

Final Report, December 2005: Joint Fire Science Program RFP 2001-3

Task 2 “. . . determine local biological . . . effects of wildland fire, fuel treatments”

Task 3 “Address local knowledge gaps significant to fire management . . .”

Project Title:

Prescribed fire for fuel reduction in northern mixed grass prairie: influence on habitat and population dynamics of indigenous wildlife

Project Location:

U.S. Department of the Interior-National Wildlife Refuge System in
northwestern and north central North Dakota:

Lostwood National Wildlife Refuge
Des Lacs National Wildlife Refuge
Upper Souris National Wildlife Refuge
J. Clark Salyer National Wildlife Refuge

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This final report summarizes study results to date. A modified version of this report is presented along with contact information for obtaining copies of technical publication at the following 2 web sites.

U.S. Fish and Wildlife Service-Des Lacs National Wildlife Refuge Complex
<http://deslacs.fws.gov/>

U.S. Fish and Wildlife Service-J. Clark Salyer National Wildlife Refuge Complex
<http://www.fws.gov/jclarksalyer/>

EXECUTIVE SUMMARY

An average of roughly 10,000 ha of grasslands, primarily northern mixed-grass prairie, is treated annually with prescribed fire on the U.S. Department of the Interior's National Wildlife Refuges (NWRs) in the Dakotas and eastern Montana. This management continues despite sparse information on effects of fire on wildlife, introduced and native plants, and wildlife-habitat relationships in the northern mixed-grass prairie ecosystem. To address basic information gaps, we assessed direct and indirect, short and long term impacts of fire or fire suppression on vegetation and wildlife population dynamics at 4 NWRs in northwestern and north central North Dakota during 1997-2003; most work was conducted at Des Lacs NWR and J. Clark Salyer NWR. Funding from the Joint Fire Science Program during the final 2 years of our work helped us expand the inferential value of our studies while giving land managers a novel chance to more clearly identify opportunities and limitations with prescribed burning in relation to the mission and goals of their respective NWRs. Our chief goals were to document effects of prescribed burning of northern mixed-grass prairie on the abundance, productivity, and nest site selection of migratory birds, especially grassland songbirds; measure influences of major sources of woody fuels and habitat edges (e.g., woodland, cropland, wetland) on occurrences and productivity of common bird species; and assess relationships between fire history and vegetation composition and structure on several spatial and temporal scales.

Our study area lies within a cool-season (C_3)-dominated, needlegrass-wheatgrass (*Stipa-Agropyron*) association. However, the contemporary prairie we studied on the NWRs is invaded by introduced, cool-season grasses and native shrubs and trees, as are most other prairie tracts managed by the U.S. Fish and Wildlife Service and other conservation agencies in the northern Great Plains region. We used 2 basic approaches to examine fire effects on vegetation and wildlife. First, we designed short-term (<10 years) field experiments to test specific hypotheses regarding fire effects on vegetation structure, plant community composition, and wildlife abundance and productivity. Secondly, we assessed long-term (60-100 years) changes in plant communities associated with changes in fire disturbance regimes during and after settlement of the region by persons of European descent. To address study objectives, we used standard methods to collect, analyze, and report data.

Fire is a fundamental ecological process in the evolution and maintenance of northern grasslands. In summarizing our objectives, our collective studies generally indicate the following for northern mixed-grass prairie.

- (1) **Avian occurrence/abundance and nest densities:** Most species of breeding grassland birds are adapted to recurring fire (i.e., every 4-6 years) in northern mixed-grass prairie, returning to pre-burn levels of abundance and nest density following declines the first growing season after burning and by nesting in unburned patches.
- (2) **Fire effects on nest survival:** Fire had almost no discernable impact on nest survival for all species of grassland birds examined, except Savannah sparrow (*Passerculus sandwichensis*) nest survival was reduced in the first post-burn growing season, a decrease that mainly was the result of increased nest parasitism by brown-

headed cowbirds (*Molothrus ater*). In contrast, survival rates of mallard (*Anas platyrhynchos*) and gadwall (*A. strepera*) nests were highest during the first post-fire growing season.

- (3) **Fire effects on nest site selection:** Fire consumed most residual vegetation. Despite reductions in plant litter, “skips” (i.e., unburned patches) remained after burning and these typically were sites where songbirds and ducks nested. For example, litter depth at nests of clay-colored sparrow (*Spizella pallida*) and Savannah sparrow were similar among study units the first, second, and third post-fire growing seasons after burning even though litter within these units nearly was absent, on average, during the first post-fire growing season.
- (4) **Fire effects on small mammals:** Deer mice (*Peromyscus maniculatus*) were 5-6 times more abundant during the first post-fire growing season, when litter was mostly absent. Most other small mammal species were much less common during the first post-fire growing season than during 2-5 growing seasons after fire, over which time residual vegetation was incrementally more abundant.
- (5) **Fire effects on vegetation composition and structure – short term effects:** The structure of contemporary northern mixed-grass prairie vegetation is markedly influenced by fire during the first, second, and third post-fire growing seasons after burning, or by the interaction between numbers of burns and time since the last fire, but the composition generally is unchanged over the short term (< 10 years). Among major introduced grass species, fire probably reduces the frequency of Kentucky bluegrass (*Poa pratensis*), but smooth brome (*Bromus inermis*) may be unaffected or slightly decrease with fire. However, frequencies of native herbaceous flora do not increase with prescribed burning in loamy soils dominated by smooth brome and Kentucky bluegrass, at least in the short term.

Fire effects on vegetation composition and structure – long term effects:

(a) influence of fire suppression on distribution of trees and tall shrubs:

Significant changes occurred in the extent of woodland cover across the 4 present-day NWRs during the 1800s and 1900s. Woodlands were rare when the region was settled by Europeans in the early 1900s, but expanded in river valleys mainly during the early- to mid-1900s, and in sandhills and a terminal moraine during mainly the mid- to late-1900s, changing much of the mixed-grass prairie to parkland and woodland edge.

(b) influence of long-term suppression of fire and grazing disturbances on prairie floristics:

We sampled the general floristic makeup of prairie on 2 NWRs (4300 ha total) that had been managed mainly by rest since the 1930s. The prairies were moderately to severely invaded by the introduced grasses, smooth brome and Kentucky bluegrass. Plant assemblages composed of native species were rare. We also sampled floristics on nearby, privately-owned prairies that had been grazed annually for decades.

Native herbaceous flora was prevalent on grazed prairie near 1 of the 2 NWRs. The findings demonstrate pitfalls of managing disturbance-dependent grasslands as relatively static, late-succession systems for many decades, without basic inventory and monitoring to comprehend and address associated ecological changes.

- (6) **Influences of tall woody fuels and habitat edges on productivity:** We detected no relationships between nest survival and prevalence of woody fuels at the nest site and nest patch scales. Survival of nests of 1 of 2 common sparrow species we studied increased as patches of tall shrub and trees decreased in the landscape, validating the importance of reducing these fuels for grassland bird management.
- (7) **Predictive models for land managers:** Land managers typically apply prescribed fire to try to emulate the region's natural fire regime. We provide models that forecast abundance, nesting density, and nest survival among breeding grassland bird species, and for the physiognomy (structure) and composition of grassland vegetation at several spatial and temporal scales, relative to successive, post-treatment seral stages and other potentially interacting factors (e.g., weather, landscape effects).
- (8) **Occurrence and productivity of uncommon grassland bird species:** In addition to examining fire history relationships for species of birds that commonly nest in northern mixed-grass prairie, we amassed a database that includes roughly 5000 nests of 35 less common bird species that use grasslands as breeding habitat. The data will provide new insights on species breeding biology, including nest site selection and nest survival relative to various temporal and spatial scales of habitat and disturbance. Basic natural history data will be supplied for species for which such information is scarce, such as Le Conte's sparrow (*Ammodramus leconteii*), Brewer's blackbird (*Euphagus cyanocephalus*), and Sprague's pipit (*Anthus spragueii*).

Our data support the notion that bird species native to northern mixed-grass prairie are well adapted to frequent defoliation by fire. In general, decreases in species abundance and nesting density during the first growing season after burning are offset by increases in following years, compared to pre-burn levels; nest survival appears unaffected. Short term unavailability of breeding habitat probably is outweighed by long term benefits from using fire to restore and maintain vegetation structure and manage fuel loads (i.e., reduce accumulating litter and woody vegetation) in northern mixed-grass prairie. Our data also indicate that occurrence and survival of nests of at least some bird species is negatively associated with the extent of trees and tall shrubs in the landscape; efforts to reduce these fuels via prescribed burning seem warranted for improving the productivity of grassland birds, as well as addressing other prairie restoration objectives.

To date, our work has resulted in 7 technical publications in peer-reviewed journals, another 7 manuscripts currently in review for publication or soon to be submitted for publication, 1 graduate (M.S.) thesis, 15 presentations at various professional conferences and symposia, and a web page available through 2 NWR web sites.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	2
PROJECT DELIVERABLES	6
Deliverables to date: publications and theses.....	7
Manuscripts in review or in preparation for publication	7
Presentations at conferences and symposia.....	8
INTRODUCTION AND STUDY OBJECTIVES.....	10
STUDY AREA.....	11
METHODS.....	12
General approach.....	12
Experimental design	12
Sampling to assess fire history effects on abundance of grassland birds.....	14
Fire effects on nest survival among grassland bird species.....	14
Modeling fire and other effects on avian abundance and nest survival.....	15
Avian nest site selection and fire.....	15
Fire effects on relative abundance of small mammals.....	16
Short-term fire effects on vegetation.....	16
Long-term fire effects on vegetation	17
<i>Changes in woodland cover on prairie refuges in North Dakota</i>	<i>17</i>
<i>Land management history and floristics in mixed-grass prairie</i>	<i>17</i>
RESULTS	18
Fire effects on abundance of grassland birds.....	18
Fire effects on nest densities of grassland birds	19
Effects of fire and distribution of tall woody fuels on the survival of grassland bird nests	19
Influence of fire on avian nest site selection	19
Fire effects on small mammals.....	20
Short-term fire effects on vegetation structure and composition	20
Long-term fire effects on vegetation communities.....	21
LESSONS LEARNED	22
LITERATURE CITED.....	23
TABLES	24
FIGURES	26

PROJECT DELIVERABLES

Electronic and hardcopy versions of this report are submitted to the Joint Fire Science Program office. A condensed version of this report is presented, along with technical publications and photos from the study, under the following 2 web sites, and represents an important component of our final report.

U.S. Fish and Wildlife Service-Des Lacs National Wildlife Refuge Complex
<http://deslacs.fws.gov/>

U.S. Fish and Wildlife Service-J. Clark Salyer National Wildlife Refuge Complex
<http://www.fws.gov/jclarksalyer/>

Deliverables outlined in this report exceed our initial proposed list of deliverables, but also differ in some respects, as follows:

- 1) **Fire effects on grassland bird productivity (direct and indirect, short-term effects on breeding bird abundance and nest survival via alterations in nest site and nest patch habitat composition and structure):** deliverables proposed were exceeded; some results already have been published, while other results are in review or in preparation for publication. Deliverables encompass much more than anticipated regarding short-term fire effects on northern mixed-grass prairie vegetation. Includes a recently published, extensive background assessment of the status of vegetation composition on 2 NWRs of the study area where fire effects on grassland bird nesting was studied intensively.
- 2) **Fire effects on small mammal communities (changes in relative abundance and species composition in response to prescribed fire):** deliverables proposed have been completed, although manuscripts have not yet been submitted for publication.
- 3) **Fire effects on avian nest site selection (nest site level, nest patch level, and plot level of resource selection on prescribe-burned study units):** deliverables proposed have been completed (M.S. thesis), although manuscripts have not yet been submitted for publication.
- 4) **Fire effects on avian niche selection:** this area was not addressed due to unanticipated overhead that significantly reduced realized funding compared with that requested.
- 5) **Woody fuels effects (influence of woody fuel area, density, and distribution, and other landscape attributes, on the distribution and fate of grassland bird nests):** deliverables proposed were exceeded, although not as a Ph.D. dissertation as originally proposed. Results currently are accepted or in preparation for publication. Includes a recently published, extensive assessment of long-term changes in woodland cover across the study area.

Deliverables to date: publications and theses

** asterisk indicates publications from studies conducted prior to JSFP support, but for which final manuscript revision and publication were completed in part with JFSP support*

- *Danley, R. F., R. K. Murphy, and E. M. Madden. 2004. Species diversity and habitat of grassland songbirds during grazing of prescribe-burned, mixed-grass prairie. *Western North American Naturalist* 64:72-77.
- *Grant, T. A., E. M. Madden, and G. B. Berkey. 2004. Tree and shrub invasion in northern mixed-grass prairie: implications for breeding grassland birds. *Wildlife Society Bulletin* 32:807–818.
- Grant, T. A., E. M. Madden, T. L. Shaffer, P. J. Pietz, and N. K. Kadrmas. 2006. Nest survival of clay-colored and vesper sparrows in relation to woodland edge in mixed-grass prairies. *Journal of Wildlife Management*. *In press*.
- Grant, T. A., and R. K. Murphy. 2005. Changes in woodland cover on prairie refuges in North Dakota, USA. *Natural Areas Journal* 25:359–368.
- Grant, T. A., T. L. Shaffer, E. M. Madden, and P. J. Pietz. 2005. Time-specific variation in passerine nest survival: new insights for old questions. *Auk* 122:661–672.
- Ludwick, T. J., and R. K. Murphy. 2006. Fire history, passerine abundance, and habitat on a North Dakota Drift Plain prairie. *Prairie Naturalist*. *In press*.
- Murphy, R. K., and T. A. Grant. 2005. Land management history and floristics in mixed-grass prairie, North Dakota, USA. *Natural Areas Journal* 25:359–368.
- Nenneman, M. P. 2003. Vegetation structure and floristics at nest sites of grassland birds in north central North Dakota. Thesis, University of Montana, Missoula, Montana, USA.

Manuscripts in review or in preparation for publication

- Grant, T. A., E. M. Madden, T. L. Shaffer. Fire effects on nest survival of grassland songbirds and ducks breeding in northern mixed-grass prairie. *Journal of Wildlife Management*.
- Grant, T. A., E. M. Madden, T. L. Shaffer and J. S. Martin. Fire effects on grassland songbirds breeding in northern mixed-grass prairies of North Dakota. *Journal of Wildlife Management*.

Grant, T. A., T. L. Shaffer, E. M. Madden. Time specific variation in songbird and duck nest survival in North Dakota. *Auk* or *Condor*.

Murphy, R. K. Coinciding historical change in prairie habitat and nesting raptors in northwestern North Dakota. *Western North American Naturalist*.

Murphy, R. K., T. L. Shaffer, C. R. Rubin, J. D. Derrig, and A. Ryba. Influences of woody patch distribution on survival and parasitism rates of grassland passerine nests in a northern prairie. *Wilson Bulletin*.

Shaffer, T. L. and T. A. Grant. Modeling nest parasitism rates: implications for estimating nest survival. *Ecology*.

Shaffer, T. L. and F. R. Thompson, III. Making meaningful estimates of nest survival with model-based methods. *Studies in Avian Biology*. In review.

Presentations at conferences and symposia

Grant, T. A., E. M. Madden, T. L. Shaffer. 2005. Fire effects on avian occurrence and nest survival in northern mixed-grass prairie. The Wildlife Society 12th Annual Conference, Madison, Wisconsin.

Grant, T. A., E. M. Madden, T. L. Shaffer. 2006. Fire effects on avian occurrence and nest survival in northern mixed-grass prairie. Fourth North American Duck Symposium and Workshop, Bismarck, North Dakota.

Grant, T. A., E. M. Madden, T. L. Shaffer, and G. B. Berkey. 2003. Tree and shrub invasion in northern mixed-grass prairie: implications for breeding grassland birds. 64th Midwest Fish and Wildlife Conference, Kansas City Missouri.

Grant, T. A., E. M. Madden, T. L. Shaffer, P. J. Pietz, and G. B. Berkey. 2004. Grassland passerine nest survival in relation to woodland edge and nest age. The Wildlife Society 11th Annual Conference, Calgary, Alberta.

Grant, T. A., and R. K. Murphy. 2003. Changes in woodland cover in north central and northwestern North Dakota. The Wildlife Society 10th Annual Conference, Bismarck, North Dakota (Poster).

Grant, T. A., and R. K. Murphy. 2005. Changes in woodland cover on prairie refuges in North Dakota. Invasive Species Workshop, Bismarck, North Dakota.

Grant, T. A., T. L. Shaffer, E. M. Madden, and P. J. Pietz. 2003. Time-specific variation in passerine nest survival: new insights for old questions? 64th Midwest Fish and Wildlife Conference, Kansas City Missouri.

- Grant, T. A., T. L. Shaffer, and S. K. Davis. 2005. Time-specific variation in passerine nest survival: new insights for old questions? Cooper Ornithological Society 75th Annual Meeting, Humboldt, California.
- Ludwick, T. J., and R. K. Murphy. 2005. Fire history and abundance and habitat of passerines on a North Dakota Drift Plain prairie. North Dakota Chapter of the Wildlife Society, Mandan, North Dakota.
- Murphy, R. K., T. A. Grant, and E. M. Madden. 2004. Prescribed fire for fuel reduction in northern mixed-grass prairie: influence on habitat and population dynamics of indigenous wildlife. Joint Fire Science Program, principle investigator workshop, Phoenix, Arizona. (Poster)
- Murphy, R. K., and T. A. Grant. 2005. Land management history and floristic integrity in mixed-grass prairie, North Dakota. North Dakota Chapter of the Wildlife Society, Mandan, North Dakota.
- Murphy, R. K., and T. A. Grant. 2005. Land management history and floristics in mixed-grass prairie, North Dakota. Invasive Species Workshop, Bismarck, North Dakota.
- Nenneman, M. P., T. A. Grant, E. M. Madden, and I. J. Ball. 2003. Nest-habitat selection by clay-colored sparrow, Savannah sparrow, and blue-winged teal in north central North Dakota. 64th Midwest Fish and Wildlife Conference, Kansas City Missouri.
- Pietz, P. J., T. A. Grant, E. M. Madden, T. L. Shaffer, D. A. Buhl, N. J. Kadrmas, and R. Sweitzer. 2006. Factors affecting predation and parasitism rates of grassland passerine nests in North Dakota. International Ornithological Congress. (Poster)
- Shaffer, T. L., and T. A. Grant. 2004. New opportunities in the analysis on nest survival data. The Wildlife Society 11th Annual Conference, Calgary, Alberta.
- Shaffer, T. L., and T. A. Grant. 2005. Logistic-exposure model for avian nest survival and nest parasitism rates. Cooper Ornithological Society 75th Annual Meeting, Humboldt, California.

INTRODUCTION AND STUDY OBJECTIVES

Northern mixed-grass prairie has declined 70–90% across states and provinces in the northern Great Plains, mainly due to conversion to cropland (Samson et al. 2004, Samson and Knopf 1994). The quality of remaining prairie tracts is increasingly diminished by fragmentation, the spread of woody and introduced plants, suppression or misapplication of fire, and certain livestock grazing practices (Samson and Knopf 1994, Grant and Murphy 2005, Murphy and Grant 2005). Concurrent with this decline is the reduction in breeding populations of most grassland-dependent bird species, especially those endemic to the northern Great Plains (Peterjohn and Sauer 1999).

An average of roughly 10,000 ha of grasslands, mostly native mixed-grass prairie, is prescribe-burned annually on National Wildlife Refuges (NWRs) in the Dakotas and eastern Montana, primarily to maintain or improve habitat for wildlife, attempt to restore native vegetation, and reduce accumulating fuels and the risk of catastrophic wildfire. Although prescribed fire has been used widely in the northern Great Plains for nearly 30 years, supportive published data on its effects specific to plant and wildlife communities in the region are scarce. Most available information on effects of fire on wildlife and wildlife-habitat relationships in northern mixed-grass prairie is anecdotal and unreliable, or is weakly inferred from different grassland ecosystems, especially tallgrass prairie. Consequently, managers can only vaguely predict impacts of prescribed fire as an ecological process that maintains prairies and populations of wildlife native to the northern Great Plains region. Depending on timing, frequency, and intensity, prescribed fire may not necessarily enhance the ecological integrity of native mixed-grass prairie communities and associated wildlife as surmised, and in some cases may be detrimental. Thus, our objectives were to:

- (1) Document effects of fire history on occurrence/abundance of grassland passerines and upland-nesting ducks in examples of northern mixed-grass prairie characteristic of NWRs.
- (2) Assess fire history effects on avian nest survival, including potential influences of fire history on rates of predation and nest parasitism.
- (3) Quantify nest site habitat of nesting passerine birds, and compare to composition and structure of available habitat, accounting for fire history and its potential effects on nest site vegetation.
- (4) Document effects of fire history on small mammal composition and abundance in northern mixed-grass prairie.
- (5) Assess short- and long-term effects of fire and fire suppression on the structure and composition of vegetation in northern mixed-grass prairie, and establish an extensive basis for long-term monitoring.
- (6) Assess influences of primary targets of prescribed fire – woodlands and woodland edges and other major sources of woody fuels – on passerine productivity and nest site selection.

- (7) For land managers, provide basic models and other predictive tools supported by the findings, and synthesize relevant literature.
- (8) Provide information on occurrence and productivity of less common grassland bird species (e.g., upland-nesting shorebirds, ground-nesting raptors) as encountered.

STUDY AREA

We conducted investigations at 4 NWRs (8000-24,000 ha) in north central and northwestern North Dakota (Figure 1): Lostwood NWR, Des Lacs NWR, Upper Souris NWR, and J. Clark Salyer NWR. These NWRs lie within the northern mixed-grass prairie physiographic region (Coupland 1950, 1992) of the northern Great Plains. Lostwood NWR is within the relatively narrow (20- to 30-km wide), rolling to hilly Missouri Coteau physiographic subregion. Des Lacs NWR, Upper Souris NWR, and J. Clark Salyer NWR are within the extensive Drift Plain physiographic subregion, which generally is characterized by flat to slightly rolling topography.

The landscape that includes each NWR was uniquely shaped by glaciation during the end of the Pleistocene Epoch. The Missouri Coteau, which encompasses Lostwood NWR, is dead ice moraine deposited by the Wisconsin glacier over a previously occurring escarpment (Bluemle 1991). Soils are thin, often gravelly loams derived from glacial till. Des Lacs NWR, Upper Souris NWR, and J. Clark Salyer NWR are associated with the Souris River (Figure 1). Des Lacs NWR and, to a lesser degree, Upper Souris NWR, are characterized by steep, high-relief (50 m deep) valleys, while J. Clark Salyer NWR is low relief river valley. Upland soils of Des Lacs NWR, Upper Souris NWR, and the northern half of J. Clark Salyer NWR are mostly well-drained, moderately deep loams formed in glacial till. The southern one-half of J. Clark Salyer NWR is within a flat, deltaic outwash plain, characterized along the south and east sides by sandhills formed from wind and wave action of historic Glacial Lake Souris. Soils in this part of J. Clark Salyer NWR are mainly sand and gravel; water drainage is poor near the Souris River and the water table can be close to the surface in sandy soils, especially during years of above average precipitation.

Native vegetation of the study area is a cool-season (C_3)-dominated, needlegrass-wheatgrass (*Stipa-Agropyron*) association (Coupland 1992, Bragg 1995). Other native plant species characteristic of this association include cool-season graminoids such as Junegrass (*Koeleria pyramidata*; nomenclature follows Great Plains Flora Association 1986) and several bluegrass (*Poa* spp.) and sedge (*Carex* spp.) species; several warm-season (C_4) grass species, mainly blue grama (*Bouteloua gracilis*), sideoats grama (*B. curtipendula*), plains muhly (*Muhlenbergia cuspidata*), prairie dropseed (*Sporobolus heterolepis*), and big bluestem (*Andropogon gerardii*); the low shrubs (to 1.5 m tall), western snowberry (*Symphoricarpos occidentalis*) and silverberry (*Elaeagnus commutata*); and many forb species, mainly Asteraceae and Fabaceae. However, contemporary native prairie on the NWRs, especially the “drift prairie” (i.e., native prairie on the Drift Plain), is extensively invaded by Eurasian grasses, primarily

smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*). Native prairie on the NWRs also is invaded to varying degrees by trees and tall shrubs, especially quaking aspen (*Populus tremuloides*), green ash (*Fraxinus pennsylvanica*), chokecherry (*Prunus virginiana*), hawthorn (*Crateagus spp.*), and willow (*Salix spp.*), all of which are native to the region.

Climate of the study area is continental, with short summers and long, cold winters. Annual precipitation, although highly variable, averages roughly 42 cm (1936-1990 data, from NWR records).

NWRs where we conducted our studies have attributes and management issues similar to those on most other NWRs and on the somewhat similar, but smaller “Waterfowl Production Areas” that are managed by the U. S. Fish and Wildlife Service in the northern Great Plains. Attributes and issues among grasslands managed by other conservation agencies and organizations in the region also tend to be similar. Specifically, these grassland tracts are: 1) chiefly native prairie invaded by cool-season, introduced grasses and forbs, and often by native woody vegetation ; 2) managed mainly by rest, with periodic defoliation by fire, livestock grazing, or hay harvest; 3) usually large enough to contain area-sensitive species of grassland birds (e.g., northern harrier [*Circus cyaneus*], marbled godwit [*Limosa fedoa*]); 4) characterized by scattered or nearby, large seasonal and semi-permanent wetlands; and 5) bordered by annually tilled cropland and, to a lesser extent, by native rangeland, seeded grassland, and seeded hayland.

METHODS

General approach

We used 2 basic approaches to examine fire effects on vegetation and wildlife communities. First, we designed short term (< 10 years) field experiments to test specific hypotheses regarding fire effects on vegetation structure, plant community composition, and wildlife abundance and productivity. Secondly, we assessed long term (60-100 years) changes in plant communities resulting from altered fire disturbance regimes during and after settlement of the northern Great Plains.

Experimental design

At J. Clark Salyer NWR, we conducted 2 field studies. For the first, we designed a field experiment to isolate fire from other effects (e.g., edge and area effects, effects of defoliation by grazing or haying) that might influence the species composition and structure of grassland vegetation, the occurrence and abundance of wildlife, and/or the nest survival of grassland birds. We used a 450-ha study site in the drift prairie portion of the refuge. The site was comprised of 7 contiguous study units, each with unique prescribed fire histories (Figure 2; Table 1). We burned selected study units in August-September, beginning in 1997, to mimic naturally occurring, late summer fires (Table 1). Our main explanatory variable was the number of growing seasons since the last fire had occurred (i.e., “post-fire growing seasons”). We grouped

study unit histories (41 total) into 1, 2, 3, and 4+ post-fire growing seasons for analysis. For example, study unit F was burned in 1998 and 2002 and therefore contributed 2 1-post-fire growing seasons, 1 2-post-fire growing season, 1 3-post-fire growing season, and 2 4-post-fire growing seasons to our sample during 1998–2003 (Table 1).

For the second study at J. Clark Salyer NWR, we examined nest survival for grassland birds breeding in prairies fragmented by expanding aspen woodland. Woodlands have increased because of long-term fire suppression beginning with settlement of the region circa 1900. Specifically, we examine nest survival of grassland birds relative to the distance nests were located from aspen woodland edges and relative to other habitat features near the nest. During 1997, 1998, and 2002, we studied nest survival in 3 grasslands mostly surrounded by aspen woodland; study grasslands were located within the southern 1/2 of J. Clark Salyer NWR.

At Des Lacs NWR, we conducted 2 field experiments. During the first (2001–2003), we assessed relationships between prevalence of woody fuel patches and the survival of grassland bird nests. This study involved 12 study units (4–7 units studied/year) scattered across the drift prairie in the northern one-half of the refuge. Each unit had been prescribed-burned once or twice, but had not experienced fire or other disturbances for at least 1 full growing season before we examined it. In the second study at Des Lacs NWR (2003), we examined relationships between prescribed fire history, grassland bird abundance, and vegetation makeup and structure. We used 16 study units scattered widely in drift prairie in the refuge's northern one-half. Each study unit had been prescribed-burned 1, 2, or 3 times since 1992 (Table 2). Study units we investigated at J. Clark Salyer NWR and at Des Lacs NWR had not been grazed by livestock for at least 2 years prior to our study.

In the first study at Des Lacs NWR (influence of prevalence of woody fuel patches on bird nest survival), our main explanatory variable was the number of 3 x 3-m grids with tall (> 2 m high) woody fuels within a specified radius of a given nest. Calculations were derived by the FOCALSUM function in the GRID module of ARC/INFO.

In the second study at Des Lacs NWR (fire history versus bird abundance and vegetation attributes), data were derived from 1 season but represented 11 years of fire effects on vegetation that composed habitat for grassland birds. Prescribed burns had been conducted during spring (April and May) and late summer through mid-fall (August through October). To summarize fire history on each unit at Des Lacs NWR, we used a “fire index” that incorporated both the number of fires and years since the last fire into a single metric (*sensu* Madden et al. 1999):

$$\text{Fire index} = \text{number of fires/years since last fire}$$

Fire index values of our study units ranged from 0.2 (little fire experience: only 1 fire, 5 years previous) to 3.0 (moderate fire experience: 3 burns, the last only 1 year previous; Table 2). The number of burns since 1992 ranged from 1 to 3. The number of years since the last fire ranged from 1 to 5.

Sampling to assess fire history effects on abundance of grassland birds

We used fixed-radius point counts (Hutto et al. 1986) to survey breeding grassland birds. At J. Clark Salyer NWR, we located 37 100-m radius point count plots on the 7 study units examined (222 total plots 1998–2003). In the study of fire history relationships at Des Lacs NWR, we located 79 75-m radius point count plots on 16 study units. We used a random, systematic design to place point count plots within each unit. The center of each plot was separated by at least 250 m from centers of adjacent point count plots. The boundary of each plot was more than 50 m from cropland and wetland edges. We visited each point count plot twice during 25 May–30 June when conditions did not impede detection of birds (i.e., no precipitation, wind <15 km/hr). We tallied birds by sight and sound during 5-minute visits to point count plots at J. Clark Salyer NWR, and during 8-minute visits to point count plots at Des Lacs NWR. We switched the order of visitation so each plot was surveyed once during an early (0530–0645 hrs CST) period and once during a late (0645–0800) period. In our analyses, “indicated pairs” were derived from detections of singing males or observed pairs, or, in the case of brown-headed cowbirds (*Molothrus ater*), the presence of females. For each species on each point count plot, we considered abundance to be the maximum number of indicated pairs between the 2 visits. For each study unit, abundance of a given species was the mean abundance among point count plots within the unit. Bird species detected at greater than 10% of all point count plots were considered common and were used in our analysis (sensu Madden et al. 1999).

Fire effects on nest survival among grassland bird species

We searched for and monitored nests during roughly 15 April–15 July each year, during 1997–2003 at J. Clark Salyer NWR and during 2001–2003 at Des Lacs NWR. We systematically located nests during 0630–1500 hrs CST by flushing adult birds from their nests, using an outstretched, 25-m weighted rope that was pulled through the grass by 2 people. We also located nests incidental to other investigative activities and by observing behavioral cues of parents (e.g., carrying food). We marked nests by placing survey flags 3 m to the north and south of each nest, with the top of the flag just above the average height of the vegetation. To estimate nest age, we candled 1–2 eggs in each nest (Lokemoen and Koford 1996) or estimated nestling ages from voucher photographs of known-age young. We monitored each nest every 2–5 days until the nest either fledged young or failed. A nest was classified as surviving the interval between visits if at least 1 egg or nestling was alive on the latter visit or if at least 1 young fledged on or before the final visit. Within 1–3 days of predicted fledging, we visited the nest every day to minimize uncertainty in assigning the final nest fate. After finding the nest, visits rarely lasted more than 5 seconds and most nests were viewed from 1–3 m away. We used parental behavior (e.g., alarm calling, carrying food), presence of young near the nest, nestling age at the previous visit, evidence of nest disturbance, evidence of nestling mortality, and presence of feces and feather scales at the nest to classify nests as successful or failed. Nest success was defined as the probability that a nest survived to fledge ≥ 1 young, and was computed as the product of estimated daily survival rates for each day in the nesting cycle. We used the logistic-exposure method (Shaffer 2004) to estimate nest survival. Logistic-exposure models are similar to logistic regression models in that the daily survival rate for any nest on a given day is modeled as a

logistic function of the values of explanatory variables for the nest on that day. We used the GENMOD procedure of SAS to estimate the regression coefficients in our logistic-exposure models (Shaffer 2004). We then estimated daily survival rates from the resulting logistic function (see Shaffer 2004 for details). Each interval between visits to a nest was treated as 1 observation in the analysis. The response variable was whether the nest survived the interval.

Modeling fire and other effects on avian abundance and nest survival

Using an information-theoretic approach (Burnham and Anderson 2002), we developed plausible *a priori* models with and without fire effects included (i.e., the number of post-fire growing seasons) to determine whether fire altered bird abundances, nest densities, or nest survival rates at J. Clark Salyer NWR. We evaluated our candidate models with Akaike's Information Criterion for small sample sizes (AIC_c; Burnham and Anderson 2002). Where appropriate, we used model-averaging to avoid potential effects of model-selection uncertainty (Burnham and Anderson 2002). Where fire effects were important, we plotted avian nest survival as a function of post-fire growing seasons while holding other habitat variables at their median values. In some cases, we also use linear regression and ANOVA to test *a priori* hypotheses regarding fire effects on birds or vegetation attributes. We used the same approach at Des Lacs NWR to develop candidate models, with and without fire effects included, to examine relationships between the prevalence of tall woody fuels and bird nest survival.

In our study of fire history relationships at Des Lacs NWR, we used simple linear regression to examine relationships between the fire index and bird species abundance, or vegetation composition or structure. We also used regression to evaluate relationships between bird species abundances and vegetation variables that were significant ($P < 0.1$) in the initial regression analysis.

Avian nest site selection and fire

We studied selection of nest site habitat by Savannah sparrow (*Passerculus sandwichensis*), clay-colored sparrow (*Spizella pallida*), and blue-winged teal (*Anas discors*) at J. Clark Salyer NWR. Nests were located and monitored according to the protocol described previously. Our general approach was to measure and compare nest site vegetation structure and composition at 3 spatial scales: nest site plot (around the nest bowl), nest patch plot (within 30 m of the nest), and field plot (i.e., the study unit in which the nest occurred). A nest site plot was centered on the nest. A nest patch plot was located by pacing a random distance (between 5 and 30 m) and direction from the nest; 3 nest patch plots were measured for each nest to reduce variability introduced by measuring atypical nest patch plots. Fifteen field plots were selected from the study unit by locating randomly generated UTM coordinates with a GPS unit. Nest site, nest patch, and field plots were 5-m radius circles either centered on the nest or on the center of the random plot. Vegetation measurements followed a modification of BBIRD (Martin et al. 1997). We also compared bird use of habitats within 1, 2, or 3+ post-fire growing seasons. To

prevent excessive disturbance at active nests, we measured vegetation at nest sites soon after (i.e., within 7 days) young had fledged, or after the estimated date of fledging for failed nests.

We used split-plot analysis of variance (ANOVA) to examine habitat selection by birds at J. Clark Salyer NWR. In the ANOVA model, burn unit by year combinations were used as blocks, and within these blocks nest plots, nest patch plots, and field plots were used as the plot level factor. Blocks were nested within post-fire growing season (i.e., 1, 2, or 3+ seasons) to investigate effects of burning on nest site selection. This model allowed us to control for variation associated with year and study unit while determining factors that affected use of nest sites, the local spatial scale at which they operate, and effects of fire on nest site vegetation.

Fire effects on relative abundance of small mammals

Small mammals were captured within prescribed fire study units previously described for J. Clark Salyer NWR. The primary effects variable in this study was the number of post-fire growing seasons. Trapping was conducted in 1998-2000 and in 2002. Within each fire treatment unit, we used a combination of a 30-m trap grid and a single, 30-m “drift fence array” to capture small mammals and other terrestrial vertebrates. Each trap grid included 21 museum special snap traps and 9 double-spring Victor rat traps arranged systematically. Drift fence arrays consisted of partly buried, 30-m long, 0.6-m tall aluminum valley with a 0.3 x 0.3 x 0.8-m long, 0.6-cm mesh funnel trap in the center and a total of 8 20-l pitfall traps with funnel rims (Vogt and Hine 1982). Pitfalls were paired on either side of the fence, at both fence ends and midway between fence ends and the central funnel trap. Trap grids and fences were sampled for 10 consecutive nights in June and again in July. Drift fence arrays and trap grids were checked for captures in early to mid-morning. Because small mammal populations had not been sampled in our region, all captures were euthanized and transferred to museum collections at the University of North Dakota and the Nebraska State Museum for further study. All specimens were identified to species by using standard keys. Sex, age, weight, and standard linear measurements were recorded for each specimen.

Short-term fire effects on vegetation

Short-term changes in vegetation structure and composition that could be attributed to fire were assessed in conjunction with our study of fire effects on breeding bird abundance. Each year we measured vegetation structure and composition at J. Clark Salyer NWR during late spring and early summer, 1998-2003, using point count plots as focal areas for sampling. Following Grant et al. (2004), we established 2 parallel 70-m transects along a random compass bearing (1 transect on each side of the plot center), with subsample points placed at 10-m intervals along each transect ($n = 16$ /point count plot). We measured litter depth (i.e., the height of any horizontal, dead vegetation that formed a mat extending continuously from the ground; Madden et al. 1999), vegetation density, vegetation height, and the ratio of dead:live vegetation at each subsample point. Within each point count plot we also used 4 100-m belt transects to measure plant community composition, based on dominant plant group categories (Grant et al.

2004). Last, we used GIS to delineate the distance from point count plot center to nearest woodland, cropland, and wetland edges, using 1:7920 digitized aerial photographs.

At Des Lacs NWR, we also measured vegetation structure and composition in conjunction with our study of fire history-bird abundance relationships. We measured vegetation on each point count plot during late spring and early summer. Eight measures of vegetation height-density (visual obstruction readings; Robel et al. 1970) were collected along each of 2 randomly located, 50-m transects within each point count plot ($n = 16$ measures/plot); the mean of these was computed for the point count plot. Along these transects we also recorded litter depth at 12.5-m intervals ($n = 10$ measures/point count plot), and used belt transects to measure vegetation composition (Grant et al. 2004).

Long-term fire effects on vegetation

We conducted 2 separate studies to assess long-term changes in the general composition and structure of northern mixed-grass prairies, potentially resulting from an altered fire regime and modifications in other disturbances during and after settlement of the region by Europeans.

Changes in woodland cover on prairie refuges in North Dakota – We estimated the historical occurrence of woodland across our study area from many sources and partitioned our analysis into the following eras: presettlement (1730s to circa 1880), settlement-to-refuge establishment (circa 1880 to mid-1930s), and refuge era (mid-1930s to present). We compiled presettlement histories primarily from published journals and expedition narratives of early naturalists, explorers, and military personnel. We reconstructed settlement-to-refuge establishment histories from Government Land Office Survey records on landscape features from the 1880-1890s, U.S. Biological Survey notes, landscape photographs, narratives from early naturalists, and interviews of local residents. Our assessment of refuge era changes was more quantitative. We measured the number and extent (ha) of woodland patches on refuge era black and white aerial photographs (1:7920 and 1:15,840) and quantified the total change in percent woodland for each refuge from 1938 through 1985-1997. We quantified rates of change among consecutive, 10- to 15-year intervals using aerial photographs from 1938, 1953, 1969, 1979, 1985, 1991, or 1997, depending on availability for each NWR. We also sought to compare and contrast rates of change among woodland types that increased or decreased during this 50- to 60-year period, and also to comprehend possible effects associated with local edaphic factors or influences of refuge management practices.

Land management history and floristics in mixed-grass prairie – During 1998-2002, we measured the general floristic makeup of northern mixed-grass prairie on 4300 ha of drift prairie at Des Lacs NWR and J. Clark Salyer NWR. These prairies had been managed mainly by rest and periodic light, season-long grazing since the refuges were established in the mid-1930s. Tracts totaling roughly two-thirds of the drift prairie on each NWR were prescribe-burned (spring or late summer), usually just once, during the early 1970s through early 1990s. For comparative purposes we also measured about 1200 ha of privately owned drift prairies within 2 km of each NWR. These prairies had not been burned since at least the mid-1900s, and instead

had been annually grazed, season long, at moderate to heavy stocking rates. During late summer we used 25-m belt transects to record frequencies of plant species or species groups (Grant et al. 2004). We distributed 1 transect/5-8 ha of drift prairie, except on the grazed prairie near Des Lacs NWR, where we sampled half as intensively because the vegetation makeup within varied less than that on drift prairie elsewhere in our study area. Transects were distributed randomly, and each was oriented along a random compass bearing. Transect data were summarized by percentage frequency of occurrence according to plant species group, life form, or invasion class (i.e., mostly [$>50\%$ canopy cover] or somewhat [$5-50\%$ canopy cover] invaded by introduced plant species, or devoid of introduced plant species). The data were averaged for the drift prairie of each NWR and for privately owned drift prairie adjacent to each NWR. We simply used 95% confidence intervals to discern significant differences between these means.

RESULTS

Fire effects on abundance of grassland birds

We determined short term effects of defoliation by prescribed fire on species richness and abundance of breeding grassland birds at J. Clark Salyer NWR during 1998-2003, and relationships between prescribed fire history and abundance of birds at Des Lacs NWR during 2003. At J. Clark Salyer NWR, fire altered the structure of vegetation within study units, especially litter, maximum vegetation height, and the ratio of dead:live vegetation (see following sections), which, in turn, influenced bird species richness and abundance. Species richness and total pairs of all bird species combined declined during the first post-fire growing season; abundance for some species may also have declined 4+ post-fire growing seasons (Figure 3). Of 8 species for which we had sufficient samples, abundances of 6 were affected by the temporal proximity of the most recent fire. Abundances of sedge wren (*Cistothorus platenis*), clay-colored sparrow, Le Conte's sparrow (*Ammodramus leconteii*), Savannah sparrow, bobolink (*Dolichonyx oryzivorus*), and western meadowlark (*Sturnella neglecta*) decreased during the first post-fire growing season but generally recovered to pre-burn levels within 2–3 post-fire growing seasons (Figure 4).

At Des Lacs NWR, 6 passerine species were sufficiently common to support our analysis of relationships between bird abundance and a fire index that reflected interaction between numbers of prescribed fires conducted in the previous 10 years and time since the most recent fire. Three endemic, historically common passerine species – Baird's sparrow (*Ammodramus bairdii*), chestnut-collared longspur (*Calcarius ornatus*) and Sprague's pipit (*Anthus spragueii*) – were rare or absent regardless of fire history of study units. Abundances of common bird species were not strongly influenced by the index (Figure 5), which contrasts published findings from the nearby Missouri Coteau physiographic subregion (Madden et al. 1999). (*Note: this work currently is in press in the Prairie Naturalist: Ludwick and Murphy 2006 in Deliverables*)

Fire effects on nest densities of grassland birds

Fire-associated changes in vegetation structure at J. Clark Salyer NWR (1998-2003) influenced nest densities of grassland birds. For most species, nest density declined during the first post-fire growing season, especially for clay-colored sparrow, Savannah sparrow, mallard (*Anas platyrhynchos*), and gadwall (*Anas strepera*; Figure 6). Bobolink nest densities were highest during the first 2 post-fire growing seasons. Nest densities of blue-winged teal, northern pintail (*Anas acuta*) and northern shoveler (*Anas clypeata*) were unaffected by fire, although their patterns of post-fire response were similar to that of gadwall and mallard. Like bird relative abundance (previous section), nest densities recovered to preburn levels within 2-3 post-fire growing seasons (Figure 6).

Effects of fire and distribution of tall woody fuels on the survival of grassland bird nests

Prescribed fire had little effect on nest survival for most grassland bird species at J. Clark Salyer NWR. Among passerine birds, fire reduced Savannah sparrow nest survival, a decrease that mainly was the result of increased nest parasitism by brown-headed cowbirds during the first post-fire growing season (Figure 7). In contrast, mallard and gadwall nest survival was highest during the first post-fire growing season (Figure 8).

In 1997-98 and 2002, we examined nest survival of clay-colored sparrows and vesper sparrows (*Pooecetes gramineus*) relative to the distance nests were located from aspen woodland edges and relative to other habitat features near the nest. Contrary to what other studies have reported, we found that clay-colored and vesper sparrow nest survival was higher for nests located near woodland edges than for nests located far from edges. In addition, vesper sparrow nest survival increased as the percent cover of tall shrubs near the nest increased (*Note: this work currently is in press in the Journal of Wildlife Management: Grant et al. 2006 in Deliverables*)

At Des Lacs NWR, we had sufficient data to examine influences on nest survival for 2 species, clay-colored sparrow and Savannah sparrow. We detected no relationships between nest survival and prevalence of woody vegetation at nest site and nest patch scales. At the landscape scale, however, survival of clay-colored sparrow nests decreased as the number of tall woody patches within 100 m increased. Survival of Savannah sparrow nests was uninfluenced by numbers of tall woody patches in the landscape, however (Figure 9).

Influence of fire on avian nest site selection

At J. Clark Salyer NWR, we sought to determine how fire proximately affects the composition and structure of grassland vegetation and, ultimately, how fire shapes nest site selection by grassland birds. Fire altered the structure of grassland vegetation, and these changes affected selection of nest sites by grassland birds. Clay-colored sparrows nested in patches that

were taller and denser than those generally available within nesting fields. Most grassland bird species require some dead plant material in which to construct nests. However, fire consumes most residual vegetation within study units, temporarily reducing the density of grassland bird nests, especially during the first post-fire growing season. Despite reductions in plant litter, “skips” (i.e., unburned patches) remained after a fire and these skips typically were sites where ducks and songbirds placed their nests. For example, litter depth at clay-colored sparrow and Savannah sparrow nests was similar among units with 1-, 2-, or 3-post-fire growing seasons, even though litter within these units nearly was eliminated, on average, during the first post-fire growing season (Figure 10). (*Note: this work currently is in thesis format: Nenneman 2003 in Deliverables*)

Fire effects on small mammals

Population levels of small mammal species were highly variable among years 1998-2000 and 2002 at J. Clark Salyer NWR, making it difficult to assess fire effects on relative abundances of these species. Dramatic fluctuations were most evident among voles (*Microtus* spp.), shrews (*Sorex* spp.), and jumping mice (*Zapus* spp.). In particular, the relative abundance of meadow voles (*M. pennsylvanicus*) fluctuated 12-fold over the 4 years. Regardless, we detected fire-associated changes in the relative abundance of several species. Deer mice (*Peromyscus maniculatus*) were 5-6 times more abundant during the first post-fire growing season, when plant litter was mostly absent (Figure 11). In contrast, voles, shrews, and ground squirrels (*Spermophilus* spp.) were less common during the first post-fire growing season than during 2-5 growing seasons after fire, when residual vegetation was more abundant.

Short-term fire effects on vegetation structure and composition

Annual precipitation and unit fire histories affected vegetation structure and, to a lesser extent, plant community composition at J. Clark Salyer NWR, 1998–2003. Fire had little overall effect on the composition of plant communities within study units during 1998–2003, except fire decreased Kentucky bluegrass cover during the first and second post-fire growing seasons (Figure 12). Conversely, cover of native grasses and forbs declined as units were rested (i.e., no disturbance) for 4+ post-fire growing seasons (Figure 12). Fire strongly influenced vegetation structure, especially the amount of residual vegetation within study units. Maximum vegetation height, litter depth, and the ratio of dead:live vegetation decreased for the first post-fire growing season (Figure 12). Significant fuels in the form of plant litter accumulated during each subsequent post-fire growing season. The ratio of dead:live vegetation and maximum vegetation height generally recovered to pre-burn levels by the second post-fire growing season (Figure 12).

At Des Lacs NWR, vegetation composed exclusively of native graminoids or of a mix of native graminoids and forbs occurred rarely, regardless of fire history. The frequency of smooth brome decreased with increasing applications of fire (Figure 13). Native-dominated, herbaceous vegetation may have increased as smooth brome-dominated vegetation declined with increasing fire experience, but the trend was not significant. Litter depth and vegetation height-

density decreased with increasing fire experience (Figure 13). There was little variation in vegetation structure, however, especially in plant height-density, among units that experienced the most fire. We detected no relationships between bird species abundances and vegetation composition and structure, perhaps because smooth brome continued to be a pervasive structural influence on all study units regardless of fire history.). (*Note: this work currently is in press in the Prairie Naturalist: Ludwick and Murphy 2006 in Deliverables*)

Long-term fire effects on vegetation communities

We found that significant changes occurred in the extent of woodland cover across our study area during the 1800s and 1900s. Woodlands were rare when the region was settled by Europeans in the early 1900s, except green ash-American elm (*Ulmus americana*) woodland occurred within the floodplain of the Souris River, and stunted copses of quaking aspen-bur oak (*Quercus macrocarpa*) occurred along fire-protected scarps of sandhills prairie in north central North Dakota. Ash-elm woodland expanded in valleys of the Des Lacs and Souris rivers especially along adjoining, intermittent tributaries (coulees), mainly during the early- to mid-1900s (Figure 14). Aspen woodland expanded in sandhills of the Souris Lake Plain and in the Missouri Coteau during mainly the mid- to late-1900s, changing much of the mixed-grass prairie to aspen parkland (Figure 14). With settlement by people of European descent, large herbivores were extirpated from the region and natural and anthropogenic fires were suppressed. These changes are implicated in expansion of woodland into native prairies. (*Note: this work recently was published in Natural Areas Journal: Grant and Murphy 2005, in Deliverables*)

We sampled general floristic makeup on 4300 ha of drift prairie at Des Lacs NWR and J. Clark Salyer NWR during 1998–2002. These prairies had been managed mainly by rest since the 1930s. We also sampled about 1200 ha of nearby, annually grazed drift prairie for comparative purposes. Vegetation dominated by low native shrub was common on both NWR prairies and on grazed prairies near Des Lacs NWR, occurring roughly in a 1:3 ratio with herbaceous-dominated vegetation, versus < 1:5 historically. Nearly all prairies were moderately to severely invaded by introduced plant species, mainly smooth brome and Kentucky bluegrass on NWRs, and Kentucky bluegrass, almost exclusively, on adjacent grazed prairies (Figure 15). Smooth brome-dominated types were twice as prevalent as Kentucky bluegrass-dominated types on NWRs, indicating that with little or no fire and grazing disturbance, smooth brome may be more competitive than Kentucky bluegrass, at least in northern mixed-grass prairies of the Drift Plain. Plant assemblages composed of native species were encountered rarely, except they occurred fairly often on grazed drift prairie next to J. Clark Salyer NWR. (*Note: this work recently was published in Natural Areas Journal: Murphy and Grant 2005, in Deliverables*)

LESSONS LEARNED

Fire is an ecological process that is fundamental to the evolution and maintenance of northern grasslands. Our data suggest that in northern mixed-grass prairie:

- Most species of breeding grassland birds are adapted to fire that occurs frequently (i.e., every 4-6 years). Although their abundance and nest density decrease the first breeding season after a late summer burn, many birds still find nest sites in unburned patches. Bird abundance and nest density return to pre-burn levels in following years.
- Fire appears to have little impact on nest survival among grassland bird species, including the first year after burning.
- Relative abundances of most small mammal species return to pre-burn levels incrementally during the second to fifth years after burning, while that of the deer mouse decreases.
- Vegetation physiognomy (structure) changes markedly during the first 3 years after burning, or through the interaction between years since fire and the number of burn treatments applied. Plant litter, the significant source of fuel in grasslands, accumulates incrementally each year after fire treatment.
- Plant species composition generally is unchanged by prescribed burning during relatively short periods (< 10 years), at least in areas characterized by relatively rich, loamy soil and dominated by the introduced grasses, smooth brome and Kentucky bluegrass, such as the Drift Plain areas in our study.
- Smooth brome is the most dominant herbaceous plant species in Drift Plain prairie that is characterized mainly by long-term rest. Kentucky bluegrass is the most dominant herbaceous plant species in Drift Plain prairie that is characterized by long-term grazing by livestock and no fire.
- In the absence of recurrent fire following settlement (early 1990s), the extent of green ash-American elm woodland increased markedly in river valleys mainly during the early to mid-1900s, and quaking aspen increased in sandhills and along terminal moraines mainly during the mid- to late 1900s, changing much of the remnant prairies to parkland in the Drift Plain and adjoining subregions of the northern mixed-grass prairie.
- Decreased productivity in at least some grassland bird species is strongly associated with increases in woodland edge and in the prevalence of woody patches in northern mixed-grass prairie landscapes. Conversely, productivity of 2 shrub-associated grassland bird species increases with proximity to woodland edge.

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TABLES

Table 1. Number of post-fire growing seasons for 7 study units at J. Clark Salyer NWR, North Dakota, during 1998-2003. Shaded cells indicate occurrences of late summer (August-September) prescribed fire treatments.

Burn unit	Area (ha)	Year					
		1998	1999	2000	2001	2002	2003
A	69	8	9	1	2	3	4
C	43	1	2	3	4	1	2
D	69	5	6	1	2	3	1
F	69	5	1	2	3	4	1
G	49	12	1	2	3 ^a	2	3
H	47	1	2	3	4	1	2
I	41	2	3	4	5	1	2

Table 2. Fire history and physical characteristics of study units sampled for passerine birds and vegetation on Drift Plain prairie at Des Lacs NWR, northwestern North Dakota, 2003.

Unit	Size (ha)	No. point count plots	Prescribed fire history		
			No. burns ^a	YSF ^b	Fire index ^c
2	49	3	1	5	0.20
37	68	4	1	4	0.25
40	65	3	2	5	0.40
8	125	6	1	2	0.50
5	36	3	2	4	0.50
38S	75	4	3	4	0.75
7	125	7	1	1	1.00
36	109	8	2	2	1.00
3	85	7	2	2	1.00
10	150	6	3	2	1.50
38N	75	5	3	2	1.50
39	74	4	3	2	1.50
41	64	3	2	1	2.00
31	84	4	2	1	2.00
6	124	8	3	1	3.00
35	65	4	3	1	3.00

^a No. prescribed fires conducted, spring 1992 through spring 2002.

^b YSF = no. years since the last prescribed fire was conducted.

^c Fire index = no. fires/no. years since last fire (Madden et al. 1999).

FIGURES

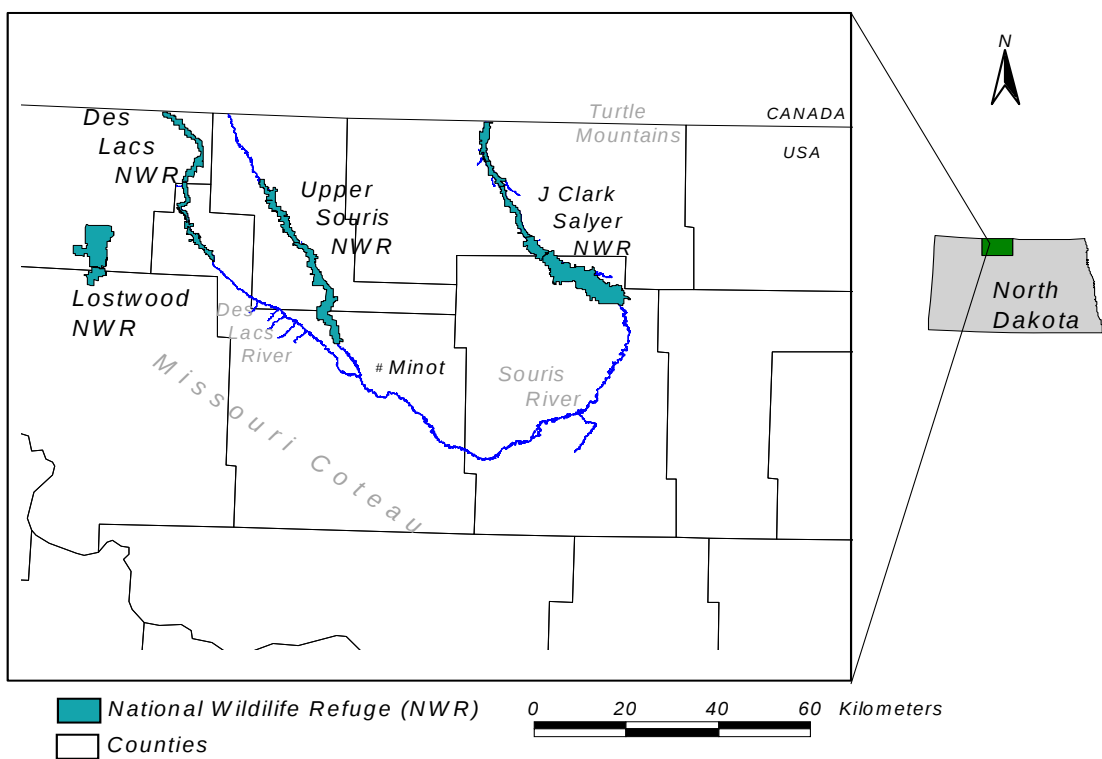


Figure 1. Location of 4 National Wildlife Refuges used for fire effects studies during 1998-2003 in North Dakota.

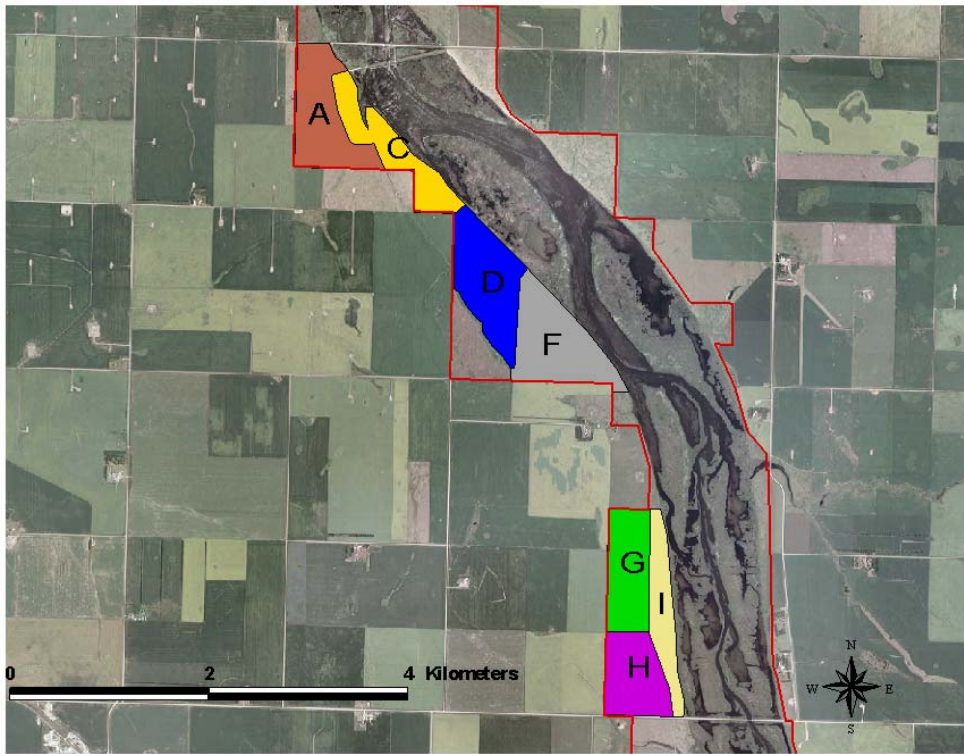


Figure 2. Example of a fire effects study site, this the 450-ha site at J. Clark Salyer NWR. Within the NWR boundary (shown in red) is drift prairie composed of native grasses and forbs intermingled with non-native grasses and forbs, especially Kentucky bluegrass and smooth brome. Seven study units (A-I) are each 41-69 ha and have unique burn histories (see Table 1). The study area is bordered to the east by semipermanent wetlands associated with the Souris River and to the west by agricultural lands used mostly for small grain and oil seed farming. The study site in the drift prairie at Des Lacs NWR was similar with regard to adjacent land use, but study units within generally were scattered.

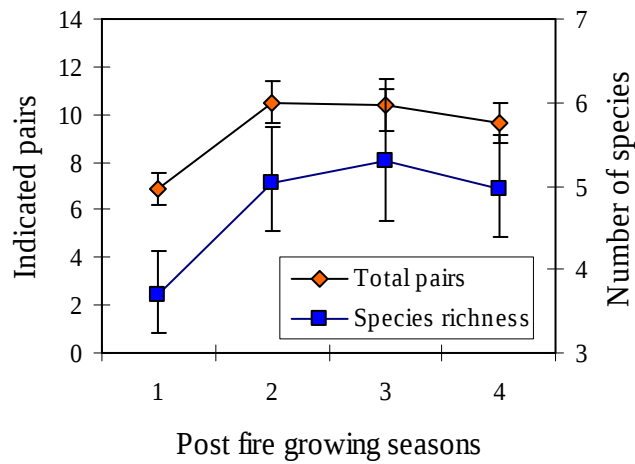


Figure 3. Species richness and total number of indicated pairs (error bars represent 95% confidence intervals) of all grassland bird species combined relative to the number of post-fire growing seasons on J. Clark Salyer NWR, North Dakota, 1998-2003. Bird pairs and species richness are reduced during the first growing season after fire, but recover to preburn levels within 2-3 growing seasons.

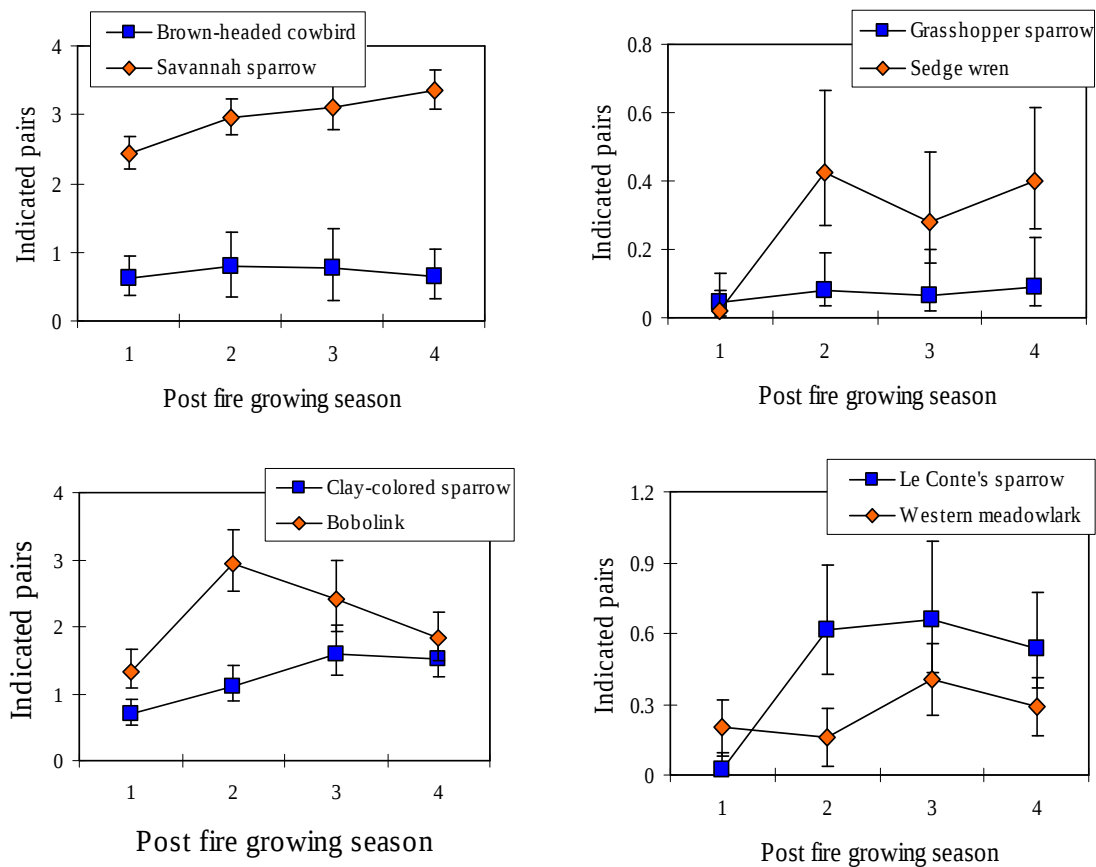


Figure 4. Relationship between relative abundance (indicated pairs) of 8 common grassland bird species and the number of post-fire growing seasons on J. Clark Salyer NWR, North Dakota, 1998-2003. Error bars represent 95% confidence intervals. Relative abundances of Savannah sparrow, clay-colored sparrow, bobolink, sedge wren, Le Conte's sparrow, and western meadowlark were reduced during the first post-fire growing season. Brown-headed cowbird and grasshopper sparrow were not affected by fire history. Most species recovered to pre-burn abundance levels by 2-3 post-fire growing seasons. The relative abundances of bobolink, and Le Conte's sparrow declined after 3 post-fire growing seasons.

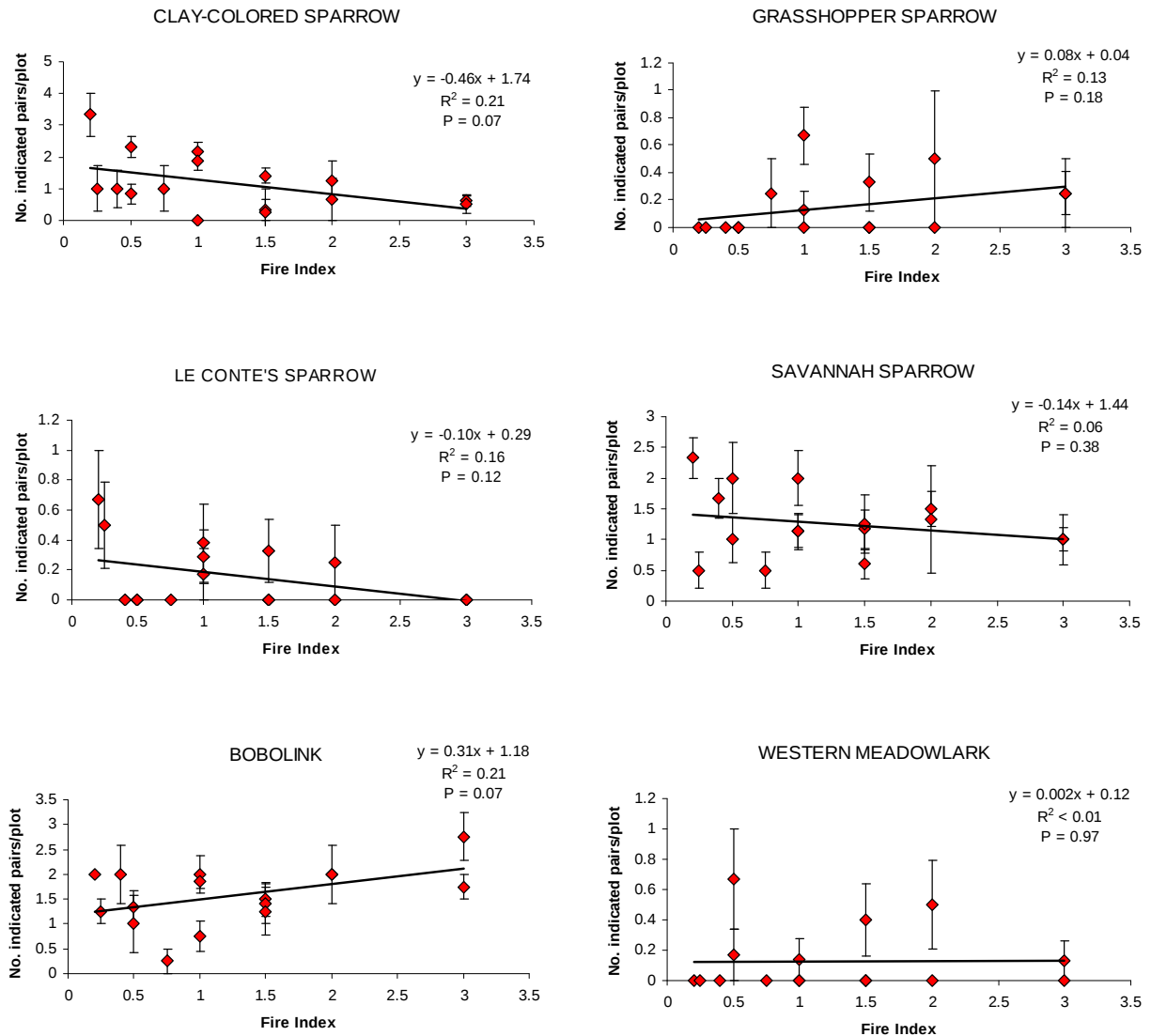


Figure 5. Relationships between prescribed fire history and abundances of common grassland bird species in Drift Plain prairie at Des Lacs National Wildlife Refuge, North Dakota, 2003, based on linear regression ($n = 16$ management units sampled). Fire history for a given study unit is expressed as an index based on the number of fires/years since last fire (Madden et al. 1999). Bird abundance is the mean number of indicated pairs per 75-m radius point count plot, as determined by 8-min counts (Hutto et al. 1986). Vertical bars represent standard errors around the mean for each study unit. There was no evidence of strong relationships between abundance and fire history among common species. However, bobolink and clay-colored sparrow abundances related weakly to fire (bobolink positively, clay-colored sparrow negatively).

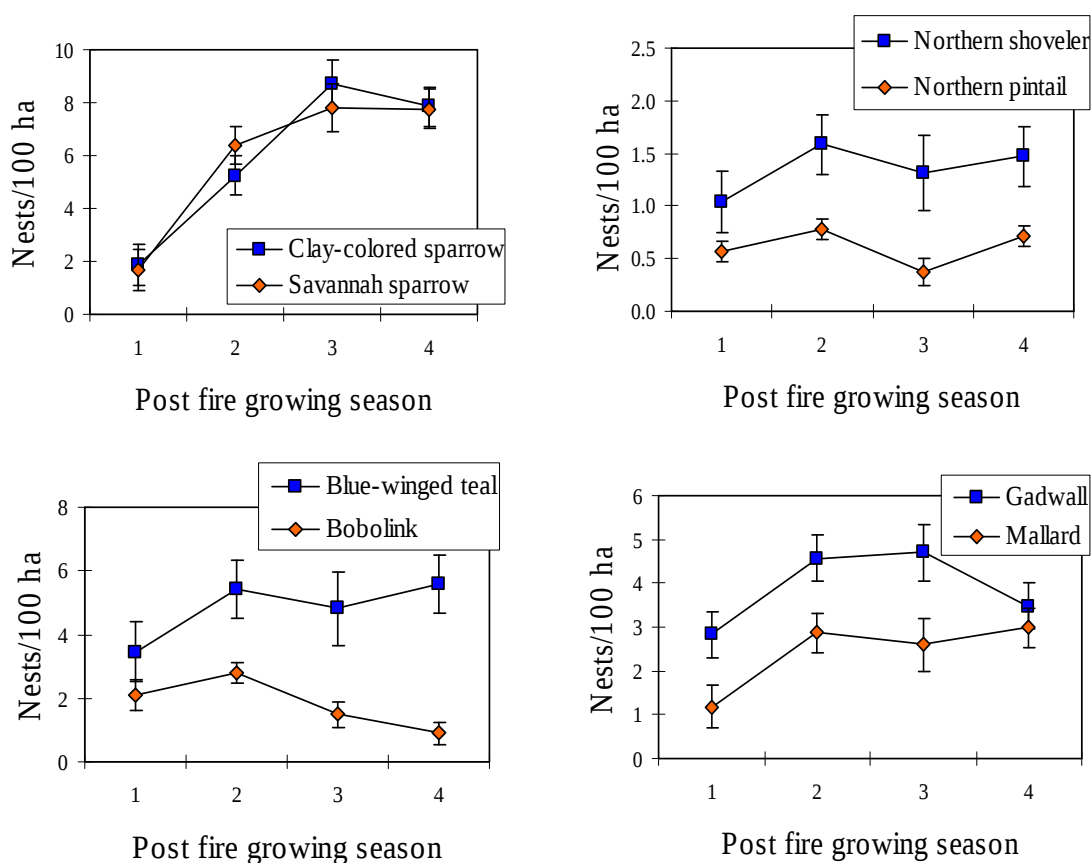


Figure 6. Nest densities for 3 passerine and 5 duck species relative to the number of post-fire growing seasons on J. Clark Salyer NWR, North Dakota, 1998-2003. Nest densities of all species were reduced during the first post-fire growing season but generally recovered to pre-burn levels 2-3 growing seasons after fire. Bobolink nest densities were highest during the second post-fire growing season and declined with each subsequent growing season.

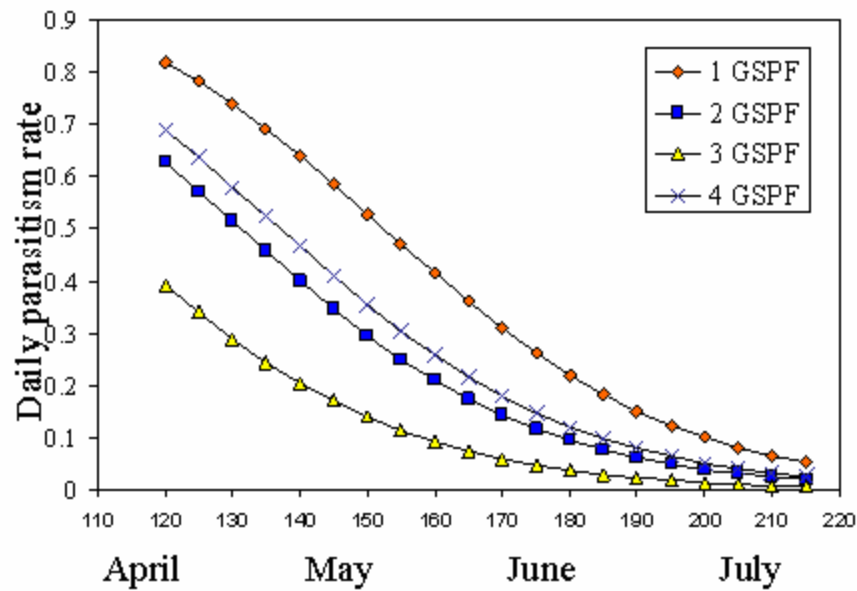


Figure 7. Daily parasitism rate for Savannah sparrow nests relative to the date of the nesting season and number of post-fire growing seasons on J. Clark Salyer NWR, North Dakota, 1998-2003. Savannah sparrow nest survival declined late in the nesting season and was lowest in the first post-fire growing season. Lower nest survival was caused by an increase in parasitism by brown-headed cowbirds during the first post-fire growing season.

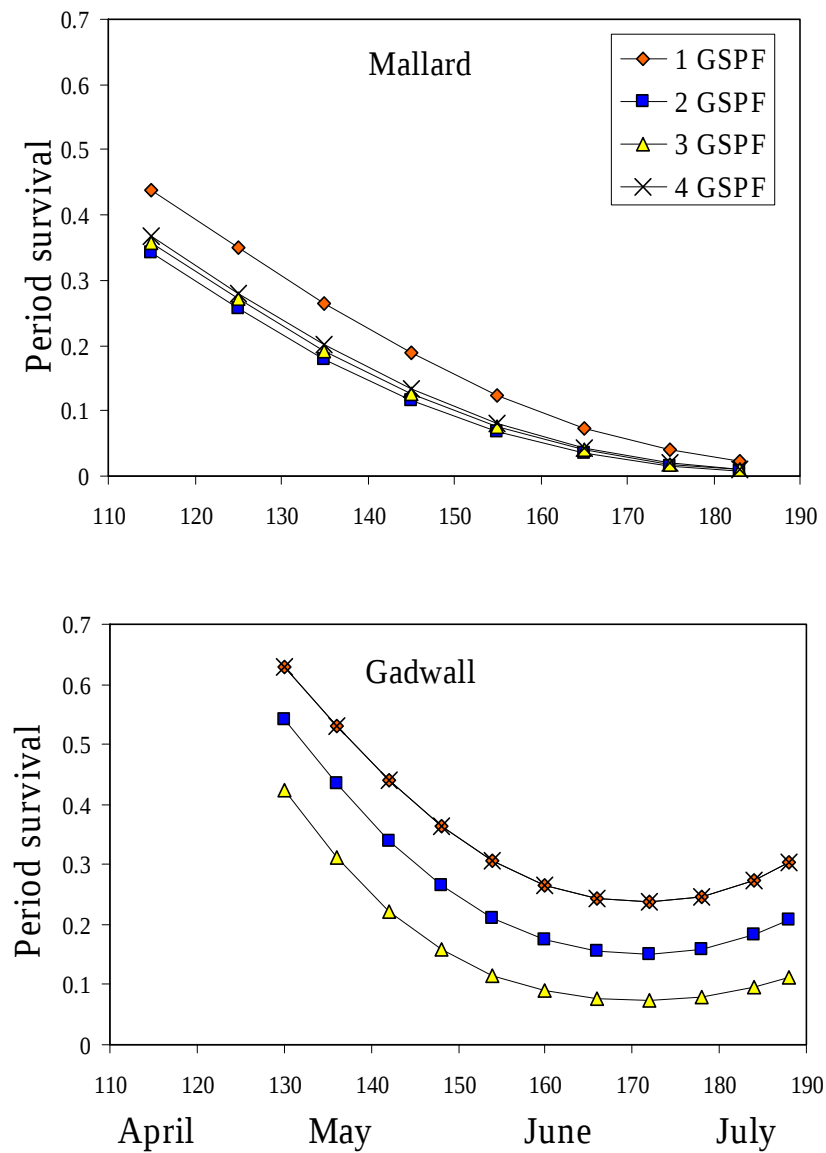


Figure 8. Period survival of mallard and gadwall nests relative to date of the nesting season and number of post fire growing seasons on J. Clark Salyer NWR, North Dakota, 1998-2003. Mallard nests survival decreased late in the nesting season and was highest for nests located in recently burned study units. Gadwall survival was higher for nests initiated early in the nesting and for nests located in units 1 and 4+ growing seasons after fire.

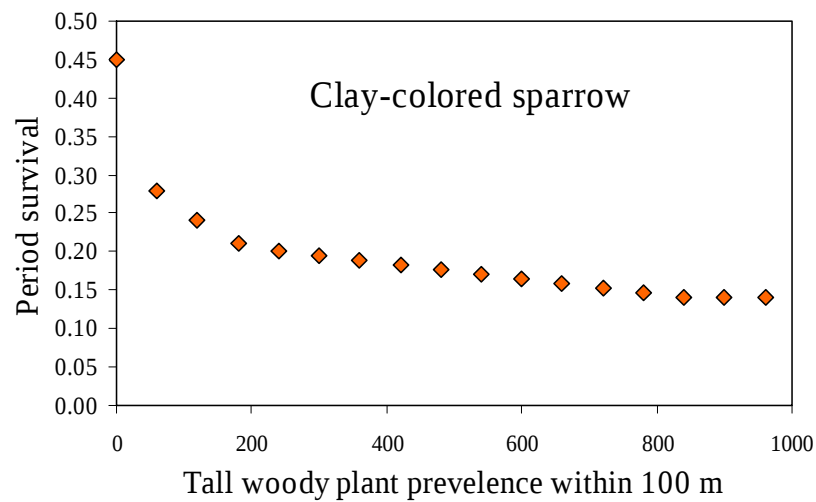


Figure 9. Period survival of clay-colored sparrow nests relative to the prevalence of patches of tall woody fuels invading the drift prairie landscape at Des Lacs NWR, North Dakota. Woody patch prevalence is based on the number of 3 x 3-m grid squares within 100 m of the nest, which contained tall shrubs or trees. Nest survival decreased as the number of patches of tall shrubs and trees increased. Nest data were collected during 2001-2003.

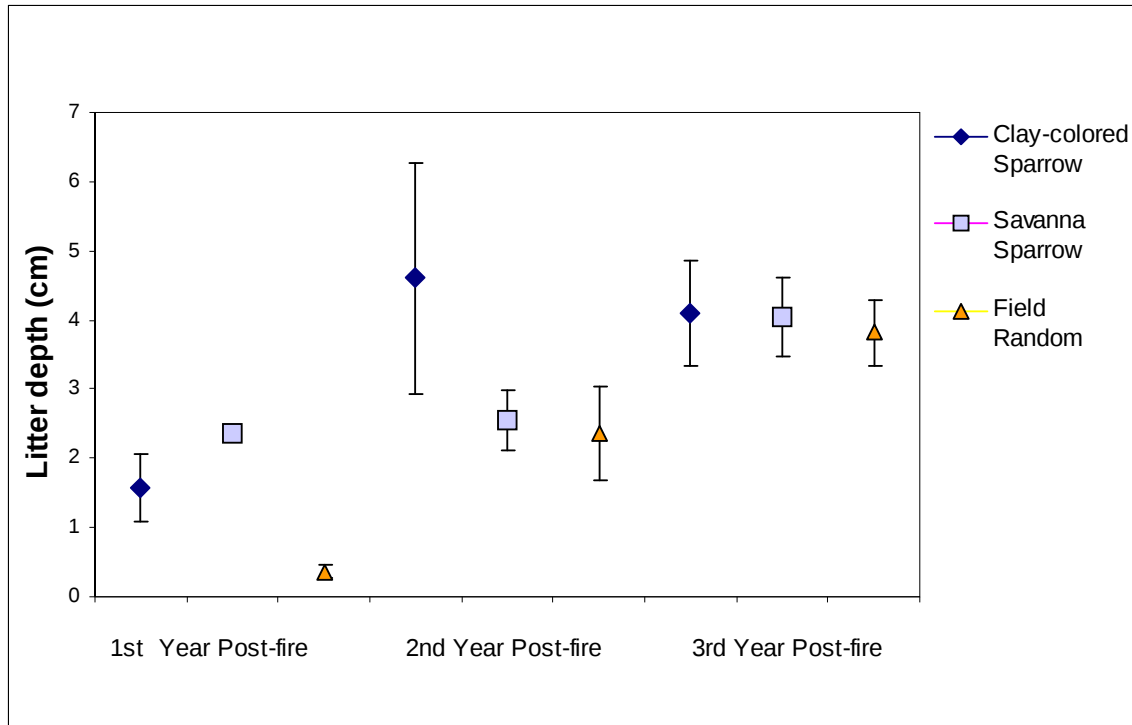


Figure 10. Mean litter depth (cm) within 1, 2, and 3+ post-fire study units for clay-colored sparrow, Savannah sparrow, and random field plots at J. Clark Salyer NWR 1999-2000. Litter increased during each growing season post-fire, and both clay-colored and Savannah sparrows selected nest site with higher litter levels than available in random field plots, except during the 3rd post-fire growing season. Although litter is mostly eliminated following a fire, both sparrow species found micro sites of unburned residual vegetation within which to build their nests.

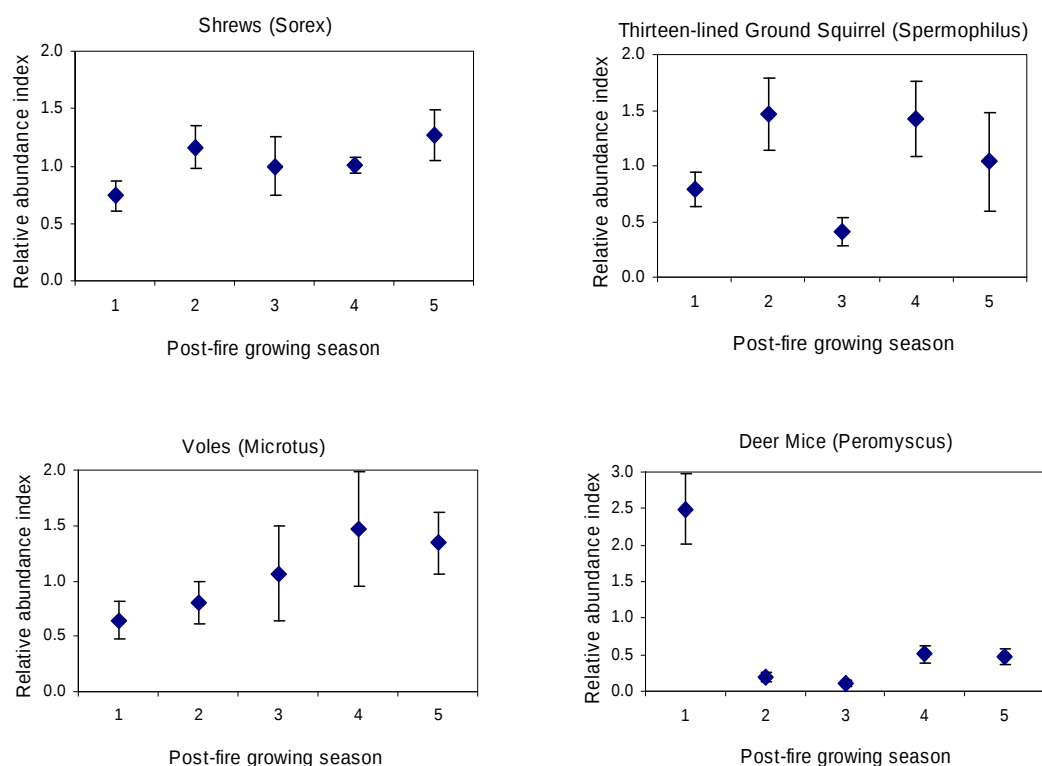


Figure 11. Relationships between prescribed fire history and abundances of common grassland small mammal groups on J. Clark Slayer NWR, 1998-2000, and 2002. The relative abundance index (error bars are SE of the mean) was calculated by dividing total captures for each unit by the average number of captures/year for each species; this corrects for high variability in captures among years for some species. Note that deer mouse relative abundance was highest during the first growing season following fire. In contrast, shrew and vole relative abundance was low in the first post-fire growing season and increased during subsequent growing seasons.

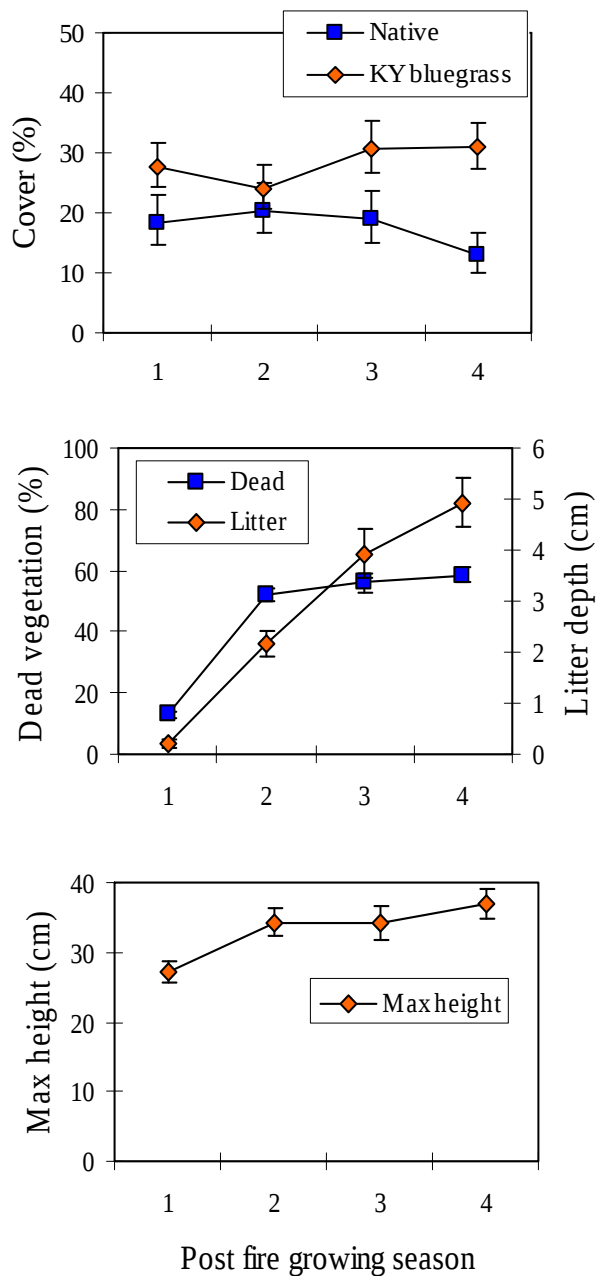


Figure 12. Short-term response of vegetation structure and composition to prescribed fire on J. Clark Salyer NWR, North Dakota, 1998-2003. Fire reduced cover of Kentucky bluegrass during the first post-fire growing season. Cover of native grasses and forbs decreased after 3 season post-fire. Litter depth, maximum vegetation height, and the ratio of dead:live vegetation were reduced immediately after burning. Litter accrued during each subsequent growing season. Maximum vegetation height and the ratio of dead:live vegetation recovered to pre-burn levels during the second post-fire growing season.

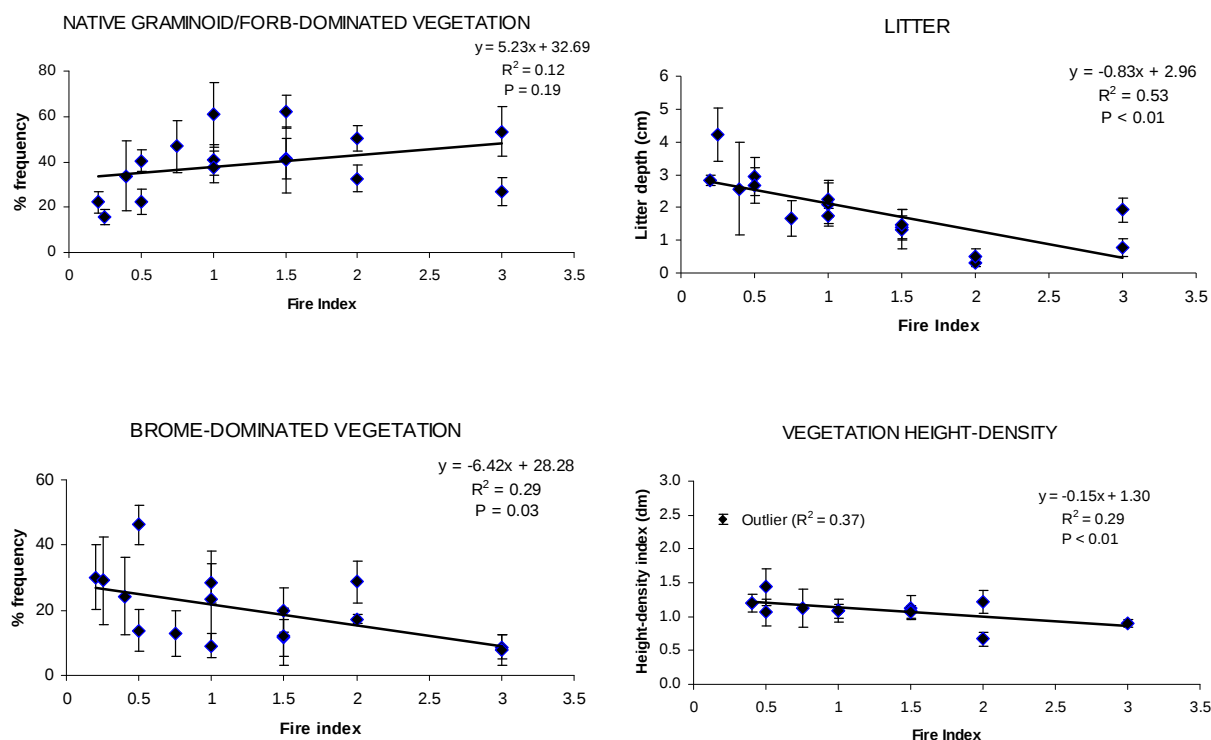


Figure 13. Examples of relationships between prescribed fire history and the general composition and structure of vegetation in Drift Plain prairie at Des Lacs National Wildlife Refuge, based on linear regression ($n = 16$ management units sampled, except vegetation height-density data were not collected from 3 units). Fire history for a given study unit is expressed as an index based on the number of fires/years since last fire (Madden et al. 1999). Vertical bars represent 1 standard error around the mean for each study unit. Smooth brome decreased with increasing levels of prescribed fire “experience,” but was not necessarily replaced by native herbaceous vegetation. Plant litter, a major source of fuel for prescribed fire, and the overall height and density of vegetation, were reduced by repeated fire. Data were collected in 2003.

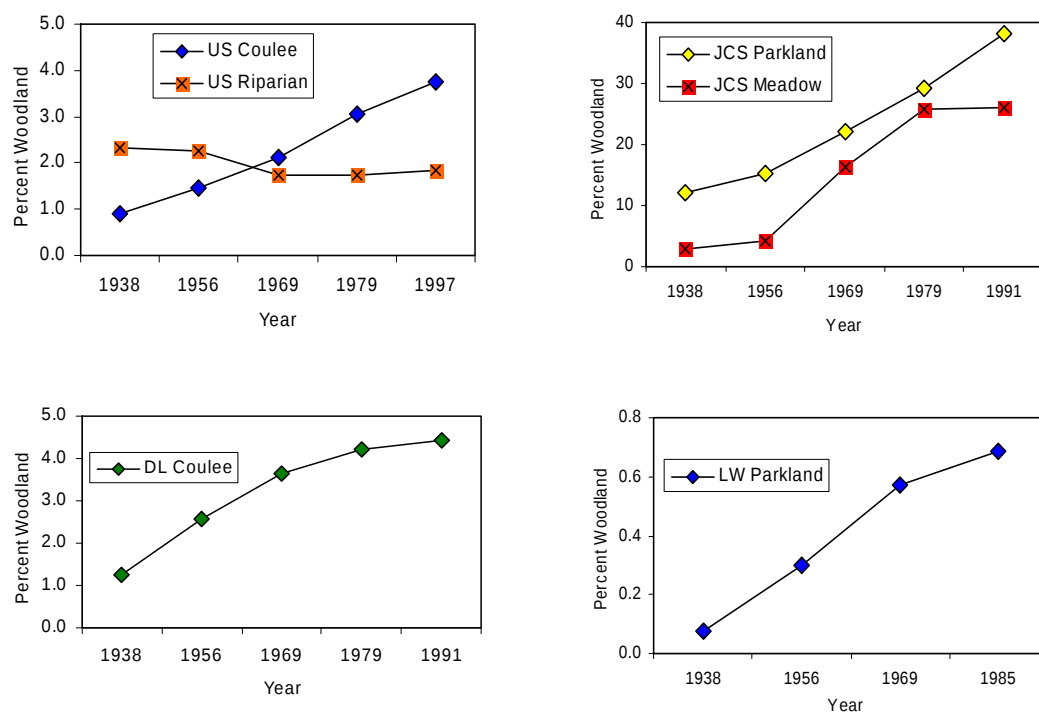


Figure 14. Changes in percent cover of 4 woodland types on 4 National Wildlife Refuges located in north central and northwestern North Dakota from 1939 to 1997. Except for riparian woodlands, the extent of all other woodland types increased significantly since 1938, primarily because of the reduce frequency and extent of natural and prescribed fires.

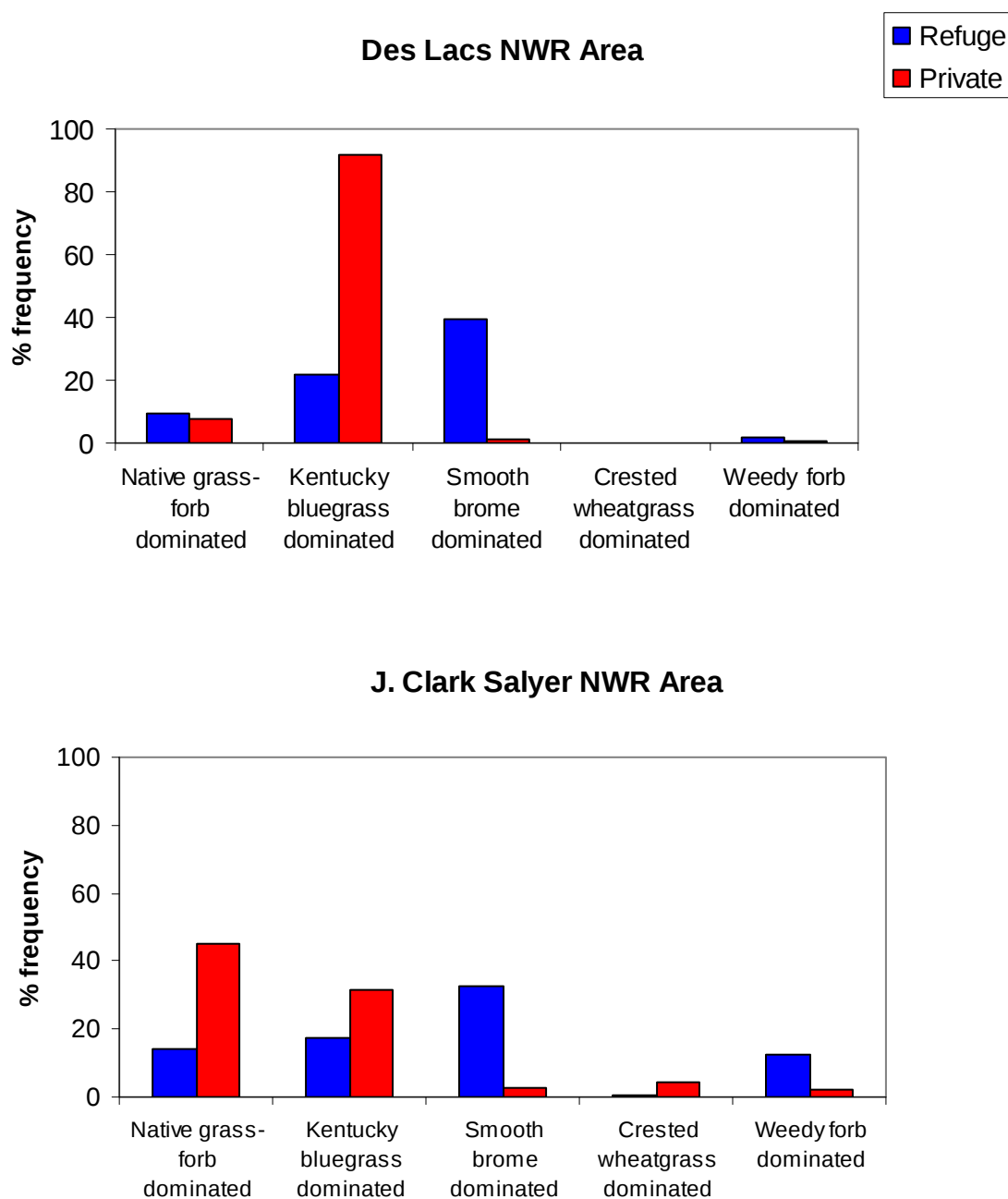


Figure 15. Frequencies of major herbaceous components of drift prairie vegetation on Des Lacs National Wildlife Refuge and J. Clark Salyer National Wildlife Refuges and on nearby, privately owned, annually grazed drift prairie in northwestern and north central North Dakota, based on data collected from randomly located belt transects during 1998-2003. Native dominated grass-forb communities were rare on both NWRs and on private pastures. Smooth brome is almost absent on private pasture with a long-term grazing history but no fire. In contrast, Kentucky bluegrass is dominant on private pastures, but may be reduced by fire on NWRs.