

Short Communication

Subtle effects of a managed fire regime: A case study in the longleaf pine ecosystem



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ABSTRACT

Land managers often use fire prescriptions to mimic intensity, season, completeness, and return interval of historical fire regimes. However, fire prescriptions based on average historical fire regimes do not consider natural stochastic variability in fire season and frequency. Applying prescribed fire based on averages could alter the relative abundance of important plant species and structure. We evaluated the density and distribution of oak (*Quercus* spp.) and persimmon (*Diospyros virginiana*) stems and mast after 22 yr of a historical-based growing-season fire prescription that failed to consider the variability in historical fire regimes. We randomly established 30 25-m transects in each of 5 vegetation types and counted reproductively mature oak and persimmon stems and their fruits. In upland longleaf pine (*Pinus palustris*) stands, this fire regime killed young hardwood trees, thereby decreasing compositional and structural heterogeneity within the upland pine vegetation type and limiting occurrence of the upland hardwood vegetation type. Acorns and persimmons were disproportionately distributed near firebreaks within low intensity fire transition zones. Mast was maintained, though in an unnatural distribution, as a result of an elaborate firebreak system. Our data indicate managed fire regimes may fail to mimic spatial distribution, frequency, and intensity of historical disturbances even when the fire prescription is based on empirical reference fire regimes. To maximize structural heterogeneity and conserve key ecosystem functionality, fire prescriptions should include variations in frequency, season, application method, and fire weather conditions rather than focusing on an average historical fire regime.

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1. Introduction

Maintaining biodiversity at the landscape scale is a complex goal for land managers. As a result, management goals and prescriptions often are focused on habitat requirements of species of special concern (e.g., endangered species) (Bean, 2009; Franklin, 1993). However, homogeneous management for specialized target species can result in unintended or unnoticed changes in ecosystem structure or abundance of non-focal species (Bean, 2009; Doremus, 1997; Franklin, 1993). In this case, it may be prudent to use multiple indicators, and not just the species of concern, to monitor ecosystem health. For example, groups of bryophytes (Pinho et al., 2012) or plant assemblages may be used as indicators for terrestrial ecosystem health or landscape heterogeneity (Baumberger et al., 2012; Druckenbrod and Dale, 2012; Vilches et al., 2013).

Heterogeneity of vegetation structure and composition has been considered a precursor to maintaining biodiversity (Baumberger

et al., 2012; Simberloff, 1997), and fire regimes have a profound impact on plant community heterogeneity at the landscape scale (Whitlock et al., 2010). In fact, heterogeneous applications of fire were necessary to maintain the differing structural requirements of specialized ant species (Anderson, 1991), vertebrate diversity in the boreal forest of British Columbia (Brunnel, 1995), avian species diversity in the North American tall grass prairies (Fuhlendorf et al., 2006), lizard species diversity in the wet-dry tropics of Australia (Braithwaite, 1987), and legume diversity in the longleaf pine (*Pinus palustris*) ecosystem (Hiers et al., 2000). Similarly, the biodiversity of the longleaf pine ecosystem depends on a combination of relatively high rainfall, porous, sandy soils, and an active cycle of fires, which naturally created a mosaic of plant communities (Greenberg, 2001). Further, in this system, longleaf pine forest is the prevailing vegetation type, making other less prominent plant communities (e.g., upland hardwood) easy to overlook. Although the importance of heterogeneity in natural fire regimes to the persistence of prevailing longleaf dominated plant communities is well documented (Aschenbach et al., 2010; Beckage et al., 2005; Fill et al., 2012), less prominent vegetation types rarely are acknowledged despite

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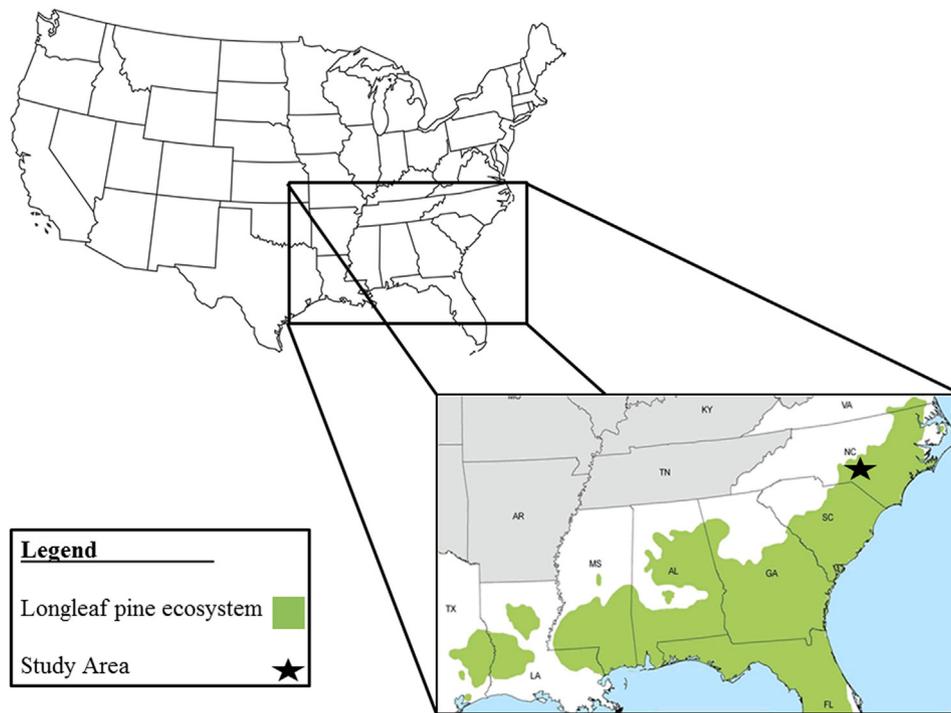


Fig. 1. Location of Fort Bragg Military Installation, NC, USA within the historical range of the longleaf pine ecosystem.

their importance to the function of the ecosystem. For example, hardwood mast in longleaf pine ecosystems is readily consumed by many animal species, some of which also use the cover provided by mast-producing plants.

A growing body of literature supports the use of prescribed fire to restore and maintain fire-dependent ecosystems and managers have attempted, in many cases, to advocate fire regimes that emulate nature. However, prescribed fires may not emulate nature without including historical variability even if they are based on historical references of average frequencies and seasons. Therefore, homogenous fire regimes could differentially promote some native taxa and fail to promote others. To determine if a historically based fire regime yielded a heterogeneous distribution of hardwoods, we measured the distribution and density of reproductively mature oak (*Quercus* spp.) and common persimmon (*Diospyros virginiana*) stems and fruits after 22 yr of managed prescribed fire regime at Fort Bragg Military Installation (FB), North Carolina, USA. We extrapolated mast and stem density to evaluate landscape-scale availability of acorns and persimmon fruits and reproductively mature oak and persimmon stems. Our objective was to evaluate landscape level effects of a homogeneously applied ecosystem-based fire prescription on distributions of select hardwoods and mast. We selected oaks and persimmons as indicators of ecosystem health because historically these tree species persisted only in areas burned less frequently and intensely in the longleaf pine ecosystem (Greenberg, 2001; Greenberg and Simons, 1999), and because the mast from the two species is a keystone food source for many wildlife (Kellner et al., 2013). Furthermore, ecosystem changes associated with decline of these and other hardwood tree species may go unnoticed because hardwoods were historically less prevalent than longleaf pine, were heterogeneously distributed across the landscape, and were not considered beneficial to the focal endangered species which is the major driver of the fire management regimes at FB and across the longleaf pine ecosystem (i.e., red-cockaded woodpecker – *Picoides borealis*; Cantrell et al., 1995). We hypothesized hardwood stems and associated mast would be unnaturally confined along human-induced fire shadows (e.g.,

firebreaks) in upland pine stands because of the lack of variability in fire applications.

2. Methods

2.1. Study area

Fort Bragg Military Installation (FB) (73,469-ha; 35.1° N, –79.2° W) is located within the threatened longleaf pine-wiregrass (*Aristida stricta*) ecosystem of the Sandhills physiographic region in North Carolina, USA (Fig. 1). Fort Bragg received an average yearly rainfall of 120 cm and averages ~175 frost-free days per year in the recorded past until 2006 and was characterized by rolling hills with elevation ranging from 43 m to 176 m (Sorrie et al., 2006). At FB, dominant mast producing tree species include turkey oak (*Quercus laevis*), common persimmon, sand post oak (*Quercus stellata*), bluejack oak (*Quercus incana*), blackjack oak (*Quercus marilandica*), and blackgum (*Nyssa sylvatica*). Their fruits are eaten by squirrels (*Sciurus* spp.), gray fox (*Urocyon cinereoargenteus*), striped skunk (*Mephitis mephitis*), white-tailed deer (*Odocoileus virginianus*), coyote (*Canis latrans*), raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginianus*), eastern cottontail (*Sylvilagus floridanus*), and numerous birds, including northern bobwhite (*Colinus virginianus*) and wild turkey (*Meleagris gallopavo*) (Glasgow, 1977). Hunter-harvest records at FB indicate that populations of several mast-dependent game species, including white-tailed deer and southern fox squirrel (*S. niger niger*), have declined concomitantly with the application of the current fire prescription (Jones, personal communication).

In accordance with management recommendations for red-cockaded woodpecker, about 8% of the forest is targeted for annual thinning to maintain ~11.5 m²/ha basal area and prevent hardwood encroachment (Cantrell et al., 1995). Beginning in 1989, a 3-yr growing-season fire-return interval was initiated to maintain structural requirements for red-cockaded woodpecker and maximize biodiversity (Cantrell et al., 1995). This fire prescription was derived from climatic patterns of natural ignition sources (Beckage

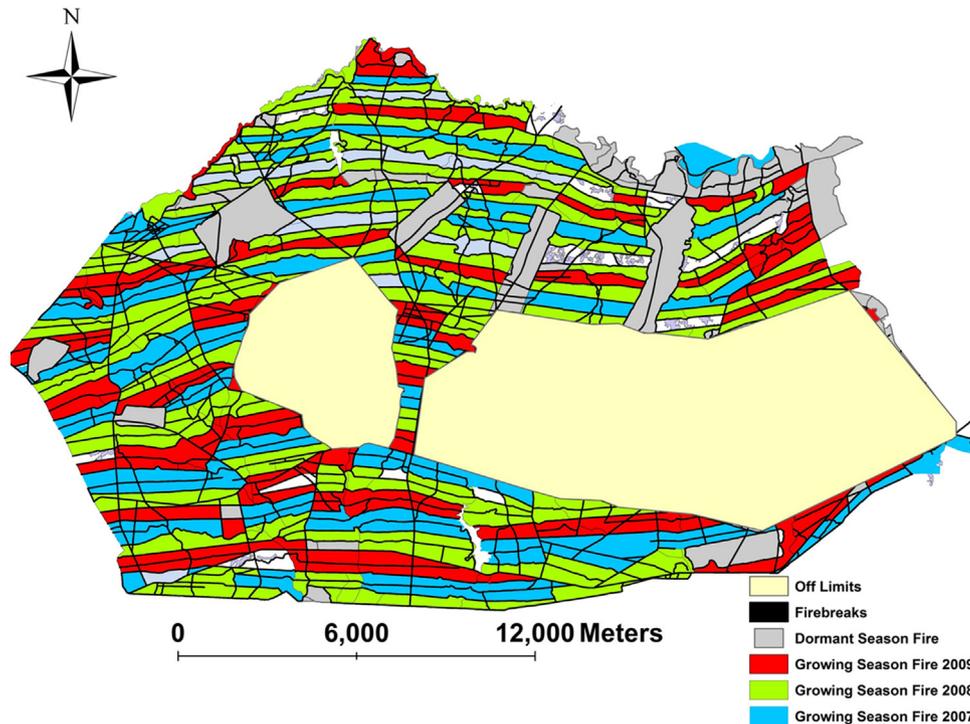


Fig. 2. Three-yr growing-season fire prescription and firebreak system for Fort Bragg Military Installation, NC, USA, 2007–2009.

Table 1

Mean oak and persimmon mast and stem density (number/25 m²) within vegetation types at Fort Bragg Military Installation, NC, USA.

Vegetation type	Mast density	SE	Stem density	SE	Mean separation ^a
LIFTZ	50.97	14.96	18.50	5.03	A
Upland hardwood	48.77	10.67	16.70	1.67	A
Bottomland hardwood	0.50	0.96	1.59	0.80	B
Upland pine	3.47	1.87	3.24	1.84	B
Open	0.00	0.00	0.00	0.00	B

^a Vegetation types with different letters were significantly different at alpha = 0.05.

et al., 2005; Slocum et al., 2007, 2010) and historical descriptions of forest structure (Streng et al., 1993; Waldrop et al., 1992), which indicated natural fire season varied regionally but was dominated by growing season (~75% June–August; Fill et al., 2012) with a 3-yr fire-return interval on average (Fig. 2; Cantrell et al., 1995). The fire prescription at FB follows the historical average frequency and season but does not consider historical variability. Due to limitations in resources, manpower, and adequate fire weather, some stands miss a scheduled fire on occasion and are burned in the following dormant season. However, these stands are moved immediately back into the 3-yr growing-season fire-return interval. To maximize efficiency of burning, stands are initially lit with a backing fire. A backing fire is the safest and least intense firing technique and is started along a baseline such as a road, plow line, stream, or other barrier and allowed to move into the wind (Wade and Lundsford, 1990). At FB, once fires have progressed an adequate distance from the firebreak, additional fires are set around other boundaries often using the ring fire and strip head fire techniques. Firebreaks at FB are generally oriented east and west to facilitate prescribed burning and military activities.

2.2. Vegetation types

We assigned 5 vegetation types using a geographic information system overlay map of land cover and firebreaks provided by the U.S. Department of Defense: Upland Hardwood (UH), Bottomland

Hardwood (BH), Upland Pine (UP), managed opening (Open) and Low Intensity Fire Transition Zone (LIFTZ). We characterized UH as any upland forest stand dominated by hardwood species (primarily oak), BH as hardwood-dominated forest stands (primarily blackgum) associated with drainages, UP as upland longleaf pine-dominated forest, and Open as unforested areas maintained as grasslands. We defined LIFTZ as UP \leq 25 m from a firebreak. Wiregrass (primary plant influencing the spread of fire in this system; Noss, 1989) is typically less intact in hardwood-dominated stands because of a decrease in sunlight to the forest floor, and flame heights tend to be shorter and less influenced by proximity to firebreaks.

2.3. Vegetation sampling

During September 2011, we randomly established 30 25-m transects in each of the 5 vegetation types ($n = 120$). The observers used 8-mm \times 42-mm binoculars to count fruits on reproductively mature oak and persimmon for 60 s on each stem that overlapped the transect. Trees were deemed reproductively mature if they were dominant or co-dominant in the canopy, ≥ 4.5 cm diameter breast height, or were producing fruit (Greenberg and Simons, 1999). Stem densities were based on the total number of stems that fit these criteria whose canopy overlapped transects. Throughout the study, the same 3 observers conducted mast surveys to reduce biases associated with viewer detection and speed.

Table 2
Landscape level percentage of oak and persimmon mast and stems by vegetation type at Fort Bragg Military Installation, NC, USA.

Vegetation type	% Land area	% of mast	% of stems
Firebreaks	6	0	0
LIFTZ	17	80	66
Upland hardwood	2	8	6
Bottomland hardwood	11	1	4
Upland pine	35	11	24
Open	28	0	0

2.4. Data analysis

We conducted a general linear model to compare fruit density and stem density among vegetation types using SPSS (IBM, Cary, NC). We used the Tukey's Honestly Significant Difference multiple comparison test to compare means when we detected vegetation type effects. We set $\alpha = 0.05$.

We used a vegetation type overlay in a geographical information system to calculate the area of each vegetation type. We excluded lakes and danger areas, which were areas that were completely inaccessible. We extrapolated mast density and stem density to the landscape level by multiplying the area of each vegetation type and respective mean mast and stem density.

3. Results

3.1. Mast density

Mast was unnaturally concentrated along firebreaks following 22 yr of homogeneously applied fires. Mean fruit density was greater in low intensity fire transition zones (LIFTZ) than upland pines (UP) ($P < 0.001$), bottomland hardwoods (BH) ($P < 0.001$), and openings (open) ($P < 0.001$) (Table 1). Mean fruit density was greater in upland hardwoods (UH) than UP ($P < 0.001$), BH ($P < 0.001$), and open ($P < 0.001$). Mean fruit density was not different between LIFTZ and UH ($P = 0.757$). However, all detected persimmon fruits were in LIFTZ (mean fruits/25 m² 4 ± 3). When extrapolated to the landscape scale, a disproportionate percentage of mast available at FB falls within LIFTZ (Table 2). Also, UH provided a disproportionate amount of mast at the landscape scale with 8% of mast produced in 2% of the area (Table 2). Mast availability was disproportionately low in all other cover types (Table 2).

3.2. Stem density

Similar to mast, hardwood stems were concentrated along firebreaks. Oak stem density was greater in LIFTZ than UP ($P < 0.001$), BH ($P < 0.001$), and open ($P < 0.001$) (Table 1). Oak stem density was greater in UH than UP ($P < 0.001$), BH ($P < 0.001$), and open ($P < 0.001$). Oak stem density was not different between LIFTZ and UH ($P = 0.154$). However, all detected persimmon stems were in LIFTZ (mean stems/25 m² 3 ± 2). When extrapolated to landscape scale, a disproportionate percentage of stems (oak and persimmon) were within LIFTZ (Table 2). Also, UH provided a disproportionate number of stems at the landscape scale with 6% of stems produced in 2% of the area (Table 2). Stem density was disproportionately low in all other treatments (Table 2).

4. Discussion

The homogeneous application of firing technique, return interval (3 yr), and season (summer) of prescribed fires decreased landscape heterogeneity of plant communities by differentially promoting the prevailing cover type (longleaf pine) and suppressing less-prominent hardwoods. Our study indicates that LIFTZ

are of unquestionable importance to mast-dependent taxa at FB under current management regimes. Historically, the heterogeneity of disturbances allowed succession of hardwoods in some areas (Greenberg and Simons, 1999), and fire regimes likely were more variable on the landscape than a homogeneously applied, 3-yr growing-season fire prescription (Aschenbach et al., 2010; Beckage et al., 2005; Fill et al., 2012; Greenberg and Simons, 1999). Also, stand conditions were not homogeneous but rather a heterogeneous matrix of stand ages, structural conditions, and plant communities, which included patchy distributions of mature hardwoods in longleaf dominated stands (Greenberg, 2001; Greenberg and Simons, 1999). The occurrence of specialized, xeric-adapted species and wide-ranging generalist species in the longleaf pine ecosystem indicates that variable burning intensities, intervals, and spatial extent created a range of microhabitats and stand conditions within these plant communities (Greenberg and Simons, 1999; Marcoux et al., 2013). Furthermore, fire tolerance of tree species declines with decreasing bark thickness and stem diameter (Harmon, 1984). Thus, variability in fire resistance among flora is an important consideration when managing fire-maintained ecosystems. For example, intense fires in UH likely kill persimmon before they reach maturity but not thicker-barked oaks that dominate the UH overstory (Harmon, 1984; Van Lear and Harlow, 2001). However, in LIFTZ, both oaks and persimmons were protected from intense flames because of proximity to the ignition source along firebreaks (i.e., low fire intensity is consistently maintained in close proximity to firebreaks). Conversely, fire in the forest interior of UP was intense and frequent enough to prevent fire-adapted hardwood species from reaching reproductive maturity (Greenberg and Simons, 1999). This phenomenon can be exacerbated by use of the ring fire technique, which burns hotter as the flames converge in the interior of the stand and is a technique not recommended for use in forested stands because of the possibility of damage to flora and fauna (Wade and Lundsford, 1990).

Although efforts to restore habitat for the federally endangered red-cockaded woodpecker have been successful (i.e., hardwood encroachment into UP stands has been reduced), the lack of a more diverse set of ecological indicators may lead to failed conservation of some species. For example, Kilgo and Vukovich (2012) reported red-headed woodpecker (in decline; *Melanerpes erythrocephalus*; Sauer and Hines, 2008) survival rates were increased by patchy distributions of cover associated with upland hardwoods in the longleaf pine ecosystem. Also, numerous other biota occurring in longleaf pine ecosystems may be negatively affected by decreasing hardwood encroachment. Further, less common vegetation types may be considered only when an Endangered Species Act listed species is present. For example, the Saint Francis' satyr (*Neonympha mitchellii francisci*), a federally endangered butterfly endemic to FB, requires wetlands that are maintained by infrequent burning (Kuefler et al., 2008). Before the satyr was listed, firebreaks were used to keep fires from burning into wetlands at FB. After being listed, firebreaks near wetlands were abandoned, allowing fires to burn into wetlands. Negative implications of obstructing intermittent fire in wetlands were not considered until the presence of a listed species. Thus, current policies may encourage homogeneity when focal species require a narrow suite of vegetation conditions, particularly when competing vegetation types are not linked to other ecological indicators.

Misrepresentation of natural ecosystem functions is a common flaw in restoration and management around the globe (Marcoux et al., 2013; Vandvik et al., 2005). Contemporary conservation involves management regimes that are generally less diverse, in terms of disturbances and fine-scale temporal and spatial variability, than historical land disturbance (Vandvik et al., 2005). This trend could negatively affect biodiversity on the landscape, and negative effects could be overlooked depending on the focus of

management. Variables such as the range of historical frequency, the seasonal distribution of fires, and historical variability in ignition conditions (e.g., relative humidity, wind velocity, fuel moisture, etc.) should be incorporated into fire prescriptions. Each of these variables plays a key role in fire behavior and as a result influences fire effects on biota (Agee, 1996; Cheney et al., 1993). Because these variables often are overlooked, fire regimes may be predisposed to excluding variation. For example, most land managers work during the daytime and accordingly fires may then only be lit diurnally, thereby neglecting the historical prevalence of nocturnal lightning ignitions. Furthermore, many lightning ignitions were associated with rain events and therefore some fires would be lit with high fuel moisture which limited the intensity and scope of fires (Bessie and Johnson, 1995). For example, less intense fire associated with fuels high in moisture may lead to a patchy spread of fire. In managed fire regimes where fires are lit diurnally, during summer, and rarely during high moisture conditions, as is the case at FB, management practices may never achieve the mosaic present historically. The lack of mosaic created by consistent ignition conditions could be solely responsible for the unnatural distribution of hardwoods and mast we observed at FB.

Biodiversity is driven by non-vertebrate biota and only can be conserved by landscape- or ecosystem-scaled approaches (Franklin, 1993; Walker, 1992). The challenge is designing policy to improve management of heterogeneity at the landscape scale. Furthermore, management prescriptions must be representative of historical heterogeneity in disturbances that are executable at the local level. At FB, the manpower needed to support the current prescribed fire regime is reasonable if burned areas are large and linear, which allows quick application of fire along firebreaks and efficient maintenance of the 3-yr fire-return interval. Homogeneously applied fires are efficient, but efficient application comes at the expense of landscape heterogeneity.

5. Conclusions

We were able to demonstrate the homogenizing effects of prescribed fire when historical variability of fire regimes was not executed. The distribution and density of hardwood stems and associated mast served as an indicator of the aforementioned homogenization because their distributions were in close proximity of ignition sources where fire temperatures were lowest. We recommend fire managers vary firing techniques, ignition locations, and firing conditions using historical variance in fire season and frequency as a guide. Furthermore, policies encouraging ecosystem-based management strategies are needed on all landscapes, and not just areas with listed species or critical habitats. Moritz et al. (2013) provided bounded ranges of variation guided by historical data as a framework for future fire regime management; their strategy could be useful to guide future fire regimes in the longleaf pine ecosystem.

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