Shared community patterns following experimental fire in a semiarid grassland

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Abstract

This paper presents a synthesis of experimental research testing effects of seasonal fire on community structure of plants, arthropods, and small mammals in shortgrass steppe. These groups of plants and animals share the same environment, and therefore, the species in the groups were predicted to respond in a similar way to changes in their environment resulting from fire. The experimental design was completely randomized with 3 treatments and at least 4 replicate 2-ha plots per treatment. Treatments were growing- and dormant-season fires and unburned. Response variables included: plant species richness; abundance and species richness of beetles (coleopterans), and grasshoppers, crickets, mantids, and walkingsticks (orthopterans); and relative abundance of three species of small mammals: *Onychomys leucogaster* (northern grasshopper mouse), *Spermophilus tridecemlineatus* (thirteen-lined ground squirrel), and *Reithrodontomys montanus* (plains harvest mouse). The groups exhibited some shared patterns of community structure in response to fire, while other patterns appeared to be species-specific. The dormant-season fire treatment was the only treatment that had statistically significantly higher plant species richness than the unburned treatment. Mean orthopteran species richness was significantly higher on both fire-treated plots than unburned plots, however, there were no significant differences in mean abundances. Coleopteran species numbers were significantly higher on growing-season fire-treated plots than on unburned treatments, but there were no significant differences among dormant-season fire *vs.* unburned treatments. Coleopteran abundance did not differ significantly among treatments. All three mammal species responded differentially to the fire treatments. Relative abundance of the northern grasshopper mouse was significantly higher on both fire-treated plots than on unburned plots. Relative abundance of the plains harvest mouse averaged lower on both fire treatments than the unburned treatment, but was not statistically different. The thirteen-lined ground squirrel appeared unaffected by fire. Many of the mechanisms behind the species-specific and shared response patterns may be attributed to the life histories of the species. If grassland community responses to fire are well understood and predictable, then fire can be used as an effective management tool on a landscape level to create desirable landscape patterns for managing populations of plant and animal species.

Introduction

Fire is a natural grassland disturbance that affects a variety of ecosystem factors, including nutrient cycling, species diversity, and population and community dynamics (Ford, 2003a). The reestablishment of periodic fire is fundamental to the ecological restoration of grasslands in the Southwestern United States (Ford and others, 2004). However, prior to reintroducing large-scale fire as a management tool, the appropriate fire season and fire effects on ecosystem components need to be determined (Ford and Johnson, 2006).

This paper is a synthesis of experimental research that tested the effects of seasonal fire on community structure of plants, arthropods and small mammals in shortgrass steppe of the southern Great Plains of New Mexico, USA. These groups of

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plants and animals share the same environment; therefore, they were predicted to respond in a similar way to changes in their environment resulting from fire. The research is part of a long-term, 18-year study examining effects of fire in the growing *vs.* dormant season at return intervals of 3, 6 and 9 years. The results discussed here are from pre- and post-treatment data collected between 1995-1998, and in 2003.

Steppe is a widely distributed, mid-latitude, semiarid, generally treeless grassland, dominated by short grasses and bunch grasses, and characterized by large grazing mammals and burrowing animals (Lincoln and others, 1998). The southern Great Plains includes the eastern third of New Mexico, the northern two-thirds of Texas, and most of Oklahoma (Wright and Bailey, 1982). Almost all of the grassland in this region is composed of mixed or shortgrass communities (Brown, 1994). While these communities have been altered by grazing and the indirect effects of fire suppression followed by shrub invasion, much of the grassland remains a perennial grass-dominated landscape (Brown, 1994). Shortgrass steppe is the most extensive grassland type in New Mexico, making up approximately 50 percent of the state's grassland vegetation (Dick-Peddie, 1993; Ford and Johnson, 2006).

Orthopterans (grasshoppers, crickets, mantids, walkingsticks) are important members of grassland ecosystems, functioning as consumer and prey. Often viewed as pests because they are major herbivores, orthopterans also dominate the diet of many grassland wildlife species (Ford, 2003b). The order Coleoptera (beetles) contains a third of all known insects- 300,000 species worldwide and approximately 30,000 species in North America (Milne and Milne, 1996). Beetles are conspicuous components of the terrestrial invertebrate fauna of arid and semiarid ecosystems of North America (Allsopp, 1980). They have an important role in the functioning of the shortgrass steppe ecosystem, serving as predators, prey, scavengers, and parasites. In addition, many plant-feeding species of beetles attack plants, while others pollinate flowers and consume plant pests. Changes in orthopteran and coleopteran abundances or species richness resulting from fire could have a profound effect on ecosystem function and on surrounding wildlife, which is particularly important to study with respect to threatened species, such as the burrowing owl (*Athene cunicularia)*, and mountain plover (*Charadrius montanus)*, that inhabit these grasslands (Ford, 2001; 2003b; Ford and others, 2004).

Density and diversity of rodents generally are lower in shortgrass steppe than in other North American grasslands (Grant and Birney, 1979; Stapp, 1997). Fire can significantly alter the species composition of small-mammal communities in shortgrass ecosystems. Knowledge of small-mammal responses to fire will allow scientists and resource managers to more accurately predict the effects of prescribed burns on shortgrass ecosystems, and therefore use fire more effectively as a management tool (Ford, 2002).

Methods

The study site was located in southern Great Plains shortgrass steppe on the Kiowa National Grassland (36˚ 31' 20" N, 103˚ 3' 30"W) of the Cibola National Forest in Union County, New Mexico, USA. The study site consists of approximately 160 ha of shortgrass steppe that was never plowed, though it was grazed by livestock until 1990. The site is relatively homogenous and nearly flat, with an elevation ranging from 1,455 m at the southwest corner to 1,472 m at the northwest corner. The deep, well-drained loam soils on the site support an almost shrubless grassland with a relatively tight sod of buffalograss, *Buchloë dactyloides*, and blue grama, *Bouteloua gracilis*. Average monthly temperatures range from 11-26˚ C April through September, and from 3-12˚ C October through March. Mean annual precipitation (MAP) between the years of 1931-1960 was 356 mm (Maxwell and others, 1981). In general, the majority of precipitation occurs from May through September, with peak rainfall in July. Total precipitation was slightly below average in 1996 (346 mm), the year prior to fire treatments, as well as for 1997 (331 mm), the year fire was applied. Total precipitation in 1998 (183 mm) was 50 percent below MAP and drought conditions also existed in 2003. Weather data were collected by the New Mexico State University State Climate Network at a climate station on the Clayton Livestock Research Center, located approximately 1 km from the study site (Ford and Johnson, 2006).

Experimental design

The experimental design was completely randomized, with three treatments replicated 4-5 times. The treatments were: 1) dormant-season fire applied April 1997, 2) growing-season fire applied July 1997, and 3) unburned. Response variables measured included plant species richness; abundance and species richness of beetles (coleopterans), and grasshoppers, crickets, mantids, and walkingsticks (orthopterans); and relative abundance of three species of small mammals, *Onychomys leucogaster* (northern grasshopper mouse), *Spermophilus tridecemlineatus* (thirteen-lined ground squirrel), and *Reithrodontomys montanus* (plains harvest mouse).

Treatments were randomly assigned to twelve to fifteen 140 m x 140 m plots. At least 60 m of unburned area separated plots. Drip torches were used to burn "black lines" around the inside perimeter of each burn plot. The interior of each plot was then burned using a strip headfire. Winds were gusting at approximately 9-18 km per hour when treatments were applied both fire seasons. Dormant-season fire maximum flame height was estimated to be 18-24 m in the center of the plots and each plot took approximately 15 minutes to completely burn. Growing-season fire maximum flame height was estimated to be 6 m and plots took 30-40 minutes to burn (Ford and Johnson, 2006).

Response variables

Plant species richness was measured in March 2003, six years after the 1997 fire treatments. One 100-m, 500-point basal area line-point transect per plot (a point was dropped every 20 cm) was used to measure ground cover and plant species composition. Transects were randomly located within the inner 100 m x 100 m area of the 15 plots (Ford and White, 2006).

Arthropod pre-treatment data were collected in 1995, 1996 and March 1997. Post-treatment data were collected in 1997 and 1998. Surface-active arthropods were captured by pitfall traps, which were 1-pint paint cans set into the ground with the opening flush with the ground surface. Propylene glycol was used as a preservative. Twenty pitfalls per plot, for a total of 240 pitfalls, were open two weeks, once a month for 6 months in 1997 (March-October) and for 4 months in 1998 (July-October) (Brantley and others, 2001; Ford, 2001).

Small mammal pre- and post-treatment data were collected in 1995, and once a month from March to October 1997, and from July to October 1998. Small mammals were trapped on 12 plots with Sherman live traps baited with rolled oats. One hundred traps per plot (1,200 total) were open 5-7 consecutive nights. All 12 plots were trapped concurrently. Mammals were only trapped in the inner 100 m x 100 m area of the plots. Traps were placed approximately 10 m apart in a 10 m x 10 m grid. Mammals were marked with ear tags and released after recording species identification, sex, age, mass, total length, tail length, and ear length (Ford, 2002).

Plant species richness was analyzed with Tukey's Studentized Range Test (Ford and White, 2006). Permutation methods in SAS PROC MULTTEST (SAS Institute Inc., 1989-1996) were used for sets of three pairwise comparisons among treatments and across sample periods for pre-treatment and post-treatment arthropod abundance and richness (Ford, 2001; 2003b). Small mammal relative abundance was analyzed with 1-way analysis of variance (ANOVA) and Fisher's LSD (SAS Institute Inc., 1989-1996; Ford, 2002). All results were considered significant at ($p \leq 0.05$).

Results

Plants

Twenty eight plant species were identified, including 18 grasses, eight forbs, one shrub, and one cactus. Seven grass species were common to all of the treatments (*table 1*). The dormant-season fire treatment was the only fire treatment that had significantly higher plant species richness than the unburned treatment (*table 2*) (Ford and White, 2006). See Ford and Johnson, 2006 for a complete list of plants from the study site.

Arthropods

In 1995, a preliminary survey of arthropods on the site documented the occurrence of at least 25 species of orthopterans and close to 40 coleopteran species (Ford and McPherson, 1996). Over the next 3 years of the study (1996-1998), 251 species in 70 families were collected from the site. See Brantley and others, 2001 for a complete list of surface-active arthropods from the study.

In 1996, two groups, grasshopper nymphs (40 percent) and field crickets (*Gryllus*) (40 percent) made up approximately 80 percent of orthoptera recovered from pitfall traps. There were no significant pre-treatment differences in mean orthopteran species richness, approximately 10/plot; or abundance, approximately 500 individuals/plot. Post-treatment, in 1997, field crickets made up close to 40-50 percent, and adult brown spotted grasshoppers (*Psoloessa delicatula*) and obscure grasshoppers (*Opeia obscura*) made up about 25 percent of the species composition across treatments. Mean orthopteran species numbers were significantly higher on both fire-treated plots, approximately 30/plot; than unburned plots, approximately 24/plot. However, there were no significant differences in mean abundances, around 3,000 individuals/plot, among all three treatments. By 1998, there were again no significant differences in orthopteran approximate species richness (25/plot), and abundance (500 individuals/plot) among treatments. Field crickets made up 30 percent, grasshopper nymphs 15 percent, and the blue legged grasshopper (*Metator pardalinus*) 20 percent of the collected samples of orthopterans across treatments (Ford, 2003b).

Beetle samples were composed of 29 families, 115 species, and 4,608 individuals. Ten species from six families made up 90 percent of the individuals (*table 1*). Pre-treatment species richness and abundance revealed no significant differences among the 12 experimental plots. By 1998, approximately one year and six months after dormant-season fire, and one year and three months after growing-season fire, species richness significantly differed among treatments; growing-season fire treated plots had a significantly higher number of beetle species. Species richness was also higher on growing-season plots than the dormant-season plots, but the difference was not significant. Abundance did not significantly differ among treatments (*table 2*) (Ford, 2001).

Small Mammals

From 1995 through 1998 only 9 species of small rodents were identified from the site (*table 1*). Trap success over 3 years resulted in 2,071 total captures in about 100,800 trap nights, or about 2 percent trap success. *Onychomys leucogaster* comprised about 50 percent of those captures, followed by *S. tridecemlineatus* at 20 percent, and *R. montanus* at 16 percent (Ford, 2002). All three mammal species responded differentially to the fire treatments (*table 2*). Relative abundance of the northern grasshopper mouse was significantly higher on both fire-treated plots than unburned plots. Relative abundance of the plains harvest mouse was lower on both fire treatments than on the unburned treatment, but was not statistically significant. The Thirteen-lined ground squirrel appeared to be unaffected by fire (Ford, 2002).

Discussion

As predicted, the groups did exhibit some shared patterns of community structure in response to fire, while other patterns appeared to be species-specific. There was a general pattern of increasing species richness in response to fire: species richness of plants, orthopterans, and coleopterans was higher in fire-treated plots. Similarly, northern grasshopper mouse relative abundance increased in response to fire. In contrast, plains harvest mouse relative abundance decreased in response to fire, while abundance of both arthropod orders and relative abundance of thirteen-lined ground squirrels did not respond to fire treatment. Furthermore, the response to fire lasted longer in orthopterans than in coleopterans. The response to fire season also differed among the organisms studied: 1) only dormant-season fire significantly increased plant species richness; 2) only growing-season fire significantly increased species richness in coleopterans; and 3) the responses of orthopterans and small mammals to fire were unaffected by season.

Many of the mechanisms behind the species-specific and shared response patterns can be attributed to the life history requirements of the organisms studied. For example, part of the negative response to fire by the plains harvest mouse can be attributed to its habitat and food requirements. "Fire-negative" mammals include species that forage on invertebrates in the litter layer, species that live in relatively dense vegetation and eat plant foliage, and species that use- at least partially- above-ground nests of plant debris (Kaufman and others, 1990). Fire would negatively impact these species by removing both their food source and habitat (Ford, 2002). In contrast, the northern grasshopper mouse inhabits open areas, lives and nests in burrows, and feeds primarily on grasshoppers (Whitaker, 1994). The "fire-positive" response is therefore most likely due to increased open areas and increases in grasshopper species and other insects attracted to newly greening vegetation following fire. In addition, northern grasshopper mice are partially protected from the lethal effects of fire by their burrows (Ford, 2002).

In conclusion, if grassland community responses to fire are well understood and predictable, then fire can be used as an effective management tool on a landscape level to create desirable landscape patterns for managing populations of plant and animal species, such as game animals, endangered species, neotropical migratory birds, and other featured species (Ford and McPherson, 1996).

Table 1---*Plants, beetles, and small mammals (family, species and common name), from experimental fire research site, Kiowa National Grassland, Union County, New Mexico, USA. * Shared grasses.*

Plants

ASTERACEAE, Sunflower Family
Chaetopappa ericoides, rose heath
Gutierrezia sarothrae, broom snakeweed
Machaeranthera pinnatifida, lacy tansyaster
Ratibida columnifera, upright prairie coneflower
Ratibida tagetes, shortray prairie coneflower
BORAGINACEAE, Borage Family
Cryptantha sp., catseye
BRASSICACEAE, Mustard Family
Erysimum asperum, Plains wallflower
CACTACEAE, Cactus Family
Echinocereus viridiflorus, hedgehog cactus
EUPHORBIACEAE, Spurge Family
Chamaesyce lata, hoary sandmat
MALVACEAE, Mallow Family
Spheralcea coccinea, scarlet globemallow
POACEAE, Grass Family
Aristida purpurea, Fendler three-awn*
Aristida havardii, Harvard three-awn
Bothriochloa laguroides, beardgrass or bluestem
Bouteloua curtipendula, sideoats grama*
Bouteloua gracilis, blue grama*
Buchloë dactyloides, buffalograss*
Elymus elymoides, longleaf squirreltail*
Elymus smithii, western wheatgrass
Erioneuron pilosum, hairy wooly grass, hairy tridens
Hilaria jamesii, galleta*
Hordeum pusillum, little barley
Muhlenbergia arenicola, sand muhly
Muhlenbergia torreyi, ring muhly
Panicum obtusum, vine mesquite
Schedonnardus paniculatus, tumblegrass
Sporobolus cryptandrus, sand dropseed
Vulpia octoflora, sixweeks-fescue*
POLYGONACEAE, Buckwheat or Knotweed Family
Eriogonum annuum, annual buckwheat

Beetles

CARABIDAE, Ground Beetles
Cicindela obsolete
Pasimachus californicus
Pasimachus obsoletus
CURCULIONIDAE, Snout Beetles, Weevils
Undetermined species
ELATERIDAE, Click Beetles
Agrypnus rectangularis
NITIDULIDAE, Sap Beetles
Carpophilus lugubris
SCARABAEIDAE, Scarab Beetles
Euphoria kerni
Neopsammodius interruptus
Phyllophaga glabricula
TENEBRIONIDAE, Darkling Beetles
Eusattus convexus

Small mammals

CRICETIDAE
Onychomys leucogaster, northern grasshopper mouse
Peromyscus maniculatus, deer mouse
Reithrodontomys montanus, plains harvest mouse
Sigmodon hispidus, cotton rat
HETEROMYIDAE
Dipodomys ordii, Ord's kangaroo rat
Perognathus flavus, silky pocket mouse
Chaetodipus hispidus, hispid pocket mouse
MURIDAE
Mus musculus, house mouse
SCIURIDAE
Spermophilus tridecemlineatus, thirteen-lined ground squirrel

Table 2 -- *Plant, beetle, and small mammal mean and standard deviation (SD) by treatment (Ford, 2001; 2002; Ford and White, 2006).*

Fire Treatment	Unburned	Dormant-season	Growing-season
Variable			
Plant species number	7 (1)	10 (2)	8 (1)
Coleopteran species number	16 (3)	20 (3)	25 (5)
Coleopteran abundance	297 (80)	317 (76)	376 (189)
Northern grasshopper mouse relative abundance (pct)	14 (4)	37 (17)	44 (7)
Thirteen-lined ground squirrel Relative abundance (pct)	36 (35)	37 (21)	25 (13)
Plains harvest mouse Relative abundance (pct)	43 (27)	12 (9)	14 (13)

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