

SPATIAL STRUCTURE AFFECTS LANDSCAPE ECOLOGY FUNCTION

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

1999

I would like to dedicate this thesis to my parents, Don and Dianne Whitney, for their never-ending support and encouragement since I was a child and throughout my schooling, and for helping to create my love for nature through PBS and Wild Kingdom.

ACKNOWLEDGMENTS

Sincere thanks are due to my advisor and committee chair, Dr. Larry Harris, for inspiring me as an undergraduate and encouraging me to focus on being a scholar. Dr. Doria Gordon, guided my research initiatives and provided valuable advice in all phases of the fire ecology studies. Dr. Phil Hall assisted in my studies and research proposal for the never-finished research at Camp Blanding Training Site (CBTS) near Keystone Heights, Fla.

Others influenced my work, most importantly, Kristina Jackson, a valuable friend who caused me to meet Dr. Harris and subsequently study wildlife ecology and who also helped me with the design, fieldwork and statistics of this research. Mr. Tom Hoctor assisted me with many facets of this research, challenged my thinking of ecological issues and helped me to improve as a scholar. Kelly McPherson deserves thanks for helping with statistical aspects of the experimental design and with fieldwork. Thanks go to Dr. Jack Putz and Dr. Katie Sieving for initial review of this work. Galin Jones of IFAS Statistics provided invaluable support and advice in my statistical endeavors. Paul Catlett provided assistance in my research efforts at CBTS. And, I would like to thank the biologists and technicians from CBTS and (the former) Florida Game and Freshwater Fish Commission who assisted in the one burn I was able to conduct there.

Last but not least, I would like to thank all the people who helped me in the field (especially to those who volunteered): Marty Fleming, Larry Harris, Jr., Jerzy Kozlowski, Mike McBurney, Jim Sadle, Branch Schimmenti, Rob Spitler, and Tom Workman.

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Abstract of Thesis Presented to the Graduate School
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December 1999

Chairman: Dr. Larry Harris
Major Department: Wildlife Ecology and Conservation

Landscape ecology is distinguished from other subdisciplines because it explicitly addresses the importance of spatial structure and pattern as well as spatially explicit environmental forces such as wind, fire and flood that move across the surface of the earth. These forces lead to 'horizontal' processes that formerly occurred across interconnected landscape subsystems and may well be essential to the ecological function and integrity of regional ecological systems. Sheet-flow of water, for example, is acknowledged as being critical to restoration and maintenance of south Florida's regional seascape as well as landscape. Fragmentation of ecological systems and their 'horizontal' functions, habitats, and/or populations of keystone species such as crop pollinators are all recognized as critical components of the present biodiversity crisis on earth. The degree to which restoration of formerly existing structural and/or functional connectivity can be achieved may be critical to regional ecological processes.

Fire is increasingly recognized as a premier phenomenon that is an integral variable in the maintenance of ecological integrity of many forested landscapes in the Southeastern Coastal Plain. Two small-scale experiments assessed the hypothesis that width of fuel connectors would differentially affect the rate and/or success of fire spreading across rural north Florida pasturelands. The effects of the two different treatment variables 1) width (of inter-patch connectors) and 2) orientation (of the connectors relative to ambient wind) were not sufficient to emerge as important relative to more salient variables including fuel moisture and humidity, solar position, ambient temperature and wind. Even though intuitive, head fires were shown to move through the connectors significantly faster than did backfires. In addition, the variance surrounding the means of the back fire movement rates was very small. All things considered, the experiments established that structural connectivity across otherwise open landscapes does have significant effects on the behavior of prescribed fire, arguably the single most critical variable with respect to vegetated landscapes in the lower Southeastern Coastal Plain of North America.

INTRODUCTION

Understanding how to restore and maintain spatial ecological processes can be considered the most important element of landscape ecology (Turner 1989, Harris *et al.* 1996). Landscape ecology describes the nature of ecological structure and processes as they occur in two-dimensional space over large spatial scales. In other words, the fundamental distinguishing factor between landscape ecology and broader ecological theory is that the latter does not explicate the importance of space. Interactions of ecological processes and spatial structure are the most important aspect of landscape ecology (Ims 1999, Pickett and Cadenasso 1995). Understanding fundamental ecological processes on the landscape may be critical for the maintenance of natural system integrity. Wind, floodwater and fire that usually moves across the landscape are not only important in sculpting the pattern of elements on the landscape, they are known to be critical to long-term system function (Parsons 1981, Harris *et al.* 1996).

Wind is known to be important over space and time insofar as it spreads fire and creates dune systems or aeolin landscapes. “Waves” (or gusts) of wind are very important to the spread of fire in that they can push fires quickly over large areas (Komerek 1967). The great bluffs along the Missouri River were created or “blown there” by elluviation from the Rocky Mountains. Dune formations on the southwest coast of France are not only sculpted by wind but are very actively covering forests on the back slopes (L.D. Harris, pers. comm.).

Sheet flow used to be a critical landscape process in the structural and functional aspects driving the Everglades regional system of southern Florida as well as other hydrologic systems in the SECP, such as flooding of the Suwannee River. Research has been conducted to demonstrate the influence of sheet flow of water on tree island shape in the Northern Everglades (Brandt 1997). In the 19th century, Hamilton-Disston contracted with the State of Florida to expressly prevent sheet flow by digging canals in favor of rapid water delivery to the sea. As a follow-up to Hamilton-Disston, the U.S. Army Corps of Engineers dredged a straight canal in the 1950's to subsume the highly meandered Kissimmee River that connected the Orlando chain of lakes to Lake Okeechobee. While the drainage facilities increased land available for cattle grazing, they also terribly degraded water quality in Lake Okeechobee (McCally 1999). Regional scale restoration projects, such as the restoration of rivers (Kissimmee, Ocklawaha) and water flow in the Everglades, have proven to be highly debated public policy issues due to the high monetary costs and intensive restructuring of the systems. Most ecologists, though, believe that the need to restore and maintain spatial processes is increasingly important to biodiversity conservation. Another example of the functional influences of floodwater can be seen in the historical flooding of the SECP riverine systems. Low topographic relief, causes any water-level rise to expand the water horizontally. This back-and-forth movement across the floodplain [referred to as a "seasonably migratory ecotone"] is the critical process responsible for the high productivity in the system (Harris *et al.* 1996). Spatial and temporal scales are thus functionally interrelated by these large-scale physical forces (Harris *et al.* 1996).

Fire as a Spatial Process

Fire is an important social, biological and political phenomenon in Florida. Fire shaped the spatial structure of the composition and distribution of forest types in the Southeastern Coastal Plain (Waldrop *et al.* 1992). Because fire is such a critical ecological process in the SECP, it has played a major role in sculpting the distribution of biota on the landscape. Thus, fire has long been significant to both cultural and natural history in the Southeast. With respect to fragmentation effects on the once-dominant longleaf pine system ecology, fire movement is arguably the single most important variable.

Natural fire regimes (with variable timing, stochasticity, fuel loads, and spread) that are now known to be so critical to the evolution and maintenance of biodiversity in the Southeastern Coastal Plain (SECP) are consistently altered by anthropogenic landscape fragmentation by human-built structures such as housing developments, roads and canals. Therefore, unraveling the variables that influence or control the movement of fire across landscapes is fundamental to forest management and planning. Physical environmental factors such as wind, fuel load, fuel moisture and ambient temperature are without question overriding variables of greatest influence on the nature of fire on the landscape. But, ensconced within these variables the question of connectivity should also be addressed.

There is a copious amount of literature published about fire and fire history (see Frost 1993, Komerek 1963, 1967, Platt and Rathbun 1993), yet, few experiments have

been conducted on spatial aspects of fire movement. This experiment examined the effect of spatial connectivity of patches as an initial step toward understanding inter-patch dynamics on/in fragmented landscapes. Manipulations of fuel load and width served as a proxy for connectivity and connectedness. Through these experimental factors (and assumptions), an inter-patch process was tested. Given that many physical environmental factors such as wind may exert greater influence on the rate of spread of fire than does corridor width, there is a strong need for further research examining the effect of corridor width on the nature of fire progression across the landscape.

An exceptionally high number of lightning strikes (in the region) were most likely responsible for igniting many fires that could formerly propagate across an interconnected landscape. Under such conditions even a single lightning strike could change the ecological function from that of a local disturbance to one at a systems-level (Platt and Rathbun 1993). As a consequence, biota most likely evolved in response to the frequency and intensity of recurrent factors such as this (Komarek 1963, Pyne *et al.* 1996).

Wiregrass (*Aristida beyrichiana* and *A. stricta*, see Peet 1993 a,b) is a dominant understory species that provides fine fuel load that facilitates fire spread throughout sandhills in the Southeast (Platt *et al.* 1988, Noss 1989, Whitney unpubl. data). Longleaf pine (*Pinus palustris*) also serves two critical functional roles in maintaining the pine-grassland system on uplands of the lower SECP. Not only do the remarkably long and resinous leaves complement the wiregrass as a fuel source (Platt and Rathbun 1993), the longleaf pine actually promotes fire through its highly resinous trees and related bole and branch structure (Landers 1991). Mature pines seem to serve as lightning receptors as well as the pyrogenic basis of fire (incendiary litter), which, in turn precludes hardwood

invasion beneath the crowns and into the surrounding matrix (Mutch 1970, Williamson and Black 1981, Platt *et al.* 1988, Landers 1991, Platt and Rathbun 1993) (Figure 1).

Landers (1991) suggested that the increased flammability among most species in the genus *Pinus* was under selection as a homeorhetic process that strongly favors pines on harsh sites as well as it is a mechanism for gaining dominance over otherwise competitive species. Climatic periods with frequent lightning fire under moist conditions likely selected for these and many other fire-dependent plant species with traits that tend to increase the probability of fire (Abrahamson and Hartnett 1991, Landers 1991).

One of the first Spanish explorers to chronicle and describe the SECP, Cabeza de Vaca (1528; cited in Hodge and Lewis 1907), wrote of the frequent “sprays” of lightning strikes on pines as he traveled through Florida. Bartram (1792) [some 250 years later] described the structural result; monospecific overstories of longleaf pine comprised of widely spaced trees over a wide highly-diverse savanna (Landers 1991). Since European colonization, logging, agriculture, and urbanization have degraded and replaced the pine-grassland systems of the SECP. Less than 1.0% of the estimated original 92 million acres now remain in good condition for this community type (Frost 1993). Loss of the area in longleaf pine landscapes has been so widespread that virtually no old-growth stands remain today. Those remaining stands are not sufficiently extensive to experience and/or assimilate "natural" disturbance regimes. Invasion by fungi, rust, and hardwoods are now common occurrences because there is no longer sufficiently healthy growth of wiregrass and/or needle fall to facilitate the spread of fire (that controls competitors) and smoke that both retards disease and facilitates seed germination. In addition, due to fire suppression there is a build up of “heavy roughs” (accumulation of combustible fuels) that poses a

threat of wildfires (Wade and Lunsford 1989). Because so few experiments have been conducted on fire movement, further experimentation that focuses on process conveyance across a multitude of ecosystem/landscape types should follow this research. Thus, in the eyes of Harris *et al.* (1996) [and many others] the challenge of conservation in the Southeast is that of

restoring and maintaining a spatially integrated longleaf pine ecosystem that can and will maintain the full suite of landscape ecological processes, including fire (and smoke) that is ignited in one place but allowed to disperse across the system; a system that . . . can remain viable and resilient because of its extensive nature; . . . and a system that is interdigitated with other community types that provide seasonally important services for the longleaf pine community and vice versa. (Harris *et al.* 1996 p.341)



Figure 1: Controlled burn in a longleaf pine system. Resinous trees often burn for days and continue to contribute to incipient fire long after some immediate areas have burned.

Connectivity as a Form of Structure in the Landscape

Connectivity is a fundamental feature of most natural landscapes (Merriam 1984, Noss and Harris 1986, Forman and Godron 1986, Noss and Harris 1989). The role of connectivity in reserve design resulting in creation of ecological networks is to help restore naturally connected landscapes and assist in the maintenance of indigenous ecological processes under which these landscapes evolved. Linkages that allow for spatial and temporal interactions to occur at the level of the regional landscape may well constitute a critical system attribute. The theoretical works of Preston (1962), MacArthur and Wilson (1963, 1967) and Diamond (1975), coupled with considerable empirical evidence (see Beier 1993, 1995, and Beier and Noss 1998) suggest that physically connected patches of habitat on the landscape are one means to support and maintain a greater richness of indigenous species and system integrity (Harris and Scheck 1991). Many have articulated ideas leading to this hypothesis on how dispersal and source-sink dynamics are recurrent processes in the landscape (Levin 1974, Roff 1974a, b, Roff 1975, Levin 1976, Henderson *et al.* 1985, Pulliam 1988, Harris and Gallagher 1989).

To maintain biodiversity over long periods of time, natural landscape patterns of heterogeneity and other emergent ecological processes must be recognized and addressed at the level of regional ecological planning (Harris and Kangas 1979, Harris 1984, Noss and Harris 1986, Noss 1987, Hansson and Angelstam 1991, Harris and Atkins 1991, Harris and Scheck 1991). Essential to this type of planning is the recognition of functionality of landscapes. This can be most easily maintained or restored by attaining critical minimum levels of connectivity that facilitate horizontal ecological processes.

Functional landscape systems will, in turn, allow energy flow and other ecological processes to propagate across multiple spatial scales and create critical levels of structural heterogeneity such as edges and patches.

Both the benefits (Forman and Godron 1986, Noss 1987, Henein and Merriam 1990, Hobbs 1992) and costs (Simberloff and Cox 1987, Simberloff *et al.* 1992) of corridors have been discussed in the scientific literature. Still, the consensus among leading ecologists is that an overarching paradigm of spatial connectivity is a prominent aspect of landscape structure and function.

Although the value of connectivity of the landscape seems to be recognized in both the scientific and management communities, empirical data on the roles of corridors and/or connectedness are limited (Baudry and Merriam 1988). Moreover, questions regarding the spatial distribution, configuration, and physical aspects of corridor must be better defined. Baudry and Merriam (1988) noted how connectivity is a parameter receiving value from processes moving across landscape elements while connectedness is demonstrated through structural landscape features. McDonnell and Stiles (1983) also showed how the importance of processes may be revealed through structural elements (i.e., its connectedness). For instance, several questions were posed regarding the structural aspects of corridors as well as the length and shape of corridors (spatial configuration) (McDonnell and Pickett 1988, Adams and Dove 1989, Nicholls and Margules 1991, Noss 1993). Given the entire debate, the most pervasive and recurring question pertains to corridor width: "How wide should a corridor be?" Some authors have addressed this issue (Harris and Atkins 1991, Harris and Scheck 1991, Baur and Baur 1992, Polla and Barrett 1993) and have therefore suggested that it depends on what

function it must serve (e.g., habitat, dispersal conduit for plants and/or animals, etc.; see Noss (1993). The role of environmental corridors in facilitating seed dispersal and the movement of animals and other phenomena such as disease has been reviewed in depth (Beier and Noss 1998, Simberloff *et al.* 1992, Saunders and Hobbs 1991, Harris and Gallagher 1989, Noss 1987, Forman and Godron 1986). But the role that corridors might play in the movement of an ecological process such as fire has not been experimentally addressed. A logical extension of this idea is that these processes are affected by the nature, shape, and connectedness of the habitats in which they are conveyed.

Experimental Model Systems

Wiens *et al.* (1985) noted how “so few proper experimental designs have been applied to probe the effects of patch boundary variables on ...the flow of matter between landscape elements, especially in view of the perceived importance of such processes in landscape ecology” (Ims 1999, p.46). On the other hand, it is indeed possible to construct such experiments where aspects of a landscape-level process can be tested in experimental landscapes designed at a fine (or “micro”) scale (Ims 1999). In these experimental model systems, demonstrated through the work of Ims and Stenseth (1989), Wiens *et al.* (1993), and Bowers *et al.* (1996), landscape heterogeneity and landscape-level population dynamics can be replicated and tested using experimental treatments at a small scale (Ims 1999).

Because of the difficulty of conducting larger-scale experiments, experimental model systems (EMS) may be used to evaluate ecological responses to spatial heterogeneity (Ims 1999, With 1997, Wiens 1989). These EMS consist of “microlandscapes” where researchers can mimic spatial aspects at “micro” scales in the hope of understanding broader-scale processes (With 1997). Scientists can then extrapolate results from small-scale experiments to larger scale landscapes; especially with the aid of spatially explicit modelling (O’Neill, 1979). For example, Wiens and Milne (1989) conducted an experiment that used beetles to evaluate models based on percolation theory to assess responses to various landscape configurations. These studies are most relevant because they came close to isolating a single or a few ecological processes from an otherwise “tangled bank” of confounding variables (With 1997). No ecologist doubts the need to understand horizontal or spatial processes across both real and/or “experimental” landscapes (With 1997, Rastetler *et al.* 1992, With and Crist 1996). Many consider the functional role spatial processes have in the landscape to be *the* central issue in ecology (Levin 1992, Harris *et al.* 1996). It is subsequently believed that conservation of ecosystems and communities are destined to fail if component systems are isolated from the processes that drive their function.

The purpose of this research was to investigate the role of inter-patch connectivity and configuration on the movement of fire. It was hypothesized that configuration of experimental “corridors” would affect inter-patch process conveyance. Specifically, I tested this hypothesis by manipulating fuel load and configuration and examining the resulting connectivity of fire between patches. In the larger view, fuel quality and connectedness constitute an important control in the movement of fire across a landscape.

METHODS

Each experiment consisted of a central patch where the fuel was ignited so that the fire had equal opportunity to spread outward in a 360° pattern across the landscape. The treatment variable consisted of replicated radiating “corridors” of two different widths. Orientation of the different-width corridors helped to allay the effects of stochastic variables such as wind direction and speed. The three treatments of varying width were applied to the replicated units so that each experimental corridor would have an equal chance of propagating fire outward to another patch.

The micro-scale experiment consisted of four experimental units, each unit resembling a cross that consisted of a central pyre (radius = 5 m) and four radiating “spoke-corridors” (length = 10 m). The corridor width treatment was 1 meter versus 2 meters. Within each replicate unit, the coupled linear treatments of width were randomly oriented in either a north-south or east-west direction (Figure 2). These micro-scale units were created on a mowed bahiagrass pasture converted from a sandhill community. Fuel enhancement consisted of evenly distributed pine straw loaded at 1kg/m² (dry weight) within the radiating corridors. The micro-scale prescribed fire was performed on November 23, 1996 starting at 11:15 a.m. The day was clear and sunny, with maximum air temperature of 23°, and relative humidity of 28%. Winds were variable from the south, ranging from 0-10 k.p.h.



Figure 2: An experimental unit of the micro-scale study, pre-fire.

The meso-scale experiment consisted of three experimental units of the same configuration as the micro-scale experiment. The four 15 meter perpendicular spokes that radiated out from a central pyre (radius = 10m). The corridor width treatments were 2 meters and 5 meters. Again, each replicate was located in north-south and east-west directions and each width treatment was randomly oriented to each of the cardinal directions within each unit (Figures 3 and 4). These units were established on a different converted sandhill pasture in western Alachua Co., Florida. The experimental site consisted of bare, previously burnt pasture and fuel load manipulation consisted of evenly distributed pine straw at 1.5 kg/m^2 , similar to that used in rate of spread studies such as McAlpine and Wakimoto (1991). The meso-scale study prescribed fire was performed on March 12, 1997, starting at 12:30 p.m. The day was partly cloudy and sunny, with maximum air temperature of 27° , and relative humidity was 36%. Winds were variable from the northwest, ranging from 0-10 k.p.h.

In both the micro-scale and the meso-scale prescribed fire experiments, fire was

ignited in the center of the central pyre. Fire spread and radiated out to each of the treatment spokes. Time for the fire to reach each of meter intervals was recorded so the rate of fire spread and means could be calculated (Figure 5, Figure 6). To avoid aspects of autocorrelation because cumulative time was recorded per meter for the meso study, slopes and intercepts from the linear regressions were used to test for effects. In the linear regression, time and distance were analyzed. Both the intercepts and slopes of these lines were regarded as the response variables in the appropriate ANOVA model with individual tests for plot, plot width, and interaction between orientation and width within a plot. The analysis was performed as a randomized block design, with replicates as the block effect (includes variation in land condition, terrain, weather, time, etc.) and path width as the principal treatment. A probability of 0.05 was used for all ANOVA analyses to demarcate statistical significance in the results.



Figure 3: One of the three meso-scale experimental units. Each meter of linear distance was demarcated to calculate average rate of fire spread.

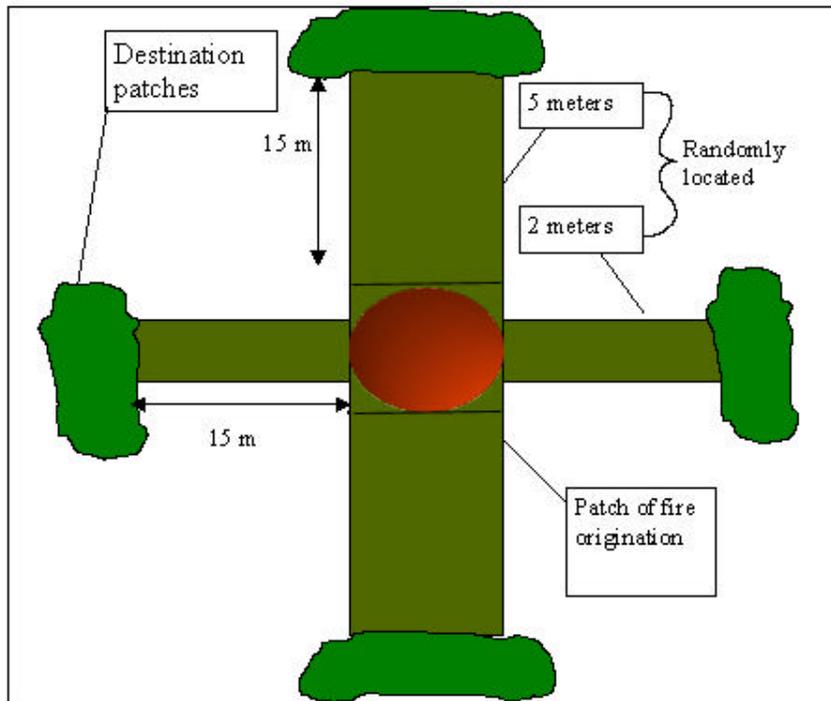


Figure 4: Conceptual design of a meso-scale experimental unit.



Figure 5: Micro-scale reconnaissance burn study.



a)



b)

Figure 6: Meso-scale burn experiment where a) fire is ignited in central patch and b) spreads along the “spokes”.

RESULTS

Effects of wind (orientation) were evident in the outcomes of both “micro” and “meso” experiments. Most apparent in the study were significant effects of orientation of the “corridors”; not surprising since wind direction (and/or speed) helps or hinders the spread of fire along a given path. Wind can hinder the spread of fire when airflow direction is opposite to the direction of fire spread. There was high correlation between time and distance for each “spoke/corridor” within experimental units. Significant differences emerged from the ANOVA for the slopes of the regression lines ($P = 0.04$, $F = 5.15$, $df = 1$); but not the intercepts for orientation of treatments ($P = 0.94$, $F = 0.0$, $df = 1$, respectively) in the micro-scale study. No significant difference was found for width ($P = 0.77$, $F = 0.08$, $df = 1$ and $P = 0.21$, $F = 1.74$, $df = 1$, respectively) nor was there any significant interaction effect between orientation and width ($P = 0.85$, $F = 0.04$, $df = 1$, $P = 0.51$, $F = 0.45$, $df = 1$, respectively).

Significant differences were evident between the regression slopes for orientation for orientation of treatments ($P = 0.003$, $F = 17.58$, $df = 1$); but not the intercepts ($P = 0.61$, $F = 0.28$, $df = 1$) in the meso-scale experiment. The analysis of the width treatments did not show significant differences for the slopes or intercepts ($P = 0.12$, $F = 2.88$, $df = 1$, and $P = 0.74$, $F = 0.12$, $df = 1$, respectively). Nor, was there a statistically significant interaction between orientation of the treatments and treatment width ($P = 0.26$, $F = 1.44$, $df = 1$, and $P = 0.82$, $F = 0.05$, $df = 1$, respectively).

Differences in the width treatments were most evident through the comparison of rates. For both micro and meso studies, there was a trend towards greater rate of spread in the wider width treatments, independent of orientation on the treatments, although these results did not show a strong enough effect to be statistically significant (Table 1, Figure 7).

Table 1: Micro and meso-study burn results, broken down by fire type (head vs. backing).

Average rate (m/s) for orientation (head vs. back)	head fires	back fires
Micro-scale	0.09	0.05
Meso-scale	0.20	0.08

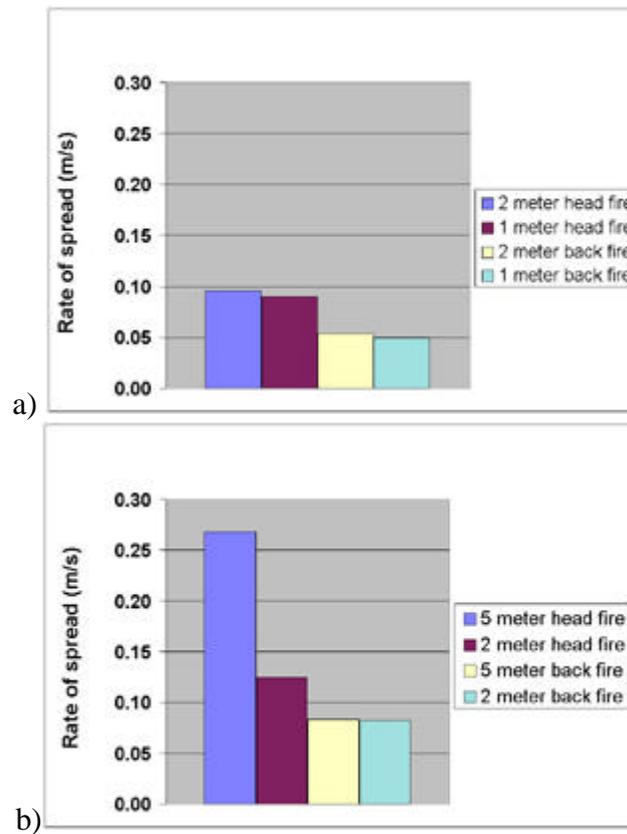


Figure 7. Comparison of rates of fire spread for all fire types in the a) micro and b) meso-scale experiments.

DISCUSSION

Corridor width, or the physical configuration of the patch-to-patch connectors, did not significantly influence fire spread in these experiments at the scale conducted. The only variable that played a significant role in the spread of fire was fire type as influenced by orientation of the “corridors.” This result was predicted because it seems to be intuitive that wind would be sufficiently strong as to favor or hinder the spread of fire along a given path. Wind has been previously demonstrated to be an influential factor in many studies (Smith and Gilbert 1974, Rothermel 1983, McAlpine and Wakimoto 1991). Wind speed and direction are strong forces that influence the intensity and rate of spread of fire, and are some of the most important factors to consider when prescribing a fire or preparing to contain or suppress a wildfire (Rothermel 1983).

Rates of spread and measures of intensity are often used to quantify behavior of wildland fires (Pyne *et al.* 1996, Johnson and Miyanishi 1995). This information allows managers to predict potential fire behavior and design methods and/or guidelines in which to suppress wildfires. It is not uncommon that fire spreads most rapidly in the direction of local wind. Head fires such as these are predicted to achieve an elongated shape as they move faster (Pyne *et al.* 1996). Although the fires exhibited through this experiment were not large enough to be typical of an average fire with respect to behavior, the trend towards a width effect in my experiments were opposite to general trends where greater width means a lower rate of spread (Rothermel 1972, Rothermel 1983, Johnson 1992).

Granted, under natural conditions (i.e., experiments conducted within existing forest and having a scale of larger magnitude) the behavior of fire within a forest would surely exhibit this response. However, for smaller fire through delineated areas or open spaces, it is not clear what type of response would most commonly be evident.

There are various synoptic factors that would influence fire movement through a corridor (Table 2) and would need to be assessed for determining potential spread. These factors are important both in prescribed fire and in fire suppression efforts.

Based upon the meso-scale experiment head fires, there appears to be some type of wind effect evident. Although there were no statistically significant differences between the corridor width treatments, there were practical differences evident in the comparison of the mean rates of spread. Differences in mean rates of spread (most evident in the meso-study head fires), showed a trend towards a width effect. This was similar to what was expected from this experiment. The wider “corridors” did have a showed a trend towards a greater rate of spread from patch to patch, although it was not significant at the $p = 0.05$ level. However, in the presence of gusty winds (when wind speed shifted from 3 to 10 k.p.h) blowing flames over the fuel, it seems that virtually no width variance at the small scale used would matter, and the much wider corridor widths would be necessary to demonstrate this effect. Almost unexpectedly, but certainly logically, the width effect revealed itself in almost every single fire that was aided by wind (head fires) along each path.

Table 2: Some synoptic factors that may influence the spread of fire through corridors.

Factors	Relevance to Fire Spread
Time	Effects from ambient temperatures and humidity (hours) to physical/chemical aspects of fuel load (decades) to slope or topographic features (centuries) (Johnson 1992).
Wind speed and direction	Local temperature differences and/or differences in terrain can have a great influence in wind from gentle breezes to persistent winds (Pyne <i>et al.</i> 1996).
Frequency of Burn	Relates to fire intensity and duff (partially decomposed organic horizon beneath litter) consumption; composition of vegetation, etc. (Johnson and Miyanishi 1995).
Fuel type	Forest type (coniferous, closed/open canopy, deciduous, open grasses, etc. (Taylor <i>et al.</i> 1997) influences fire intensity.
Fuel moisture	Dead fuels versus live fuels exhibit major differences in combustion and spread and intensity and rate of spread (Rothermel 1983).
Landscape character - Source patch sizes and ecological edge	Influences the severity of fire, exhibited by ground versus crown type fires, erosional losses, and effects on ecosystem function (Agee 1998).

Recent literature has discussed width factors in corridors for a multitude of functions (Price and Gilpin 1996, Wiens 1996, Farina 1998). Dramstad *et al.* (1996) have noted that “width and connectivity are the primary controls on the five major functions of corridors (i.e., habitat, conduit, filter, source, sink).” Specific parameters of corridor width have mostly addressed riparian or riverine corridors (Dramstad *et al.* 1996), although some specifications of width have been suggested for mammalian underpasses in southern Florida (Smith 1993). Although the overall purpose of these corridors is to retain or maintain ecological function, the specifications are mostly qualitative (such as number order in streams or variable widths of buffer zones). Because functional connectivity is a vital element of landscape studies (Taylor *et al.* 1993, Clergeau and Burel

1997), is it of utmost importance to continue research efforts on quantifying physical, structural and ecological aspects of interpatch connections in landscapes.

In spite of the fact that the experiment was designed to mitigate stochastic forces at different scales, a larger scale study would have likely revealed significant width effects (see Appendix). The scale of the two studies reviewed in this paper was small enough for environmental variables to have a strong influence on fire behavior. Fire behavior literature most often documents interior forest and/or wild fires, therefore stochastic forces affecting forest fires are somewhat buffered in comparison. These forces and variables, such as wind direction and speed, sun position and relative humidity, had a moderate to strong effect on the consumption of the fuel and respective rates of fire spread along a given path in this research. This was most evident in the comparison of mean time to reach the end patches and mean rates of spread for the 2 meter “corridors” in the micro-scale and meso-scale experiments. In the micro-study, which was conducted in November, the mean time to reach the end point of 10 meters was nearly twice the time to reach 15 meters in the meso-scale study (which was conducted in March). Although initial conditions of the experimental units were identical (with slight changes in terms of dry weight of the fuel), these differences demonstrate the importance of relative fuel moisture and ambient conditions.

Recent discussions regarding fire regimes that have been altered due to fragmentation and how landscape function may or may not have been altered imply that fragmentation is important, or at least it is a testable hypothesis. Environmental corridors are one means of maintaining and/or restoring physical connectivity in an otherwise

fragmented landscape. Surely, if fragmentation and/or inter-patch connectivity were truly important to landscape-level ecological function, wouldn't their effects be manifested on arguably the most significant ecological factor of the SECP? It is also quite possible that physical connectivity on the landscape does not necessarily mean ecological connectedness or vice-versa. The results certainly confirm that two concepts, physical connectivity and ecological connectedness, are causally related to mechanisms such as structure (e.g., corridor width) and ecological function (e.g., wind driven vs. wind-suppressed fires). To help test these hypotheses, landscape ecologists need to consider experimentation as a necessary approach (Ims 1999). This research constituted an initial attempt to gain empirical evidence regarding corridors as a conduit of energy. Though the results did not directly demonstrate implications for corridor design or fire management strategies, one can develop further hypotheses based on this research.

APPENDIX MACRO-SCALE BURN EXPERIMENT

The entire experimental aspect of this thesis research was predicated upon three spatial scales of field studies, micro-, meso- and macro-. During the summer of 1997, eight experimental plots were constructed at Camp Blanding Training Site, near Keystone Heights, Florida. The plots were located in two types of longleaf pine forest patches, sandhill habitat (four plots) and flatwoods habitat (four plots). Both of these system types evolved with frequent fire regimes (see [Introduction](#)) and contained wiregrass. The basis of this large (or macro-) scale experiment was that there might be “real-world” implications based on plot size. In other words, it may be more realistic or understandable for land managers to extrapolate data from fire behavior evident at a macro-scale designed experiment.

The design of this macro-study was similar to the first two experiments discussed in the thesis, only larger. In the plot’s center was a large 250 m² area that would have been the “central pyre”. And, similar to the other burn studies, the plot was designed like a cross with north-south and east-west aspects. These crossing aspects (previously described as “corridors” or “connectors”) were either 10 meters wide or 50 meters wide and were 100 meters in length.

For each of the plots, the vegetative cover was sampled to give a relative estimate of the percent burnable cover or connectivity of fuel for a low-intensity fire. A linear

transect was located through the center of each plot at ten meter increments. For each ten-meter length, the percent burnable vegetation was recorded. Fuel types were classified as either burnable (i.e., wiregrass, longleaf pine litter, 1/10/100 hour fuels (pine cones/twigs/down logs), turkey oak leaves, etc.) to non-burnable (i.e., herbs, turkey oaks, saw palmetto, sand, lichen, etc.) (Table 3). Percent burnable cover ranged from 30 to 100% demonstrating instances where the fuels were discontinuous (Table 4). In general, the fuels were mosaic or patchy in nature having mostly continuous fuels but including small areas where fuel connectivity was low. Averages of the fuel continuity for all transects ranged from 85% to 96%. Although the fuels were highly connected, this macro-study would have examined whether inter-patch fires would have burned to their respective completion points (although it was quite likely that they would).

Table 3. Examples of fuels (burnable and non-burnable) for each of the study areas at Camp Blanding.

Woodbury	Wolf Branch	Magnolia Lake
Longleaf pine litter	wiregrass	wiregrass
Turkey oak leaves	Longleaf pine litter	Turkey oak leaves
saw palmetto	herbaceous (<i>Vaccinium</i> sp., <i>Asimina</i> sp.)	herbaceous (<i>Asimina</i> sp., <i>Pterocaulon</i> sp.)
1/10/100 hour fuels (cones, twigs, logs)	saw palmetto	lichen (<i>Cladonia</i> spp.)
wiregrass	1/10/100 hour fuels (cones, twigs, logs)	Longleaf pine litter
lichen (mostly <i>Cladonia</i> spp.)	gopher apple	sand
sand		oak saplings
herbaceous (<i>Vaccinium</i> sp., <i>Ilex</i> sp., <i>Pterocaulon</i> sp.)		gopher apple
Longleaf pine seedlings		1/10/100 hour fuels (cones, twigs, logs)
		needle palm
		smilax

Table 4. Percent burnable cover for each transect in the six Camp Blanding study sites.

Woodbury		Wolf Branch		Magnolia Lake			
100	90	100	85	95	100	70	85
80	100	95	70	100	75	100	30
75	95	100	90	90	80	80	75
95	80	95	100	100	95	90	90
95	85	100	100	90	90	100	95
85	100	100	90	100	95	95	85
90	75	100	65	100	90	95	90
95	95	95	70	100	95	90	95
100	100	80	85	100	100	80	100
95	95	95	95	100	60	95	85
90	95	95	80	100	100	95	90
70	80	95	100	60	70	100	100

There were physical and chemical methods to delineate the experimental plots from the forest matrix. The physical method of separation involved raking no less than two feet away from the “corridor” edge and clearing the vegetation (i.e., removing down trees or cutting parts of saw palmetto) that crossed the line. The chemical method involved the application of the fire repellent gel called Barricade® (Fire Protection, Inc. 1999).

One of the eight experimental burns was nearly completed at Camp Blanding in March 1998. It was necessary to terminate the burn due to time limitations (the burn was not finished by nightfall). The average cumulative times to reach 75 meters were 4.23 hours (head fires) and 7.76 hours (back fires). Again, one can note that the back fires took nearly double the time to complete the same distance. In addition, the average rates of head versus back fires were 0.005 and 0.003 meters/second, respectively. There was not enough data collected to make any statistical inferences regarding width or orientation of the corridors. And, if I had an inkling of the upcoming multiple-year fire bans, I would have used the two smaller scale studies as base input data for a fire model that replicated the macro-scale study.

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BIOGRAPHICAL SKETCH

Karen Angela Whitney was born in Miami, Florida. She arrived in Gainesville in the summer of 1988 when she began her undergraduate career. After starting her undergraduate education in psychology, she met Dr. Larry Harris, who would become her graduate chair. Since that time, Karen has pursued her scholastic endeavors in wildlife, landscape ecology and conservation biology. Karen was involved in many aspects of the wildlife department, from being an undergraduate representative of the Wildlife Department and member of student council to being president of the student chapter of The Wildlife Society.

After graduating, Karen moved to the state of Washington for a year to pursue higher education, but due to funding limitations, she was unable to start her graduate career there. Thanks to the Florida Greenways Program and Professor Peggy Carr, Karen was able to return to the University of Florida to more deeply examine landscape ecological theory and experimentation. This allowed her to experience more of Dr. Harris' tutelage, learn the "ins and outs" of ecological modeling using geographic information systems (GIS), and play with fire! Although experiencing many hardships throughout her graduate career, from the death of her father to the multiple years of fire bans, Karen was finally able to analyze and bring her data together in a cohesive state. She now endeavors to combine work in ecological modeling and landscape analysis with natural resource management.