importance of hardwoods in the understory, counterproductive to the goals of longleaf pine ecosystem restoration (Hodgkins 1958; Lewis and Harshbarger 1976; Plocher 1999). Results from this study suggest that only 41% of the longleaf included in this survey, circa 196,000 acres, was burned repeatedly over a recent 5-year time span (1996 to 2000). Furthermore, only 19 land managers (9 public and 10 private) account for 92.6% of this burning, whereas the other 34 land managers included in this study burn only 7.4% of this area.

Active burning by the many small holders of longleaf not included in this study is rather unlikely. Not only do researchers perceive hostility towards burning by this group (Cely and Ferral 1995) but they are also unlikely to manage their forestlands for any purposes, even profit-oriented ones (Megalos 1999), much less conduct prescribed burns. Thus, the area of longleaf burning repeatedly between 1996 and 2000 in the Carolinas probably did not exceed 200,000 acres. This number is encouraging and may suggest that longleaf pine ecosystem restoration efforts, especially by the federal land management agencies, may improve the future for many of the South's most rare and endangered native species.

A larger percentage of the longleaf area included in this study was burned once between 1996 and 2000, approximately 315,295 acres or 67 percent. Again, the dedication to burning of nineteen individuals (9 public and 10 private) accounted for 80% of this area (252,000 acres). Part of the disparity between the areas burned repeatedly and burned once is certainly due to the prevalence of 3-year burn rotations. If one-third of a longleaf tract is burned every year, then it takes six years to burn all areas twice (i.e., frequently). Surely some tracts that are burned infrequently for hazard reduction, perhaps once every seven to ten years, were included in this area as well. Other tracts, depending on site conditions influenced by drainage, soil moisture, nutrient levels, etc. may not accumulate fuel quickly enough to burn more frequently than every four or five years (Abrahamson and Hartnett 1990; Christensen 1993b; Christensen 2000). Nonetheless, shortest fire return intervals are associated with greatest biological diversity and least importance of hardwoods (Walker and Peet 1983). Thus, the need to increase burning on many longleaf sites still exists. Furthermore, increasing the area burned every 2 to 3 years will most surely favor the success of longleaf seedlings and perennial grasses and herbs over hardwoods.

What of these patterns of burning? The path model used in this analysis shows that management objectives and ownership are the most important overall determinants of land manager behavior. Some public land managers burn widely and repeatedly because of the many fire dependent species that might inhabit the longleaf pine woodlands they manage or as part of concerted ecosystem restoration goals designed to provide habitat for these species in the future (Estill 1999; Johnson and Gjerstad 1998; McFarlane and Boxall 2000). This study also shows that other public land managers burned little between 1996 and 2000. One would expect the management objectives for publicly owned longleaf tracts to be quite similar (e.g., provide habitat for endangered species, preserve natural areas, provide habitat for non-game wildlife, etc.). Something other than management objectives must explain this phenomenon, but this study does not adequately address the differences in behavior between active and somewhat active public burn programs. Anecdotal evidence and conversations with several survey respondents indicate for many state and local parks 1) administrators may have little interest in burning, 2) may not know of its importance to longleaf pine ecosystems, or 3) may not have the financial or human resources to regularly conduct burns (Cely and Ferral 1995). Furthermore, areas that have not burned in many years to decades may have fuel loads which only expert prescribed burners may be able to handle. Thus, there may also be a need for burner training on public lands.

The path model better explains differences in burning behavior among private land managers. Differences in burning activity are largely based on management objectives. Some private land managers burned widely and repeatedly because they work primarily to provide habitat for game animals, especially the bobwhite quail. Prescribed fire has long been used to improve and maintain nesting and foraging sites for this important game species (Cely and Ferral 1995; Komarek 1974; Rosene 1969). Other private land managers manage longleaf primarily for forest goods, which do not require active burning for successful production. In fact there is some amount of consensus among members of the forestry community that regular burning may decrease aspects of pine growth, relative to longleaf stands that are not burned regularly. This idea has been supported by field research (Boyer 2000).

Area managed with longer than preferred prescribed burn intervals

Among public land managers, those with active burn programs and those with less active burn programs expressed a nearly equal amount of unintended fire exclusion. Large restoration gains could be made on these large, infrequently burned areas of public longleaf holdings. The eight public land managers with somewhat active burn programs would like to burn 55% of the area they manage more frequently. This is encouraging especially considering the small area these individuals burned repeatedly (8375 acres, or 5.5% of the total burned repeatedly by all public longleaf managers included in this survey). Those public land managers with active burn programs would like to burn 75,000 acres more frequently, or 31% of the total area these nine manage. If successful, these nine managers could increase the publicly owned area burned frequently by 50% (75,000-acre increase out of 145,500 acres burned repeatedly between 1996 and 2000) to encompass nearly all the longleaf managed by these individuals. Overall, public land managers would like to burn 139,000 acres of longleaf more frequently (38.8% of the total area these 17 individuals manage).

Burning among the 36 private respondents show that the ten with currently active burn programs come close to meeting their burning preferences. Only 15% (6400 acres) of their lands are managed with longer than preferred burn rotations. Based on their current uses of prescribed fire, they would probably burn all 41,500 acres that they collectively manage four to five times or more per decade, just the right frequency for supporting optimum species diversity. Those private land managers with less active burn programs would prefer to increase their burning on 38,000 acres of land (54% of the 70,000 acres these 26 individuals manage). However, it seems unlikely that, based on current management objectives and use of prescribed burning, many of these additional acres would be burned repeatedly over a 5 year time span. Overall, private land managers would like to burn 44,500 acres of longleaf more frequently (39.7% of the total area these 36 individuals manage).

As the results of path analysis suggest, those areas not burned as frequently as land managers would like are most affected by the constraints of proximity to the wildland-urban interface, and secondarily the management objectives of the different land managers. Thus, it appears that (1) nearby residential development, (2) lack of suitable weather, (3) liability risk, (4) heavy fuel loads resulting in high prescribed burning risks, (5) public opinion and acceptance, and (6) smoke management and air quality concerns have a large negative impact upon longleaf pine management by reducing the frequency with which many longleaf tracts are burned. Presumably these tracts are located in or near the wildland-urban interface or near smoke sensitive structures (e.g., roads, hospitals, houses, schools, etc.) where weather conditions, liability risks, heavy fuel loads, and public opinion would seemingly be most difficult to manage (Brennan et al. 1998; Fried, Winter, and Gilless 1999; Winter and Fried 2000). Smoke management and air quality concerns affect all longleaf tracts, those near the wildland-urban interface and those protected from the side effects of land use change. Nonetheless, any constraints that limit the amount of longleaf burned repeatedly have the potential to create long-term consequences of ecosystem degradation and failed attempts at ecosystem restoration.

The case of seasonal burning

The previous discussion and the path model focus on burning in general, without regard for season. However, growing season burns more closely resemble the natural fire regime from which humans have deviated (Streng 1993). Seasonal burning may not greatly affect species diversity, but growing season (April to September) burns are known to better control hardwood competition, promote flowering among native herbs and grasses, and promote the height growth of longleaf pine seedlings (Glitzenstein 1995; Platt 1988a; Streng 1993). Long-term use of dormant season burns may also act as a selective force leading to the increased importance of plant taxa like *Pteridium* at the potential expense of the smaller grasses and forbs that comprise the bulk of longleaf ecosystem diversity (Streng 1993). However, many species living in open, grassy habitats are known to be fire dependent; few, if any, are season dependent. Burning is the primary concern, though growing season burns are most ecologically accurate.

Results of this study showed that public land managers burned nearly 50% of the total public area burned between 1996 and 2000 during the growing season. Respondents noted that 105,500 of 256,000 acres burned were burned between April and September. Burning during the growing season seems to help public land managers meet their management objectives of (1) eliminating woody forest underbrush, (2) approximating the natural fire regime of longleaf pine ecosystems, and (3) promoting fire dependent elements of longleaf pine ecosystems (e.g., flowering and seedset of grasses and herbs). On the other hand, private land managers conducted a small fraction, 14%, of their burning between 1996 and 2000 during the growing season. Only 8,500 of 59,000 acres were burned between April and September. They noted several reasons why dormant season (October to March) burns were more advantageous than growing season burns: (1) more predictable weather, (2) less damage to quail nests, (3) kills fewer longleaf pine seedlings, and (4) a tradition of burning during the dormant season. Thus it appears that private land managers for the most part perceive growing season burns as risky. Not only might unanticipated changes in the weather, which are more likely to occur during the growing season, send a fire out of control, but they might also interfere with management objectives, providing habitat and nesting sites for quail and growing a new crop of trees. Private land managers also believe they are well practiced at dormant season burning.

The effects of "certified burner" laws and the Safe Harbor Program

Surprisingly, burner certification and enrollment in the Safe Harbor program for red-cockaded woodpeckers, does not appear to be correlated with burn behavior. This is perhaps explained in part by differences in enrollment eligibility. Burner certification applies only to non-federal land managers, just as participation in the Safe Harbor Program does. Quite possibly, then, the rather extensive and frequent burning activity of federal land managers may disguise any gains these programs have made for burning on private and non-federal public lands.

These programs may also do little to fundamentally change behavior. People with active or somewhat active burn programs may participate in either program merely for extra liability protection (from either growing woodpecker populations or interaction of the side effects of burning with the general public) without much intent of burning extra area. More significant encouragement might come from even greater liability protection, which respondents noted as an important part of expanded burning, especially in the wildland-urban interface. Safe Harbor may also do little to change one's management objectives. Certainly some enrolled in Safe Harbor have active burn programs and signed up to make sure they do not have more liability with growing red-cockaded woodpecker colonies. Also, burning is not a prerequisite for woodpecker habitat as it is for true fire dependent species. Participating managers simply have to control woody understories, which can be accomplished with chemical and mechanical alternatives.

Programs to make burning easier and improve longleaf pine management

While management objectives are most positively correlated with burn behavior, constraints most negatively affected the burning preferences of land managers with currently active burn programs. Thus, to enhance the ability of these land managers to burn their longleaf tracts several times a decade, that is to manifest these preferences into behaviors, constraints should be reduced. Respondents indicated that (1) easing of particulate matter and air quality requirement for those who conduct prescribed burning and (2) greater liability protection from state legislatures would be very beneficial. Surprisingly, respondents did not favor zoning restrictions that control residential development, which would seemingly help to control the wildland-urban interface. Perhaps this strategy is untenable and lacks political tractability. Private land managers with active burn programs also heavily favored (1) tax incentives for those who manage for endangered species and (2) tax deductions for prescribed burning expenses. This latter set of policy changes would reward private land managers for their good deeds and their use of prescribed fire in longleaf pine management.

Managers with less active burn programs, may need a greater sense of motivation from public policy makers to expand their prescribed burning programs. They also favor (1) eased particulate matter standards and (2) greater liability protection, but programs that affect management objectives would seem to be more efficacious. Such programs might include (1) tax incentives for ecosystem restoration efforts, (2) conservation payments based on various ecosystem management and conservation performance levels, or (3) endangered species mitigation banks. These programs might work for private land managers. Public land managers with somewhat active burn programs might be prompted to burn and restore remnant longleaf pine ecosystems by (1) agency policies that make active burn programs a priority and (2) education and training of public land managers about the importance of burning in longleaf pine ecosystems. Simply stating this objective would create some impetus to expand burning. Greater funding of ecosystem restoration efforts by state legislatures, the costs of which can be offset by federal assistance, would help public land managers hire and train burn crews. Some of this manpower might come from local fire fighting departments or armed forces reserved personnel.

CONCLUSIONS

To stem the further decline of remnant longleaf pine ecosystems and help to restore their role as important features of the North and South Carolina landscape, public policy makers must take it upon themselves to improve the environment for prescribed burning. This study shows that managers with active burn programs are prevented from burning significant areas of frequently (e.g., four to five times a decade or more). If policy makers work not only to reduce the constraints to prescribed burning but also provide incentives for burning, real potential seems to exist to expand frequent burning on 146,000 acres of longleaf, which would increase the area repeatedly burned by close to 75 percent. Increasing the area of frequently burned longleaf could help restore and maintain some 342,000 acres of open, park-like longleaf pine forest in the Carolinas alone. These gains would be tremendous, as only 674,000 acres of longleaf pine savanna exist throughout its entire native range in the Southeast (Frost 1993).

Policy change would help prescribed burn bosses and prescribed fire managers realize the many biological, cultural, and social benefits of regular burning. But this is an issue of local, state, and federal jurisdiction and responsibility; so to more effectively "*encourage* prescribed burning in forests by forest landowners" local, state, and federal coordination is required.

Local jurisdictions, which have nearly exclusive control over land use on the land in the Carolinas not in federal ownership (Crist, Kohley, and Oakleaf 2000; Theobald et al. 2000), could help by steering development away from rural areas or instituting rural building standards (Fried, Winter, and Gilless 1999). These changes could more effectively control expansion of the wildland-urban interface, which may benefit longleaf restoration efforts.

State governments could act by providing more comprehensive liability protection, providing technical assistance, developing incentive programs, and helping county governments develop land use plans that protect significant natural areas.

The federal government also plays an integral role in longleaf pine ecosystem restoration. The U.S. Environmental Protection Agency has already given states the authority to discount the role of prescribed fires when meeting National Ambient Air Quality Standards by considering some proportion of prescribed fire as "natural" (Federal Register, Vol. 64, No. 126/ Thursday, July 1, 1999/ Rules and Regulations). Even temporary reduction of smoke management guidelines could have long-term benefits by giving land managers a realistic opportunity to reduce heavy buildup of fuel that follows years of fire exclusion. By reducing high fuel loads and maintaining low fuel loads with regular burning, land managers could ease their smoke management burden in the future. (This policy should be coordinated with greater liability protection.) Tax incentives for those private landowners who manage for endangered species may turn a perceived liability into an asset (Bonnie 1999). Policy makers must empower longleaf managers to use regular prescribed fire to stem the 400-year-old tide that reduced the once inexhaustible longleaf pine forest of the Carolinas and the American Southeast to a critically endangered, irreplaceable component of the Southern social, cultural, and biological heritage.

APPENDIX A

Correspondence sent to survey population

Text of *Prenotice Letter*

August 9, 2000

This is Mark Knott, a graduate student at the University of North Carolina. I spoke with you earlier this summer about filling out a brief questionnaire regarding the longleaf pine sites that you manage. A few days from now you will receive that questionnaire in the mail.

I'm writing in advance just to let you know that the survey would be arriving and to please keep an eye out for it. The study is important because your management decisions have a tremendous impact upon the future of the longleaf pine resource that remains in the Carolinas. By gathering your views on prescribed fire, government policies, and the future of longleaf management, we may help to reverse the decline of longleaf, which was once the signature tree of the Southeast.

Thank you for your time and consideration. It's only with the help of people like you that our research can be successful.

Sincerely,

Mark Knott
Curriculum in Ecology
The University of North Carolina

Text of Introductory Letter

Dear longleaf pine manager

Thank you for participating in this study of longleaf pine management in the Carolinas. This is Mark Knott, a graduate student at the University of North Carolina. I contacted you earlier this summer about my research project and now am writing to introduce my research project and ask for your assistance.

As a manager of longleaf pine, your management decisions are extremely important in determining the future of the longleaf pine resource. The enclosed questionnaire has been designed to assess your management objectives, your use of prescribed fire, and the issues that you encounter each time you burn. I also ask you to consider programs that might help you to more easily meet your management objectives.

Completing this survey should take you about 20 minutes. All of your answers are completely confidential and will be released only as summaries in which no individual's answers can be identified. When you return your completed questionnaire, your name will be deleted from the mailing list and never connected to your answers in any way. This survey is voluntary. However, you can help us very much by taking a few minutes to share your thoughts on longleaf and prescribed burning. If for some reason you prefer not to respond, please let us know by returning the blank questionnaire in the enclosed stamped envelope.

If you have any questions or comments about this study, I would be happy to speak with you. My home and office number is 919-969-XXXX, or you can write me at the address on the letterhead or by email (mdknott@email.unc.edu). If you would like please contact my research advisors

Robert Peet
CB# 3280, Coker Hall
University of North Carolina
Chapel Hill, NC 27599-3280
(919) 962-XXXX
peet@unc.edu

E. Carlyle Franklin
3136 Jordan Hall
Campus Box 8006
Raleigh, NC 27695-8006
(919) 515-XXXX
carlyle_franklin@ncsu.edu

The Academic Affairs Institutional Review Board at the University of North Carolina at Chapel Hill has approved this project. You may contact the UNC-CH Academic Affairs Institutional Review Board at the following addresses or telephone number at any time during this study if you have questions or concerns about your rights as a research subject.

Academic Affairs Institutional Review Board
David A. Eckerman, Chair
CB# 4100, 201 Bynum Hall
The University of North Carolina

Chapel Hill, NC 27599-4100
(919) 962-7761
email: aa-irb@unc.edu

Thank you very much for your help with this important study.

As a consequence of your assistance, and that of others, we may help to reverse the decline of longleaf, which was once the signature tree of the Southeast.

Sincerely,

Mark Knott

Text of *Second Mailing Letter*

Dear longleaf pine manager,

Thank you for participating in this study of longleaf pine management in the Carolinas. This is Mark Knott, a graduate student at the University of North Carolina. Earlier this summer I sent you a survey to fill out but haven't heard back from you yet. So I was hoping that a second mailing would help to improve the 65% response rate that I've gotten so far. Your participation will improve this study by providing a complete assessment of those who manage large tracts of longleaf in the Carolinas. If you have already completed the survey and returned it, please disregard this mailing, and I apologize for the extra contact.

As a manager of a large amount of longleaf pine, your management decisions are extremely important in determining the future of the longleaf pine forests. The enclosed questionnaire has been designed to assess your management objectives, your use of prescribed fire, and the issues that you encounter each time you burn. I also ask you to consider programs that might help you to more easily meet your management objectives.

Completing this survey should take you about 20 minutes. All of your answers are completely confidential and will be released only as summaries in which no individual's answers can be identified. When you return your completed questionnaire, your name will be deleted from the mailing list and never connected to your answers in any way. This survey is voluntary. However, you can help us very much by taking a few minutes to share your thoughts on longleaf and prescribed burning. If for some reason you prefer not to respond, please let us know by returning the blank questionnaire in the enclosed stamped envelope.

If you have any questions or comments about this study, I would be happy to speak with you. My home and office number is 541-753-XXXX, or you can write me at the address on the letterhead or by email (mdknott@email.unc.edu). If you would like please contact my research advisors

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Thank you very much for your help with this important study.

As a consequence of your assistance, and that of others, we may help to reverse the decline of longleaf, which was once the signature tree of the Southeast.

Sincerely,

Mark Knott

Text of *Follow Up Letter*

Mark Knott
The University of North Carolina
Curriculum in Ecology
Campus Box 3275, Miller Hall
Chapel Hill, NC 27599-3275

Dear longleaf pine manager:

This is Mark Knott a graduate student at the University of North Carolina. First, I want to thank you for completing and returning the survey I sent you earlier this year that explored longleaf pine management in the Carolinas. I'm very pleased with the 75% response rate that I've gotten and all the information that was shared. However, after looking at all the data collected from the survey, I need to clarify a few things. So if you could answer 4 more short questions and then return the enclosed postcard I'd really appreciate. With your help, I feel that the results of the study would be much more meaningful.

I'll get you a summary of the results of my research as soon as I have it ready—hopefully next month. If you have questions, please let me know (541) 753-XXXX.

Sincerely,

Mark Knott

APPENDIX B

Longleaf Pine Management in the Carolinas: A Survey of Land Managers

AND

Follow up Questionnaire

Longleaf Pine Management in the Carolinas:

A Survey of Land Managers

Part 1: *The following questions concern your current use of prescribed burning (controlled burning) in the longleaf stands that you manage.*

1. **Please indicate the degree of risk you think each of the following factors poses to the longleaf site(s) you manage.** (Please mark one number for each factor)

	No risk				Extreme risk
Wildfire……………………………………………….	1	2	3	4	5
Fire suppression…………………………………………	1	2	3	4	5
Pest outbreaks (insect or disease)…………….…………	1	2	3	4	5
Restrictions resulting from the presence of endangered species…………………………………	1	2	3	4	5
Residential development resulting in smoke management problems……………………………………………….	1	2	3	4	5
Estate tax burden…….……………………………………..	1	2	3	4	5
Desire to convert longleaf to other pines…..……….………...	1	2	3	4	5

Other (Please specify)____

2. **How important is each of the following outcomes for managing your longleaf pine site(s)?** (Please mark one number for each category)

	Not at all important				Extremely important
Wood products…………….………………………………	1	2	3	4	5
Clean pinestraw………..………………………………….	1	2	3	4	5
Game animal habitat………………………………………	1	2	3	4	5
Non-game animal habitat…………………………………	1	2	3	4	5
Endangered species……………………………………….	1	2	3	4	5
Recreation…………………………………………………	1	2	3	4	5
Aesthetic enjoyment………………………………………	1	2	3	4	5
Preserve area for future generations………………………	1	2	3	4	5

Other (please specify)____

3. **How valuable is each of the following attributes of the longleaf site(s) you manage?** (Please mark one number for each reason)

	Not at all valuable				Extremely valuable
Wood products………………………….………………	1	2	3	4	5
Clean pinestraw……………………………………………	1	2	3	4	5
Hunting leases…………………………………………….	1	2	3	4	5
Recreation…………………………………………………	1	2	3	4	5
Aesthetic enjoyment……………………………………….	1	2	3	4	5
Habitat for endangered species……………………………	1	2	3	4	5
Protection of soil and water resources…………………….	1	2	3	4	5

Other (Please specify)____

4. **For each of the 3 longleaf habitat types listed below, approximately how often do you conduct prescribed burns on the type(s) you manage?** If you don't use prescribed burns place a check here ____ and skip to #9 (Please mark one interval for each habitat type. If you use a variable burn frequency, then mark the interval you most frequently use.)

Sandhills
___ Don't manage
___ Every 1 to 3 years
___ Every 4 to 6 years
___ Every 7 to 10 years
___ Every 11+ years

Savannah (wet sites)
___ Don't manage
___ Every 1 to 3 years
___ Every 4 to 6 years
___ Every 7 to 10 years
___ Every 11+ years

Flatwoods (upland sites)
___ Don't manage
___ Every 1 to 3 years
___ Every 4 to 6 years
___ Every 7 to 10 years
___ Every 11+ years

5. **Approximately what percentage of your prescribed burns do you conduct during the GROWING season (April to September)?** (Please estimate and check one)

___ 0% → skip to #7
___ 1-25%
___ 26-50%
___ 51-75%
___ 76-99%
___ 100% → do #6, skip #7

6. **From the following list, which do you consider important reasons for burning during the GROWING season (April to September)?** (Please mark one number for each category)

	Not at all important				Extremely important
Eliminates woody understory……………………………….	1	2	3	4	5
Promote elements of fire dependent systems (for example, flowering)……………………………..…….	1	2	3	4	5
Stimulate height growth of longleaf seedlings……………...	1	2	3	4	5
Approximates natural fire regime…………………………...	1	2	3	4	5
Have always used growing season burns……………………	1	2	3	4	5
Consumes less pinestraw……………………………………	1	2	3	4	5

Other (please specify)____

7. **From the following list, which do you consider important reasons for burning during the DORMANT season (October to March)?** (Please mark one number for each category)

	Not at all important				Extremely important
Easier to obtain permit………………………………………	1	2	3	4	5
Kills fewer seedlings……………...………………………	1	2	3	4	5
Less damage to quail nests…………………………………..	1	2	3	4	5
Doesn't kill all the hardwoods……………………………….	1	2	3	4	5
Weather more predictable than during growing season……..	1	2	3	4	5
Have always used dormant season burns……………………	1	2	3	4	5
Consumes less pinestraw…………………………………….	1	2	3	4	5

Other (please specify)____

8. **Below are some general reasons for conducting prescribed burns. For each one, please indicate how important it is to you in managing your longleaf pine site(s).** (Please mark one number for each reason)

	Not at all important				Extremely important
Manage fuel loads………………………………………...	1	2	3	4	5
Remove ladder fuels and make suppression easier………….	1	2	3	4	5
Provide cleaner pinestraw and make its collection easier…..	1	2	3	4	5
Open woods to allow for easier hunting…………………….	1	2	3	4	5
Perpetuate fire dependent species……………………………	1	2	3	4	5
Enhance aesthetic value……………………………………..	1	2	3	4	5
Provide habitat for game animals……………………………	1	2	3	4	5
Provide habitat for non-game wildlife………………………	1	2	3	4	5
Provide habitat for threatened and endangered species……..	1	2	3	4	5
Control of pest outbreaks……………………………………	1	2	3	4	5
Prepare seedbeds……………………………………………	1	2	3	4	5
Enhance species diversity…………………………………..	1	2	3	4	5
Preserve a piece of a disappearing ecosystem………………	1	2	3	4	5
Keep costs down (cheaper than chemical or mechanical alternatives)……………………………………………..	1	2	3	4	5

Other (Please specify)____

9. **How much does each of the following factors limit your willingness to use prescribed burns in the longleaf site(s) you manage?** (Please mark one number for each category)

	Not at all limiting				Extremely limiting
Don't know about using prescribed burns…………………	1	2	3	4	5
Want to let nature take its course………………………….	1	2	3	4	5
Public opinion and acceptance…………………………….	1	2	3	4	5
Loss of pinestraw, seedlings or trees………………………	1	2	3	4	5
High cost of planning and implementing burns……………	1	2	3	4	5
Don't like the look of a burned area……………………….	1	2	3	4	5
Landowner does NOT want to burn more…………………	1	2	3	4	5
Smoke management and air quality concerns……………..	1	2	3	4	5
Local ordinances that restrict open burning……………….	1	2	3	4	5
May harm game populations………………………………	1	2	3	4	5
Liability risk (litigation, damages, loss of public support, etc.) from smoke intrusion and escaped fire….	1	2	3	4	5
Shortage of qualified personnel or burn crews…………….	1	2	3	4	5
Avoid restrictions from the Endangered Species Act (by not providing suitable habitat)…………………….	1	2	3	4	5
Lack of appropriate weather……………………………….	1	2	3	4	5
Insurance availability or cost………………………………	1	2	3	4	5
Heavy fuel loads resulting in high prescribed burning risks..	1	2	3	4	5
Agency management policies that discourage risk-taking…	1	2	3	4	5
Availability of lower cost, less hazardous, or more effective alternatives to prescribed fire…………………	1	2	3	4	5
Residential development in or near the areas to be burned..	1	2	3	4	5

Other (please specify)____

10. **Please indicate how much each of the following factors influences the cost of prescribed burning in the longleaf site(s) you manage.** (Please mark one number for each category)

	Does not influence				Great influence
Size of the unit being burned………………………………	1	2	3	4	5
Cost of insurance………………………………………..	1	2	3	4	5
Cost of hiring burn crews………………………………….	1	2	3	4	5
Loss of income (pinestraw, seedlings, or trees)……………	1	2	3	4	5
Availability of lower cost alternatives……………………..	1	2	3	4	5
Compliance with environmental laws and regulations…….	1	2	3	4	5
Crew safety…………………………………………………	1	2	3	4	5
Safeguards to minimize the likelihood of escaped fire…….	1	2	3	4	5

Other (please specify)____

11. **Considering the total area of the longleaf site(s) that you manage, approximately what percentage are you NOT able to burn as frequently as you would like?** (Please check one)

___ 0%
___ 1 to 25%
___ 26 to 50%
___ 51 to 75%
___ 76 to 99%
___ 100 %

12. **Over the next 10 years, how do you think your use of prescribed burning will change in the longleaf site(s) you manage?** (Please check one)

___ Burn more frequently but in a smaller area
___ Burn more frequently and in a larger area
___ Burn less frequently and in a smaller area
___ Burn less frequently but in a larger area
___ Same frequency and area
___ Won’t have longleaf sites to manage
___ No opinion

Part 2: *The following questions concern the current legal and regulatory environment that impacts land management and the use of prescribed burning.*

13. **Under what type of ownership is the longleaf site(s) that you manage?** (Check all that apply)

___ Public → skip to #15
___ Individual
___ Partnership or hunt club
___ Non-government organization
___ Family-owned corporation
___ Forest industry
___ Other (please specify)______________________________________

14. **Is any part of your longleaf site(s) entered into a Safe Harbor Agreement for a threatened or endangered species?**

___ Yes
___ No

15. **Have you ever been forced to modify an activity, action, or project to be in compliance with the Endangered Species Act?**

___ Yes
___ No

16. **Both North Carolina and South Carolina have passed laws that protect "certified burners" from part of the liability risk they assume when they conduct prescribed burns. These Acts provide limited protection from smoke intrusion for those who follow specific requirements.**
Does protection from liability risk resulting from smoke intrusion encourage you to use prescribed burning? (Please check one)

___ Yes
___ No

17. **Are you a certified burn boss as described by the North Carolina Prescribed Burning Act of 1999 or the South Carolina Prescribed Fire Act of 1994?** (Please check one)

___ Yes
___ No

Part 3: *The following question asks you to consider programs that might help you more easily meet your management objectives through the use of prescribed fire.*

18. **Whether you currently use prescribed burning or not, please consider how effective the programs or incentives listed below might be in allowing you to more easily meet your management objectives with prescribed burning.** (Please mark one number for each category.)

	Not at all effective				Extremely effective
Technical assistance (training of burn crews, management consultation)….............................	1	2	3	4	5
Government subsidization of insurance policies………..	1	2	3	4	5
Cost-sharing of prescribed burning expenses…………….	1	2	3	4	5
Redistribution of fire suppression funds to fuel reduction funds……………………………………..…	1	2	3	4	5
Make the costs of prescribed burning tax deductible………	1	2	3	4	5
Conservation recognition to protect land from some forms of development…………………………………	1	2	3	4	5
Provision of tax incentives to those who manage for endangered species…………………………………….	1	2	3	4	5
Reimbursement for lost income…………………………..	1	2	3	4	5
Zoning restrictions that control residential development…	1	2	3	4	5
Easing of particulate matter and air quality requirements for those who conduct prescribed burning…………….	1	2	3	4	5
Greater liability protection from state legislatures………..	1	2	3	4	5
Assurance that land use restrictions will not occur if endangered species are present………………………..	1	2	3	4	5
Tradable endangered species permits or similar mitigation bank program………………………………	1	2	3	4	5

Other (please specify)____

Part 4: *For analytical purposes we need to know a little more about you. You may skip any question you'd rather not answer, but please be assured that your responses will be kept strictly confidential and used only to track demographic patterns in responses.*

19. **Approximately how many total acres of land do you manage in the Carolinas?**

____________ ACRES

20. **Approximately how much of this area currently supports the longleaf pine forest type, which according to forest classification contains at least 60% longleaf pine?**

____________ ACRES

21. **In what year were you born?**

19____

22. **Please check the highest level of education that you have completed** (Please check one)

___ Some high school
___ High school graduate
___ Some college
___ College graduate
___ Graduate degree
___ Technical degree
___ Other (please specify)______________________________________

Thank you very much for you help and cooperation!

To return the survey, please seal it in the enclosed envelope and deposit in any mailbox. The postage is paid. Please don't return the cover letter. Thank you.

Additional comments?

FOLLOW UP QUESTIONNAIRE

1. Approximately how many acres of longleaf pine forest do you manage in the Carolinas?

   ____

2. Regarding the longleaf site(s) that you manage in the Carolinas, approximately how many acres did you burn over the past 5 years (1996 to 2000)?

   ____

3. Of the area you burned over this same 5 year time period, approximately what percentage was burned more than once?

   ____

4. In what year were you born?

   ____

APPENDIX C

Path Analysis Regression Equations

Key

Shorthand	Meaning
r_{ij}	Correlation coefficient (correlation between variable i and j)
$ß_{ji}$	Path coefficient (effect of variable i on variable j
1	Ownership
2	Importance of managing longleaf for preservation
3	Importance of managing longleaf for recreation
4	Constraint due to proximity to wildland-urban interface
5	Constraint due to risk aversion
6	Behavior (prescribed fire usage)
DE	Direct effect
IE	Indirect effect
S	Spurious effect

Formulas

Correlation between ownership and preservation index
$r_{12} = ß_{21}$

Correlation between ownership and recreation index
$r_{13} = ß_{31}$

Correlation between ownership and constraint due to WUI
$r_{14} = ß_{41} + ß_{42}ß_{21} + ß_{43}ß_{31}$

Correlation between preservation index and constraint due to WUI
$r_{24} = ß_{42} + ß_{41}ß_{21} + ß_{43}ß_{31}ß_{21}$

Correlation between recreation index and constraint due to WUI
$r_{34} = ß_{43} + ß_{42}ß_{21} + ß_{41}ß_{31}ß_{21}$

Correlation between ownership and constraint due to risk aversion
$r_{15} = ß_{43} + ß_{52}ß_{21} + ß_{53}ß_{31}$

Correlation between preservation index and constraint due to risk aversion
$r_{25} = ß_{52} + ß_{51}ß_{21} +ß_{53}ß_{31}ß_{21}$

Correlation between recreation index and constraint due to risk aversion
$r_{35} = ß_{53} + ß_{51}ß_{31} + ß_{52}ß_{31}ß_{21}$

Correlation between ownership and behavior

$r_{16} = ß_{61} + ß_{62}ß_{21} + ß_{63}ß_{31} + ß_{64}ß_{41} + ß_{64}ß_{42}ß_{21} + ß_{64}ß_{43}ß_{31} + ß_{64}ß_{51} + ß_{64}ß_{52}ß_{21} + ß_{64}ß_{53}ß_{31}$

Correlation between preservation index and constraint

$r_{26} = ß_{62} + ß_{21}ß_{61} + ß_{63}ß_{31}ß_{21} + ß_{64}ß_{41}ß_{21} + ß_{64}ß_{42} + ß_{64}ß_{43}ß_{31}ß_{21} + ß_{65}ß_{51}ß_{21} + ß_{65}ß_{52} +$

$ß_{65}ß_{53}ß_{31}ß_{21}$

Correlation between recreation index and behavior

$r_{36} = ß_{63} + ß_{64}ß_{43} + ß_{65}ß_{53} + ß_{61}ß_{31} + ß_{62}ß_{21}ß_{31} + ß_{64}ß_{41}ß_{31} + ß_{64}ß_{42}ß_{21}ß_{31} + ß_{65}ß_{51}ß_{31} +$

$ß_{65}ß_{52}ß_{21}ß_{31}$

Correlation between constraint due to WUI and behavior

$r_{46} = ß_{64} + (r_{46}-ß_{46})$

Correlation between constraint due to risk aversion and behavior

$r_{56} = ß_{65} + (r_{56}-ß_{56})$

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