Effects from prescribed burning treatments on mixed grass prairie

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Introduction

Restoration of degraded grassland ecosystems requires the reactivation of the complex biological and ecological processes within native plants and within the rhizosphere organisms that convert soil organic nitrogen into inorganic nitrogen.

The primary cause of deterioration in grassland ecosystems is management practices that are antagonistic to the rhizosphere organism population. Decreases in rhizosphere organism biomass result in reductions in the quantity of organic nitrogen converted into inorganic nitrogen; this conversion is one of the primary functions of rhizosphere organisms. Decreases in the amount of inorganic nitrogen in an ecosystem cause reductions in grass biomass production and decreased native plant density (basal cover), creating larger and more numerous bare spaces between grass plants. These open spaces in the plant community provide ideal habitat for growth of opportunistic "weedy" plant species that are not dependent on the nitrogen converted by rhizosphere organisms. Once established, most opportunistic weedy species have mechanisms that aid in widening the species' distribution; the spread of the weeds indicate further degradation of the grassland ecosystem.

Additions of mineral (inorganic) nitrogen fertilizers to native grassland soils are antagonistic to rhizosphere organism populations, causing greater ecosystem degradation and pushing the plant species composition to be dominated by domesticated cool-season grasses like smooth bromegrass, crested wheatgrass, and Kentucky bluegrass. Other "quick fix" practices that treat only symptoms of the problem and do not correct the cause of the problem also result in further degradation of the ecosystem.

The solution for restoration of degraded grassland ecosystems is to correct the cause of the problem rather than just treat the symptoms of the problem. Grazing management coordinated with grass plant phenological development has been shown to stimulate rhizosphere organism increases in biomass and activity levels (Gorder, Manske, and Stroh 2004, Manske 2005), resulting in increased quantities of inorganic nitrogen (Coleman et al. 1983).

This study was conducted to investigate the possibilities of using prescribed burning treatments in the restoration of degraded mixed grass prairie ecosystems.

Study Area

The study area was the Lostwood National Wildlife Refuge, located in Burke and Mountrail counties in northwestern North Dakota between 48° 50' and 48° 30' north latitude and 102° 40' and 102° 20' west longitude. The landscape is glacial terminal moraine of the Missouri Coteau. Topography is rolling to steep hills interspersed with shallow lakes and prairie wetlands. Soils are primarily fine-loamy, mixed Typic Haploboralls and fine-loamy, mixed Typic Argiboralls. Some areas have sandy or gravelly substratum. Native vegetation is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988) of the mixed grass prairie.

The region was homesteaded between 1910 and 1930. During that period, about 25% of the upland was plowed and used as cropland. Most likely, grazing livestock had access to the remainder of the area. Naturalists' surveys of the region conducted in 1913-1915 described one lone grove of trees located at the southeastern corner of the refuge's lower long lake (Smith 1997). The trees were cut down for their wood, and the lake became known as lower Lostwood Lake.

Because of economic troubles of the time, the federal government developed relief programs to repurchase failed homestead land during the mid to late 1930's. The homestead acres repurchased under land utilization projects were designated for three specific purposes. The acres identified for grazing use and economic development from livestock agriculture became the Little Missouri National Grasslands, acres identified for recreational use became Theodore Roosevelt National Park, and acres identified for wildlife use became Lostwood National Wildlife Refuge.

The Lostwood Wildlife Refuge consists of 26,904 acres (10,896 ha) with 5,381 acres (2,179 ha) of wetlands and 5,577 acres (2,259 ha) of wilderness (Smith 1997). Early management of the refuge was based on the concept of preserving wildlife habitat with little or no disturbance (idle), and about 15% of the refuge has never been burned, grazed, or mowed.

All grazing on the refuge was stopped between 1935 and 1940. After 1940, about 59% of the refuge was grazed periodically using deferred seasonlong management with some areas grazed only one time and other areas grazed as many as 22 times over a 35-year period. Between 1940 and 1975, about 26% of the refuge was annually grazed with seasonlong management for 4.5 to 5.0 months at low to moderate stocking rates, primarily during July through November (Smith 1988). This deferred-type management that delays grazing until after the flowering stage of grasses is known to decrease grass tiller density (Sarvis 1941, Manske et al. 1988).

After 1935, some of the land parcels previously used as cropland by homesteaders (about 8% of the refuge) were allowed to “go back” by natural revegetation through secondary succession. The remaining cropland parcels were managed as cropland until the mid 1950's, when about 15% of the refuge was reseeded with domesticated cool-season grasses, primarily smooth bromegrass and crested wheatgrass (Smith 1988).

The available records indicate that the inhabitants of the region had suppressed all fires from sometime in the late 1800's and that refuge land had not been burned in over 80 years by wildfire or prescribed fire until a prescribed burning program was started in 1978 (Smith 1985b).

There were few trees on the refuge during the 1930's and 1940's, but by 1985, there were over 540 expanding aspen groves covering about 475 acres (192 ha) interspersed across the landscape located at the edges of seasonal wetlands, with about 300 aspen groves completely occupying previous wetland basins (Smith 1997).

The shrub cover on Lostwood Wildlife Refuge increased from about 5% during the mid 1930's to greater than 50% in 1979. This change, however, did not occur at a uniform rate. The shrub composition in the plant community did not change much during the first 20 years. A substantial increase in shrub cover occurred between 1953 and 1969 and, between 1969 and 1979, the western snowberry colonies expanded rapidly and invaded extensive areas of degraded grassland; as a result, over half of the refuge upland was transformed into shrubland (Smith 1988). Kentucky bluegrass was the dominant grass associated with the western snowberry colonies. Large portions of the western snowberry colonies were extremely dense and had no herbaceous understory. Decadent centers of old western snowberry colonies had been reinvaded by smooth bromegrass, quackgrass (Smith 1985a), and Canada thistle (Smith 1985b.). Native grasses and forbs were still present in low quantities in some areas but were greatly suppressed.

Refuge manager Karen Smith initiated an every-other-year prescribed burning strategy that was conducted from 1978 to 2002. The every-other-year burn regime was designed to reduce the invading western snowberry and exotic grasses and renovate the prairie ecosystem. Annual burns were not possible because of insufficient production of plant biomass for fuel (Smith 1985a). The refuge was subdivided into prescribed burn management units that used trails or mowed swaths as fire breaks. Several parcels of the refuge received no burning treatments and were used as reference control areas. The prescribed burns were conducted during four seasons: early spring (mid-late April), 1 replication; spring (May-mid June), 3 replications; early summer (mid June-July), 7 replications; and mid summer (early-mid August), 4 replications. The number of repeated every-other-year burns was 1 burn, 4 replications; 2 burns, 4 replications; 3 burns, 4 replications; and 4 burns, 3 replications. Control treatments, 6 replications, had no burning (wildfires or prescribed burns) for over 100 years, since sometime during the late 1800's. In 1990, Manske (1992) evaluated the effects of every-other-year prescribed burning after thirteen years of treatments (1978-1990). This report is a summary of that study.

Procedures

Field data were collected on permanent landscape transects that included the plant communities on the summit, shoulder, back, foot, and toe slopes from 15 prescribed burn management units with an average size of 530.5 acres (214.85 ha) and 6 control management units of no burning with an average size of 436.8 acres (176.90 ha). A standard paired plot t-test was used to analyze differences between means (Mosteller and Rourke 1973).

Aboveground herbage biomass was collected during peak growth in mid to late July by the standard clipping method (Cook and Stubbendieck 1986). The herbage material from three 0.25 m^2 quadrats (frames) located along the landscape transects for each treatment was sorted in the field by biotype categories: grasses, sedges, forbs, shrubs, and standing dead. The herbage of each biotype category from each frame was placed in labeled paper bags of known weight, oven dried at 176° F (80° C), and weighed.

Plant species composition was determined during peak growth, between mid July and mid August, by the plant shoot cover method (% shoot frequency) (Cook and Stubbendieck 1986), with one hundred 0.1 m^2 quadrats placed systematically along the landscape transects of each treatment.

Endomycorrhizal fungal infection in roots was evaluated for blue grama, western wheatgrass, smooth bromegrass, and western snowberry. Three replicated soil cores 4 inches (10.2 cm) in diameter and 4 inches (10.2 cm) in depth were collected for each of the four plant species; samples from nearly level loam soils along the permanent landscape transects of each control and prescribed burn treatment were taken with a golf cup cutter. Roots were washed over sieving, and current year's roots were removed from plant crowns by clipping. Root samples of each replicate were stored in individual vials and preserved in a solution of glycerin and lactic acid. In the laboratory, root samples were cleared and stained to enhance mycorrhizal structures using procedures described by Phillips and Hayman (1970) and modified by Kormanik and McGraw (1982). Fungal colonization in the root samples was scanned through a Nikon 107733 type 104 microscope, and percent fungal infection was assessed using a nonsystematic modification of the grid-intersect method (Giovannetti and Mosse 1980), with presence or absence (P/A) of fungal structures recorded for 100 intersected root segments.

Changes in soil microorganism activity were monitored by change in the quantity of soil inorganic (mineral) nitrogen in July and August. Five replicated soil cores 1 inch (2.54 cm) in diameter and 6 inches (15.24 cm) in depth were collected from nearly level loam soils along the permanent landscape transects of each control and prescribed burn treatment and air dried. In the laboratory, subsamples of the soil cores were evaluated for total incubated mineralizable nitrogen (N) with procedures outlined by Keeney (1982). Inorganic forms of nitrogen were extracted from soil samples by adding a reagent, 2 M KCl, at the rate of 50 ml/10 g of soil; samples were then shaken for one hour. The extract was analyzed for ammonium (NH_4) and nitrate (NO_3) by steam distillation (Keeney and Nelson 1982). Soil nitrite (NO_2) was not analyzed because it is seldom present in detectable quantities and no methods had been developed that were adequately sensitive to obtain reliable estimates of nitrite.

Gravimetric soil water data (Cook and Stubbendieck 1986) were collected on both the summit slopes and foot slopes of each landscape transect in July and August using a 1-inch (2.54 cm) Veihmeyer soil tube at depths of 0-6, 6-12, and 12-24 inches (0-15.24, 15.24-30.48, and 30.48-60.96 cm) and oven dried at 212° F (100° C). Weather data for the region were collected at the Des Lacs NWR weather station.

Results

The Lostwood Wildlife Refuge region has cold winters and hot summers typical of continental climates. January was the coldest month, and July and August were the warmest months. Plants experience temperature stress during months with mean monthly temperatures below 32.0° F (0.0° C). From November through March each year, plants in northwestern North Dakota cannot conduct active growth because mean temperatures are below 32.0° F (0.0° C).

The long-term (1936-1989) annual precipitation at the Lostwood Wildlife Refuge region is 16.50 inches (419.10 mm). The growing-season precipitation (April through October) is 13.80 inches (350.52 mm), 83.64% of the annual precipitation. The seasonal period during which the greatest precipitation occurs is spring–April, May, and June–with 6.62 inches (168.15 mm), 40.12% of the annual precipitation. June has the greatest monthly precipitation, 3.32 inches (84.33 mm). The precipitation received during the 3-month period of May, June, and July accounts for 46.67% of the annual precipitation (7.70 inches, or 195.58 mm). The precipitation received during the 5-month period of November through March averages 2.70 inches (68.58 mm), 16.36% of the annual precipitation. The seasonal period during which the least precipitation occurs is winter–January, February, and March–with 1.69 inches (42.93 mm), 10.24% of the annual precipitation.

Annual precipitation during the study period (1978-1990) averaged 15.36 inches (390.14 mm), 93.10% of the long-term mean (LTM), and growing-season precipitation, April though October, averaged 12.35 inches (313.69 mm), 89.48% of the LTM growing-season precipitation (table 1). The growing-season precipitation was greater than the long-term mean during 1978, 1982, 1984, 1985, 1986, and 1990, and lower than the long-term mean during 1979, 1980, 1981, 1983, 1987, 1988, and 1989 (table 1). The growing-season precepitation during 1979, 1983, 1987, and 1988 was 48.2%, 62.2%, 60.2%, and 69.6% of the long-term mean, respectively (table 1). The water deficiencies during 1979, 1983, 1987, and 1988 caused water stress in perennial plants so that herbage biomass production in the region was restricted.

The quantity of soil water during the growing season (July and August), to 24 inches (60.96 cm) in depth, was not significantly different among the no burn control treatments and the number of repeated every-other-year burn treatments (table 2) and the seasonal period of every-other-year burn treatments (table 3).

The total current year's production of aboveground biomass was not different after one, two, three, and four repeated prescribed burns compared to the biomass of the unburned treatment (table 4). However, the composition of the aboveground biomass changed remarkably. The contribution of grasses to the total biomass changed from 24.2% on treatments with no burns to 65.6% after four burns (table 4), an increase of 171.1%. Grass biomass decreased 24.7% after one burn and increased 109.3% after four burns (table 4). The contribution from sedges changed from 13.2% on treatments with no burns to 11.1% after four burns. Sedge biomass increased 61.6% after one burn and decreased 35.1% after four burns (table 4). The contribution from forbs changed from 15.0% on treatments with no burns to 20.3% after four burns. After one burn, the forb contribution to total aboveground biomass was 139.7% greater than that on the unburned treatments. After two and three burns, the weedy forbs decreased and the ecological status of perennial forbs improved. The forb contribution to the total biomass production after four burns was 35.3% greater than that on the unburned treatments. Forb biomass increased 78.0% after one burn and increased 4.4% after four burns (table 4). The biomass contribution from shrubs changed from 47.5% on treatments with no burns to only 3.0% after four burns (table 4), a 93.7% decrease. Shrub biomass decreased 83.1% after one burn and decreased 95.1% after four burns (table 4).

Native grass shoot frequency increased significantly as a result of repeated burning. The average increase after one, two, and three burns was 79.6%; after four burns, native grass shoot frequency increased 94.7% (table 5). The quantity of basal cover area for native grasses, however, was not well developed even after four burns. Sedge shoot frequency increased an average of 58.4% after repeated burning. Introduced grass shoot frequency decreased an average of 49.4% after one, two, and three burns and decreased 65.1% after four burns. Four burns were required to reduce introduced grasses significantly (table 5). Kentucky bluegrass shoot frequency decreased an average of 36.2% after one, two, three, and four burns. Quackgrass shoot frequency decreased an average of 84.0% after one and two burns and decreased an average of 90.9% after three and four burns. Smooth bromegrass shoot frequency decreased an average of 90.0% after one and two burns and decreased an average of 96.7% after three and four burns.

Perennial forb shoot frequency increased 39.3% after one burn (table 5) and increased an average of 7.5% after additional repeated burns of two, three, and four times. Early succession and weedy forb shoot frequency increased 8.2% after one burn, decreased an average of 7.5% after two and three burns, and decreased 50.9% after four burns (table 5). Four burns were required to reduce weedy forbs significantly (table 5).

Shrub shoot frequency decreased 36.4% after one burn, decreased an average of 46.1% after two and three burns, and decreased 58.2% after four burns (table 5). Four burns were required to reduce shrubs significantly (table 5).

Western snowberry shoot frequency decreased 62.7% after one burn, decreased an average of 55.8% after two and three burns, and decreased 64.0% after four burns. Shoot frequency of western snowberry changed little from repeated burning after the first burn. However, the aboveground biomass produced by the shrubs was greatly reduced after the third and fourth burns.

All burns cause some damage to plants, but the seasonal period that prescribed burns are conducted affects the biomass production and shoot frequency of plant biotypes differently. Effective prescribed burns are conducted during appropriate seasonal periods so that the greatest reduction to the undesirable plants is caused and the damage to the desirable plants is minimized.

Grass biomass greatly increased after spring (May-mid June) and mid summer (early-mid August) burns but decreased after early summer (mid June-July) burns (table 6). Grass shoot frequency increased significantly after burns conducted during all seasonal periods. The greatest increases occurred after spring (May-mid June) and mid summer (early-mid August) burns (table 7). Shoot frequency of native cool-season grasses increased significantly after burns conducted during all seasonal periods (table 8). Shoot frequency of western wheatgrass increased significantly after early spring (mid-late April) burns and decreased after spring (May-mid June) burns (table 8). Shoot frequency of native warm-season grasses increased significantly after burns conducted during spring (May-mid June) (table 8). Blue grama shoot frequency increased significantly after spring (May-mid June) burns (table 8). Shoot frequency of introduced grasses decreased significantly after spring (May-mid June) burns (table 7). Kentucky bluegrass shoot frequency decreased significantly after spring (May-mid June) burns (table 8) and increased after early spring (mid-late April) burns (table 8). Smooth bromegrass and quackgrass shoot frequency decreased after burns conducted during all seasonal periods. Smooth bromegrass shoot frequency decreased most after early spring (mid-late April) burns (table 8). Quackgrass shoot frequency decreased most after spring (May-mid June) burns (table 8).

Sedge biomass increased after burns conducted during early spring (mid-late April) and early summer (mid June-July) and decreased after spring (May-mid June) and mid summer (early-mid August) burns (table 6). Shoot frequency of sedges increased significantly after spring (May-mid June) burns (table 7).

Forb biomass increased after burns conducted during all seasonal periods. The greatest increases occurred after early spring (mid-late April) and spring (May-mid June) burns (table 6). Shoot frequency of perennial forbs increased after early spring (mid-late April) and early summer (mid June-July) burns and decreased slightly after spring (May-mid June) burns (table 7). Shoot frequency of weedy forbs increased significantly after early spring (mid-late April) burns and decreased after spring (May-mid June), early summer (mid June-July), and mid summer (early-mid August) burns (table 7).

Shrub biomass decreased after burns conducted during all seasonal periods. The greatest decreases occurred after early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) burns (table 6). Shoot frequency of shrubs decreased significantly after early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) burns (table 7). Shrub shoot frequency did not decrease significantly after early summer (mid June-July) burns (table 7). Silverberry shoot frequency decreased significantly after early spring (mid-late April) and mid summer (early-mid August) burns (table 9). Western rose shoot frequency decreased significantly after early spring (mid-late April) and spring (May-mid June) burns (table 9) and increased slightly after early summer (mid June-July) and mid summer (early-mid August) burns. Shoot frequency of western snowberry decreased significantly after early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) burns (table 9). Western snowberry shoot frequency did not decrease significantly after early summer (mid June-July) burns (table 9).

Endomycorrhizal fungi do not colonize the entire root. Fungal colonization occurs at the portions of current year's roots that are biologically active. Previous years' roots, mature root portions, and young growing root portions do not host fungal structures. Percent fungal infection of root segments is primarily a factor of the proportion of biologically active root portions to the amount of mature and young root portions included in the sample. Identification of biologically active root portions from mature root portions is difficult in the field, with the naked eye or low-power hand lenses. Basically, the less than 100% fungal infection in the blue grama, western wheatgrass, and western snowberry root samples in tables 10 and 11 should be considered to indicate the percent biologically active root portions within the root sample. This evaluation, however, is not applicable to the smooth bromegrass root samples. Even though the smooth bromegrass root samples contained a small amount of young and mature root portions, most of the samples consisted of biologically active root portions and the percent fungal infection in tables 10 and 11 should be considered to be close to the percent fungal infection in smooth bromegrass samples. However, almost all of the fungal infection observed in the smooth bromegrass samples was restricted to the root hairs. Very few smooth bromegrass samples had fungal colonization within the root tissue. Even with the large differences in proportions of biologically active root portions within the root samples, the percent fungal infection in blue grama, western wheatgrass, and western snowberry root samples was significantly greater than the percent fungal infection in smooth bromegrass root samples on the number of repeated every-other-year prescribed burn treatments, the seasonal period of every-other-year prescribed burn treatments, and the control no burn treatments. Smooth bromegrass had virtually no fungal infection in the biologically active root tissue and relatively low fungal infection in the root hairs. The percent fungal infection in the roots of blue grama, western wheatgrass, western snowberry, and smooth bromegrass was not changed significantly by the number of repeated every-other-year prescribed burn treatments and the seasonal period of every-other-year prescribed burn treatments from the percent fungal infection in the respective plant species on the control no burn treatments (tables 10 and 11). The quantity of endomycorrhizal fungal colonization in plant roots was not stimulated by the prescribed burning treatments.

Grassland soils have abundant quantities of nitrogen; however, most of it is in the organic form and unavailable for direct use by plants. Grassland plants can use nitrogen only in the inorganic (mineral) form. Soil microorganisms of the rhizosphere convert soil organic nitrogen into inorganic nitrogen (Ingham et al. 1985). Grassland ecosystems with greater biomass of rhizosphere organisms convert greater quantities of organic nitrogen into inorganic nitrogen (Coleman et al. 1983). The quantities of inorganic nitrogen (NH_4-NO_3) in the soils on the number of repeated every-other-year prescribed burn treatments and the seasonal period of every-other-year prescribed burn treatments were not changed significantly from the quantities of inorganic nitrogen in the soils on the control no burn treatments (tables 10 and 11). The rhizosphere microorganism biomass and activity levels were not stimulated by the prescribed burning treatments, and the quantity of organic nitrogen converted into inorganic nitrogen was not stimulated by the prescribed burning treatments.

Discussion

Western snowberry aerial stems are sensitive to fire. The top growth is usually removed completely if sufficient fine fuel is present, and even if the stems are not completely consumed by the fire, they usually die to ground level. The belowground rhizomes and rhizome crowns with clusters of aerial stems are usually not damaged by fire. The belowground parts have large quantities of buds that have the potential to develop into new aerial sucker stems. Spring burns result in great quantities of sucker stems, which become visible about two weeks following the burn, and because carbohydrate stores can be completely replenished by the new plant material in one growing season, spring burns decrease shrub biomass but do not decrease stem frequency, even after numerous years of repeated burns. Prescribed burns conducted during early summer (mid June-July) cause the least reduction in western snowberry shoot frequency and shrub biomass production. These early summer burns coincide with western snowberry's major carbohydrate replenishment period, which occurs from full leaf expansion stage through most of the flowering stage, from early June to mid July.

Prescribed burns conducted during early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) result in decreased western snowberry shoot frequency and shrub biomass production. These burns coincide with the first two carbohydrate drawdown periods of western snowberry. The first carbohydrate drawdown period occurs during early spring, from mid April to early June (9 June), when the plants are in rapid growth to full leaf expansion stages. The second carbohydrate drawdown period occurs during the major portion of fruit fill stage, from mid July to mid August. Burns conducted during carbohydrate drawdown periods have greater success at western snowberry reduction than burns conducted during carbohydrate replenishment periods.

Kentucky bluegrass is increased by earlier burns and decreased by later spring burns. Weedy forbs are increased greatly by spring burns. However, four repeated burns conducted every-other-year significantly reduce the undesirable plants of introduced grasses, early succession and weedy forbs, and shrubs from mixed grass prairie habitat. Native grasses, sedges, and perennial forbs are not reduced by repeated every-other-year burning and benefit from the reduction in competition for sunlight from the taller shrubs.

Repeated every-other-year prescribed burning did not increase native grass basal cover (density), prescribed burning did not increase endomycorrhizal fungal infection of prairie plant roots, and prescribed burning did not increase the quantity of soil organic nitrogen converted into inorganic nitrogen. Stimulation of vegetative reproduction in grasses, stimulation of rhizosphere organism biomass and activity levels, and stimulation of biogeochemical cycling are the key physiological and ecological processes that grassland managers must activate in order to improve native plant health and vigor and to restore degraded ecosystems. Grassland fires do not improve mixed grass prairie ecosystems biologically or ecologically.

Historically, fire had been an environmental factor on mixed grass prairie, with an estimated fire return interval of 5 to 10 years on the moist regions and around 25 years on the dry regions (Wright and Bailey 1982, Bragg 1995). Most lightning-set fires occurred in July and August, and a large portion of the Indian-set fires occurred between July and early November (Higgins 1986). The Northern Plains mixed grass prairie has probably had considerably more late-season fires, occurring after mid July, than spring or early summer fires.

Spring burns during late April or May are severely detrimental to native cool-season grasses because of the removal of the valuable growth of the fall tillers and overwintering secondary tillers. June and early July burns are usually detrimental to native grass plants and hurt western snowberry plants only a little. Prescribed fire during August causes the least damage to native cool- and warm-season grasses and perennial forbs. An August fire removes all or most of the top growth of western snowberry and results in fewer sucker shoots the following year than a spring burn. August burns can be nearly nondetrimental to desirable plants when the soil is not dry, and August burns can cause considerable damage to the undesirable woody plants. Late April and May prescribed burns are less likely to escape control measures compared to August burns; however, the growth pattern and biological requirements of herbaceous vegetation in the mixed grass prairie match the August burns more closely (figure 1).

Conclusions

Grassland ecosystems in the mixed grass prairie degrade when managed with long-term idle (no defoliation) treatments and low to moderately stocked deferred grazing treatments. Ecosystem degradation does not occur at a uniform (linear) rate across time. The rate of decline begins slowly and accelerates progressively. The change in plant composition to greater abundance of nonrhizosphere species is basically a symptom, and the degree of plant species change lags behind the degree of ecosystem degradation.

Treatments that are designed to remove undesirable plant species do not restore ecosystem functions. Treatments that stimulate rhizosphere organism populations and enhance ecosystem biogeochemical cycles restore degraded grassland ecosystem processes; this restoration is followed by the improvement in plant composition to a greater abundance of rhizosphere species.

Prescribed burning can be used to kill western snowberry aerial stems to ground level and reduce shrub stem frequency, but fire alone will not eliminate western snowberry. Four repeated every-other-year burns can reduce introduced grasses, early succession and weedy forbs, and undesirable shrubs and woody plants.

Prescribed burning, however, cannot restore degraded grassland ecosystems because fire does not stimulate vegetative reproduction by tillering, a process that results in increased grass basal cover; fire does not stimulate endomycorrhizal fungal colonization of grass roots; fire does not stimulate rhizosphere organism biomass and activity levels; and fire does not stimulate conversion of soil organic nitrogen into inorganic nitrogen.

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Table 1. Precipitation in inches for growing-season months and the annual total precipitation for 1978-1990, Lostwood Wildlife Refuge, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1936-1989	1.28	2.02	3.32	2.36	1.94	1.87	1.01	13.80	16.50
1978	0.58	5.13	2.76	1.45	0.84	2.55	0.64	13.95	14.96
% of LTM	45.31	253.96	83.13	61.44	43.30	136.36	63.37	101.09	90.67
1979	1.59	1.75	0.61	1.32	0.04	0.84	0.50	6.65	8.72
% of LTM	124.22	86.63	18.37	55.93	2.06	44.92	49.50	48.19	52.85
1980	1.81	0.08	1.41	1.63	3.12	2.22	2.08	12.35	15.59
% of LTM	141.41	3.96	42.47	69.07	160.82	118.72	205.94	89.49	94.48
1981	0.41	0.50	4.06	2.77	2.71	1.31	0.65	12.41	15.34
% of LTM	32.03	24.75	122.29	117.37	139.69	70.05	64.36	89.93	92.97
1982	0.38	2.23	1.82	3.12	1.22	2.06	4.64	15.47	19.56
% of LTM	29.69	110.40	54.82	132.20	62.89	110.16	459.41	112.10	118.55
1983	0.19	1.30	1.44	2.42	1.37	1.04	0.82	8.58	12.19
% of LTM	14.84	64.36	43.37	102.54	70.62	55.61	81.19	62.17	73.88
1984	5.74	0.36	1.70	1.29	0.98	2.54	4.10	16.71	19.48
% of LTM	448.44	17.82	51.20	54.66	50.52	135.83	405.94	121.09	118.06
1985	0.69	4.77	1.81	0.99	3.98	2.07	1.60	15.91	18.40
% of LTM	53.91	236.14	54.52	41.95	205.15	110.70	158.42	115.29	111.52
1986	1.71	2.59	1.77	5.85	0.67	1.95	0.76	15.30	18.04
% of LTM	133.59	128.22	53.31	247.88	34.54	104.28	75.25	110.87	109.33
1987	0.10	1.80	0.89	3.83	0.73	0.66	0.30	8.31	12.16
% of LTM	7.81	89.11	26.81	162.29	37.63	35.29	29.70	60.22	73.70
1988	0.05	2.36	2.73	1.67	0.30	2.31	0.19	9.61	13.19
% of LTM	3.91	116.83	82.23	70.76	15.46	123.53	18.81	69.64	79.94
1989	0.70	1.30	3.31	2.66	0.80	1.59	0.48	10.84	16.37
% of LTM	54.69	64.36	99.70	112.71	41.24	85.03	47.52	78.55	99.21
1990	1.26	2.39	2.41	4.24	2.28	0.57	0.03	14.44	15.69
% of LTM	100.78	118.32	72.59	179.66	117.53	30.48	2.97	104.64	95.09
1978-1990	1.17	2.04	2.06	2.56	1.46	1.67	1.29	12.35	15.36
% of LTM	91.41	101.14	61.91	108.34	75.50	89.30	127.88	89.48	93.10

Table 2. Inches of soil water, 0-24 inches in depth, on summit and foot slopes with deep loam soils on the number of repeated every-other-year burn treatments.

	Depth in inches	No Burns 5 reps	One Burn 3 reps	Two Burns 3 reps	Three Burns 4 reps	Four burns 2 reps
Summit Slope						
July	0-24	3.00a	3.47a	3.11a	2.37a	2.53
August	0-24	2.31b	2.79b	2.17b	2.30b	2.35b
Foot Slope						
July	0-24	3.47c	3.47c	3.24c	2.88c	4.42c
August	0-24	2.58d	3.02d	2.45d	2.69d	3.35d

Data from Manske 1992
Means in the same row and followed by the same letter are not significantly different ($p<0.05$).

Table 3. Inches of soil water, 0-24 inches in depth, on summit and foot slopes with deep loam soils on the seasonal period of every-other-year burn treatments.

	Depth in inches	No Burns 5 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 1 rep	Early Summer (mid Jun-Jul) 6 reps	Mid Summer (early-mid Aug) 4 reps
Summit Slope						
July	0-24	3.00a	-	-	3.03a	2.94a
August	0-24	2.31b	2.30b	-	2.51b	2.56b
Foot Slope						
July	0-24	3.47c	-	-	3.36c	3.69c
August	0-24	2.58d	-	-	2.82d	3.01d

Data from Manske 1992
Means in the same row and followed by the same letter are not significantly different ($p<0.05$).

Table 4. Live biomass production of plant biotypes on the number of repeated every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	One Burn 4 reps	Two Burns 4 reps	Three Burns 4 reps	Four Burns 3 reps
Grass Biomass	(lbs/ac)	411.61a	310.12a	762.75a	512.87a	861.51a
% change	(%)		-24.7	85.3	24.6	109.3
Sedge Biomass	(lbs/ac)	224.59b	362.93b	74.34b	238.58b	145.81b
% change	(%)		61.6	-66.9	6.2	-35.1
Forb Biomass	(lbs/ac)	255.33c	454.35c	445.14c	587.41c	266.49c
% change	(%)		78.0	74.3	130.1	4.4
Shrub Biomass	(lbs/ac)	806.83d	136.00d	237.09d	52.00d	39.57d
% change	(%)		-83.1	-70.6	-93.6	-95.1
Total Live Biomass	(lbs/ac)	1698.36e	1263.39e	1519.19e	1390.87e	1313.38e
% change	(%)		-25.6	-10.6	-18.1	-22.7

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 5. Shoot frequency of plant biotypes on the number of repeated every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	One Burn 4 reps	Two Burns 4 reps	Three Burns 4 reps	Four Burns 3 reps
Native Grass						
Shoot frequency	(%)	107.0a	194.3b	183.3ab	198.8b	208.3b
% change	(%)		81.6	71.3	85.8	94.7
Sedge						
Shoot frequency	(%)	56.7c	95.5d	97.0d	77.8cd	89.0cd
% change	(%)		68.4	71.1	37.2	57.0
Introduced Grass						
Shoot frequency	(%)	86.7e	46.3ef	31.8ef	53.5ef	30.3f
% change	(%)		-46.6	-63.3	-38.3	-65.1
Perennial Forbs						
Shoot frequency	(%)	120.5g	167.8h	125.5gh	137.5gh	125.7gh
% change	(%)		39.3	4.1	14.1	4.3
Weedy Forbs						
Shoot frequency	(%)	85.5i	92.5i	80.3ij	78.0ij	42.0j
% change	(%)		8.2	-6.1	-8.8	-50.9
Shrubs						
Shoot frequency	(%)	111.7k	71.0kl	58.5kl	62.0kl	46.7l
% change	(%)		-36.4	-47.6	-44.5	-58.2

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different (P<0.05).

Table 6. Live biomass production of plant biotypes on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Grass Biomass	(lbs/ac)	411.61a	571.59a	748.93a	347.88a	918.49a
% change	(%)		38.9	82.0	-15.5	123.1
Sedge Biomass	(lbs/ac)	224.59b	366.79b	48.88b	316.29b	103.33b
% change	(%)		63.3	-78.2	40.8	-54.0
Forb Biomass	(lbs/ac)	255.33c	771.40c	587.21c	451.17c	263.97c
% change	(%)		202.1	130.0	76.7	3.4
Shrub Biomass	(lbs/ac)	806.83d	0.0d	0.0d	226.43d	58.52d
% change	(%)		-100.0	-100.0	-71.9	-92.8
Total Live Biomass	(lbs/ac)	1698.36e	1709.78e	1385.02e	1341.77e	1344.18e
% change	(%)		0.7	-18.5	-21.0	-20.9

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 7. Shoot frequency of plant biotypes on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Native Grass						
Shoot frequency	(%)	107.0a	189.0b	219.7b	182.9b	200.5b
% change	(%)		76.6	105.3	70.9	87.4
Sedge						
Shoot frequency	(%)	56.7c	39.0c	97.3d	93.4cd	90.8cd
% change	(%)		-31.2	71.6	64.7	60.1
Introduced Grass						
Shoot frequency	(%)	86.7e	73.0e	23.7f	43.4ef	42.3ef
% change	(%)		-15.8	-72.7	-49.9	-51.2
Perennial Forbs						
Shoot frequency	(%)	120.5g	157.0g	116.7g	154.6g	127.8g
% change	(%)		30.3	-3.2	28.3	6.1
Weedy Forbs						
Shoot frequency	(%)	85.5h	129.0i	43.3h	79.3h	78.8h
% change	(%)		50.9	-49.4	-7.3	-7.8
Shrubs						
Shoot frequency	(%)	111.7j	15.0l	22.0l	81.7jk	63.3k
% change	(%)		-86.6	-80.3	-26.9	-43.3

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 8. Shoot frequency of grasses on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Native Grass						
Cool Season Grass						
Shoot frequency	(%)	89.2a	177.0b	166.0b	168.9b	169.0b
% change	(%)		98.4	86.1	89.3	89.5
Warm Season Grass						
Shoot frequency	(%)	17.8c	12.0c	53.7d	14.0c	31.5cd
% change	(%)		-32.7	201.0	-21.5	76.7
Western wheatgrass						
Shoot frequency	(%)	15.5e	42.0c	13.7e	16.4e	19.5e
% change	(%)		170.1	-11.8	6.0	25.8
Blue grama						
Shoot frequency	(%)	8.0f	4.0f	39.3g	7.4f	14.8fg
% change	(%)		-50.0	391.6	-7.1	84.4
Introduced Grass						
Smooth bromegrass						
Shoot frequency	(%)	17.5h	0.0h	2.3h	0.3h	2.3h
% change	(%)		-100.0	-86.7	-98.3	-87.1
Quackgrass						
Shoot frequency	(%)	7.8i	1.0i	0.0i	0.4i	2.8i
% change	(%)		-87.2	-100.0	-94.5	-64.7
Kentucky bluegrass						
Shoot frequency	(%)	59.5j	72.0j	21.3k	42.0j	37.3jk
% change	(%)		21.0	-64.2	-29.4	-37.3

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 9. Shoot frequency of shrubs on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Western snowberry						
Shoot frequency	(%)	58.3a	5.0b	10.3b	33.4ab	21.5b
% change	(%)		-91.4	-82.3	-42.7	-63.1
Western rose						
Shoot frequency	(%)	35.8c	8.0d	4.3d	41.7c	41.3c
% change	(%)		-77.7	-87.9	16.4	15.1
Silverberry						
Shoot frequency	(%)	17.3e	2.0f	7.3e	6.6e	0.5f
% change	(%)		-88.5	-57.7	-62.1	-97.1

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different (P<0.05).

Table 10. Mycorrhizal fungal infection of plant roots and soil mineral nitrogen (NH_4-NO_3) on the number of repeated every-other-year burn treatments.

Plant Biotypes		No Burns 6 reps	One Burn 4 reps	Two Burns 4 reps	Three Burns 4 reps	Four Burns 3 reps
Western snowberry						
Fungi infection	(%)	93.8a	84.7a	84.3a	85.2a	85.9a
Smooth bromegrass						
Fungi infection	(%)	32.3b	55.0b	50.0b	31.4b	40.1b
Western wheatgrass						
Fungi infection	(%)	66.0c	67.0c	61.3c	76.8c	63.8c
Blue grama						
Fungi infection	(%)	78.8d	77.1d	84.9d	79.9d	73.5d
Mineral Nitrogen						
NH_4-NO_3	(ppm)	9.56e	9.65e	9.41e	5.54e	8.36e

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 11. Mycorrhizal fungal infection of plant roots and soil mineral nitrogen (NH_4-NO_3) on the seasonal period of every-other-year burn treatments.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Western snowberry						
Fungi infection	(%)	93.8a	92.3a	85.5a	82.7a	86.6a
Smooth bromegrass						
Fungi infection	(%)	32.3b	33.7b	40.0b	37.2b	65.7b
Western wheatgrass						
Fungi infection	(%)	66.0c	74.7c	48.0c	73.7c	69.5c
Blue grama						
Fungi infection	(%)	78.8d	70.7d	79.6d	82.0d	76.2d
Mineral Nitrogen						
NH_4-NO_3	(ppm)	9.56e	3.64	8.47e	9.42e	7.09e

Data from Manske 1992

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Fig. 1. Western snowberry colony before (left) and after (right) four every-other-year prescribed burns during mid summer (August). Photographs were taken by Karen Smith.

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