INVENTORY

An Emerging Crisis across Northern Prairie Refuges: Prevalence of Invasive Plants and a Plan for Adaptive Management

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ABSTRACT

In the northern Great Plains, native prairies managed by the U.S. Fish and Wildlife Service (Service) can be pivotal in conservation of North America's biological diversity. From 2002 to 2006, we surveyed 7,338 belt transects to assess the general composition of mixed-grass and tallgrass prairie vegetation across five "complexes" (i.e., administrative groupings) of national wildlife refuges managed by the Service in North Dakota and South Dakota. Native grasses and forbs were common (mean frequency of occurrence 47%–54%) on two complexes but uncommon (4%–13%) on two others. Conversely, an introduced species of grass, smooth brome (*Bromus inermis*), accounted for 45% to 49% of vegetation on two complexes and another species, Kentucky bluegrass (*Poa pratensis*) accounted for 27% to 36% of the vegetation on three of the complexes. Our data confirm prior suspicions of widespread invasion by introduced species of plants on Service-owned tracts of native prairie, changes that likely stem in part from a common management history of little or no disturbance (e.g., defoliation by grazing or fire). However, variability in the degree and type of invasion among prairie tracts suggests that knowledge of underlying causes (e.g., edaphic or climatic factors, management histories) could help managers more effectively restore prairies. We describe an adaptive management approach to acquire such knowledge while progressing with restoration. More specifically, we propose to use data from inventories of plant communities on Service-owned prairies to design and implement, as experiments, optimal restoration strategies. We will then monitor these experiments and use the results to refine future strategies. This comprehensive, process-oriented approach should yield reliable and robust recommendations for restoration and maintenance of native prairies in the northern Great Plains.

Keywords: invasive species, Kentucky bluegrass (*Poa pratensis*), mixed-grass prairie, restoration, smooth brome (*Bromus inermis*)

North America's grassland biome, exemplified by the Great Plains, is arguably the continent's most endangered major ecosystem (Samson and Knopf 1994, Samson et al. 2004). The decline in extent and quality of North American prairies coincides with decreasing populations of many animal species that depend on them and is among the most challenging conservation issues of this century (Samson et al. 2004, Brennan and Kuvlesky 2005). In states and provinces of the northern prairie region, for example, native mixed-grass prairie has declined 30% to 99% and native tallgrass prairie has declined more than 95%, owing mainly to conversion to agriculture (Samson et al. 2004). This trend continues unabated for prairies in North Dakota and South Dakota (Higgins et al. 2002, GAO 2007).

Roughly 90,000 ha of native mixed-grass and tallgrass prairie are managed by the U.S. Fish and Wildlife Service (Service) east of the Missouri River in North Dakota and South Dakota (Figure 1). These areas range from isolated 16-ha tracts within agricultural settings to 15,000-ha contiguous tracts in grassland-dominated landscapes. The Service's prairies are on several large (> 5,000 ha) national wildlife refuges (NWRs) that were acquired mainly in the 1930s as inviolate areas for migratory birds and on smaller (< 1,200 ha), widely scattered tracts acquired mainly in the 1960s as waterfowl production areas (WPAs). Recent congressional mandates specify conservation of biological diversity as a primary function of most Service lands (Gergely et al. 2000). Thus as native prairie dwindles in the northern Great Plains, the role of Service lands in perpetuating native plant communities and their associated animal communities becomes increasingly important. These lands may be considered bastions of the nation's prairie heritage—small, and sometimes large, relicts where representative native biological communities are preserved.

Appropriate habitat goals and objectives for public lands where

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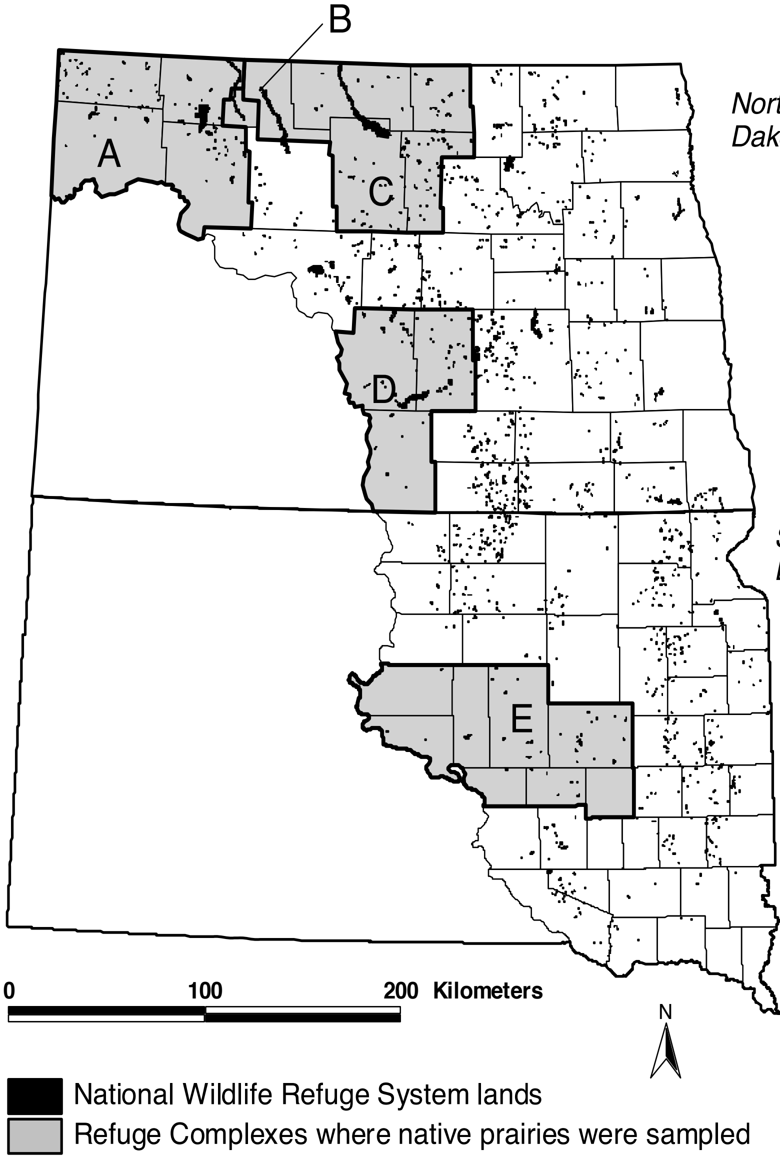

Figure 1. National Wildlife Refuge Systems lands (shaded in black) located east of the Missouri River in North Dakota and South Dakota. Prairies were inventoried within five National Wildlife Refuge Complexes (bold outline and gray shading) including: A) Des Lacs Complex, which includes Des Lacs National Wildlife Refuge (NWR) and Lostwood NWR, two smaller NWRs, and 152 Wildlife Protection Areas (WPAs), in northwestern North Dakota; B) Upper Souris Complex, which includes only the Upper Souris NWR (denoted by a line indicating the refuge), in north-central North Dakota; C) J. Clark Salyer Complex, which includes J. Clark Salyer NWR and 127 WPAs, in north-central North Dakota; D) Long Lake Complex, which includes Long Lake NWR, two smaller NWRs, and 78 WPAs, in south-central North Dakota; and E) Huron Complex, which includes 61 WPAs, in east-central South Dakota.

prairie conservation is a primary concern should place the current condition of Service-owned prairies in the context of their biological potential for maintenance or restoration. This potential could be based on a historical perspective, but this would usually be general because site-specific data on historic prairie composition are lacking. Historic (i.e., pre-Euro-American settlement) vegetation of the northern prairie region has been described broadly (e.g., Carpenter 1940, Stubbendieck 1988, Coupland 1992). However, comprehensive assessments of the current vegetation of Service-owned prairies have not been undertaken.

Recently, an extensive survey of two NWRs in North Dakota revealed that their prairies were badly invaded by introduced cool-season grasses, especially smooth brome (*Bromus inermis*; nomenclature follows GPFA 1986), Kentucky bluegrass (*Poa pratensis*), and native species of shrub, for example, western snowberry (*Symphoricarpos occidentalis*) and silverberry (*Elaeagnus commutata*) (Murphy and Grant 2005). Although many factors probably contributed to these invasions, management histories (ca. 1935–1985) common to both refuges, consisting mainly of long-term rest (i.e., no disturbance) and light, season-long grazing, are most suspect (Murphy and Grant 2005). For example, at J. Clark Salyer NWR (23,900 ha, located in north-central North Dakota), prescribed grazing decreased markedly during a 45 year period (Figure 2). Beginning in the late 1950s, grazing began to be eliminated on the refuge, primarily to benefit upland nesting ducks attracted to tall, dense nesting cover. Prescribed fires were relatively uncommon on J. Clark Salyer NWR during this same period and all wildfires were quickly suppressed, despite evidence of fires occurring every 5–6 years prior to settlement of the region (Figure 2). Implications of findings by Murphy and Grant (2005) for other Service lands and other prairie preserves in the northern prairie region are unclear, but they raise concern because many such areas have similar management histories. Our objectives in this article are twofold: 1) report the general plant composition of prairies on a cross-section of Service lands across the glaciated plains of North Dakota and South Dakota; and 2) describe an adaptive process to maintain or restore native plant communities on these prairies.

Study Area

We sampled native prairies within five "complexes" of Service-owned lands in North Dakota and South Dakota. A complex is an administrative unit that typically includes one or two large NWRs, several smaller NWRs, and many WPAs across several

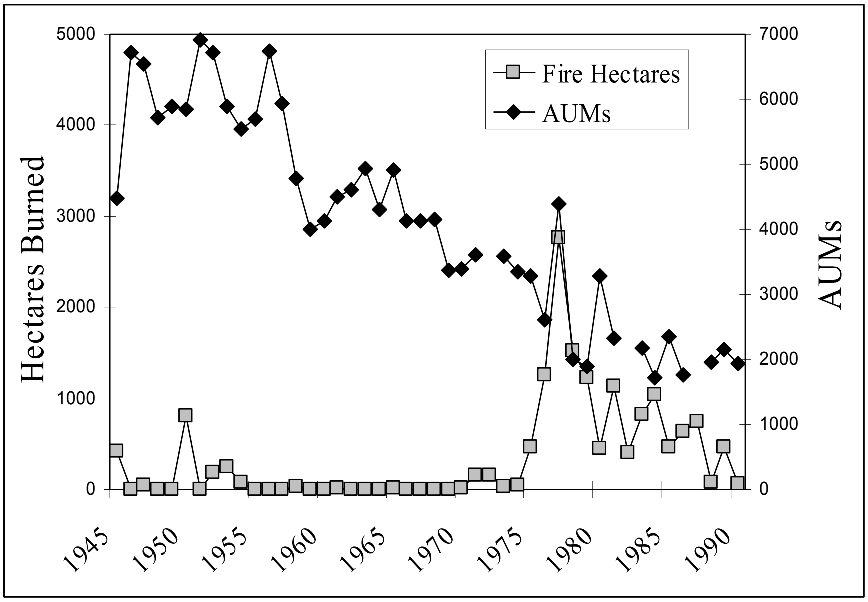

Figure 2. Grazing and fire histories during 1945–1990 on J. Clark Salyer NWR, a 23,900-ha refuge located in north-central North Dakota. This is an example of how infrequently ecological disturbances (i.e., fire and herbivory) have been applied on a large NWR relative to the importance of these factors in shaping prairie ecology. Fires in the chart represent the combined area over which prescribed fires and wildfires extended during this period, and could be compared to an average presettlement extent estimated at 4,000–5,000 ha/year. Changes in grazing extent and intensity are represented by total Animal Unit Months (AUMs) for each year over the entire refuge. Since the 1970s, grazing extent and intensity have been greatly reduced.

counties (Figure 1). The five complexes we examined were not selected at random, but rather were sampled based on opportunities for funding. Inventories of prairie within Des Lacs and J. Clark Salyer Complexes were completed in 2004. Based on these results, inventories were expanded to Upper Souris Complex in 2005 and Long Lake and Huron Complexes in 2006. Our plan is to inventory all Service-owned native prairies in North Dakota and South Dakota by 2008.

Native prairie throughout the area occurs mainly on soils dominated by gravel-loam and clay-loam glacial tills, and also sandy-loam glacial outwash. Native vegetation is northern mixed-grass prairie except in the eastern portion of the Huron Complex in south-central South Dakota, where the prairie is tallgrass (Coupland 1992, Bragg 1995). Flora include several species of cool-season graminoids, mainly needlegrasses (*Stipa* spp.) and wheatgrasses (*Agropyron* spp.), but also Junegrass (*Koeleria pyramidata*), native bluegrass (*Poa*) species, and sedges (*Carex* spp.); several warm-season grasses, mainly blue grama (*Bouteloua gracilis*), sideoats grama (*B. curtipendula*), and bluestem (*Andropogon*) species; low shrubs, mainly western snowberry and silverberry; and many forb species, mainly Asteraceae and Fabaceae. The climate of our study area is semiarid to subhumid continental, characterized by long cold winters and moderately warm summers. Annual precipitation is 40–50 cm, two-thirds of which occurs during the growing season, although droughts are common (USFWS, unpub. data).

Methods

We inventoried only areas of native sod (i.e., land never cultivated). We looked for evidence of previous cultivation for all grassland tracts in historical records, aerial photos, and field visits. Evidence of previous cropping included distinct field edges, especially deep furrows and linear ridges along preexisting fence; rock piles or rocks strewn linearly along what appeared to be a field edge (although rock sometimes was cleared for native hay harvests); lack of partly buried rocks with profuse lichen growth; and lack of clubmoss (*Selaginella densa*) or cryptogamic crust. Previous cropping histories were not always apparent, especially in sandy soils where tillage disturbance in the soil A-horizon was difficult to ascertain (these areas were mostly limited to J. Clark Salyer NWR). Some of these tracts may have been cropped for only a few years circa 1880–1930 or may have been broken but never cropped during this period. Native plants often reestablished in these areas before introduced plants (e.g., smooth brome, Kentucky bluegrass, yellow sweet clover [*Melilotus officinalis*]) were widely planted as forage or used in reclamations associated with road building or erosion control following droughts (Sather 1987, Otfinowski et al. 2007). These areas today may support a flora that approaches the most pristine plant communities on areas that were definitively documented as native sod. Some tracts were likely included in our sample. The final products were GIS maps that delineated boundaries of native sod on each Service-owned tract.

During the summers of 2002 to 2006, we used belt transects to record frequencies of plant species or species groups (Grant et al. 2004) on prairies within each Service complex. Transects were 25 m long except on some sites with very steep slopes (such as choppy sandhills at J. Clark Salyer NWR), where we used 8- or 10-m transects. We distributed one transect per 1–4 ha of prairie. Sampling intensity was consistent within each complex but varied among complexes based on the perceived heterogeneity in vegetation, needs for ancillary data, and logistical considerations. For example, we sampled one transect per hectare at Upper Souris Complex because plant communities were perceived as more diverse among prairie tracts, due mainly to greater variability in topography and soils. Additionally, Upper Souris NWR had more resources available to complete the

Table 1. Mean percentage frequency of plant species groups observed on native prairies within five National Wildlife Refuge Complexes managed by the U.S. Fish and Wildlife Service in North Dakota and South Dakota, sampled in 2002–2006. Transects sampled included 1,548 for Des Lacs Complex, 2,245 for Upper Souris Complex, 1,742 for J. Clark Salyer Complex, 931 for Long Lake Complex, and 972 for Huron Complex. Species of weedy forbs included leafy spurge (*Euphorbia esula*), yellow sweet clover (*Melilotus officinalis*), Canada thistle (*Cirsium arvense*), sow thistle (*Sonchus arvensis*), yellow toadflax (*Linaria vulgaris*), and wormwood (*Artemisia absinthium*).

	Des Lacs	Upper Souris	J. Clark Salyer	Long Lake	Huron
Native grass/forb	53.5	21.5	46.5	4.0	12.8
Kentucky bluegrass (*Poa pratensis*)	10.9	35.9	18.8	26.5	31.1
Smooth brome (*Bromus inermis*)	10.8	13.6	15.4	48.5	44.6
Crested wheatgrass (*Agropyron cristatum*)	0.5	1.6	0.5	2.4	10.6
Low shrub	19.5	25.2	9.2	16.7	0
Weedy forb	2.7	2.2	7.9	1.3	0.1

inventory. In contrast, we sampled only 0.25 transect per hectare at Long Lake Complex, where vegetation composition was more similar among tracts and personnel available to complete the inventory were limited. Data were summarized separately for each complex to avoid unequal weighting due to different sampling intensities. Transects were distributed randomly but were at least 50 m apart. Each was oriented along a random compass bearing. We classified the dominant plant species group at each of 50 contiguous belts (0.5 × 0.1 m) along each 25-m transect (16 belts for an 8-m transect), using a plant species group classification system specific to the region (e.g., Appendix A in Grant et al. 2004). We summarized transect data by percent frequency of occurrence according to specific plant genera or species categories, certain functional groups (e.g., warm-season native grasses), or life form groups (e.g., low shrub; Grant et al. 2004, Murphy and Grant 2005). Because we were primarily interested in describing low shrub (≤ 1.5 m tall) and grass-forb components of native prairies, we omitted from our analyses transects that occurred in wetland, woodland, or tall-shrub communities. The only exception to these omissions was the inclusion of wetland vegetation classes in meadow habitat (*n* = 376 transects) at J. Clark Salyer NWR. We did this because meadow is inherently a transitional habitat between upland prairie and seasonally flooded wetland.

Results

During 2002–2006, we collected data from 7,338 transects on nearly all Service-owned tracts in our study area that included more than 4 ha of native prairie. Low shrub occurred with 9%–25% frequency in native prairies across four complexes but did not occur in Huron Complex (Table 1). Native grasses and forbs were common at Des Lacs and J. Clark Salyer Complexes but relatively uncommon at Long Lake and Huron Complexes. Kentucky bluegrass and smooth brome were common to all Service-owned prairies. Smooth brome in particular was ubiquitous at Long Lake and Huron Complexes, as was Kentucky bluegrass at Upper Souris, Long Lake, and Huron Complexes. Crested wheatgrass (*Agropyron cristatum*), another introduced, cool-season grass, was infrequently encountered except at Huron Complex (Table 1). Several species of weedy forbs collectively accounted for less than 3% frequency of occurrence, except at J. Clark Salyer Complex, where leafy spurge (*Euphorbia esula*) was more common.

Discussion

Our findings confirm suspicions that many Service-owned prairies in North Dakota and South Dakota are substantially invaded by species of introduced grasses and forbs and by native shrubs (Murphy and Grant 2005). The floristic integrity of native prairies was most compromised by smooth brome and Kentucky bluegrass. Since we chose our complexes opportunistically rather than randomly, we recognize that our results could be a biased representation of Service-owned native prairies east of the Missouri River in North Dakota and South Dakota, although any such biases would be resolved as inventories of Service-owned tracts are completed (see *Phase I: Inventory all Service-owned native prairies in North Dakota and South Dakota* below). Nevertheless, given the extent and degree of invasion that we observed, our results cast doubt on the belief that Service-owned prairies suitably represent the region's prairie heritage.

Ecosystem Dysfunction and the Loss of Important Ecological Processes

Prairies in the northern Great Plains evolved with interacting grazing and fire disturbances (Higgins 1986), as well as climatic variability (Bragg 1995). The region was a significant, year-round range for bison (*Bison bison*), elk (*Cervus elaphus*), and other herbivores prior to the 1870s (Hanson 1984). Natural and anthropogenic fires were common, occurring with varying frequency depending on climate and geography (e.g., mesic mixed-grass prairies burned roughly every 5–6 years; Wright and Bailey 1982, Collins and Gibson 1990, Bragg 1995).

Widespread interaction of these natural disturbances ended by the early 1900s, however, when bison were extirpated and Euro-American settlers suppressed fires (Grant and Murphy 2005). After settlement but before establishment of NWRs and WPAs, most native prairies of present-day Service lands probably were grazed annually at moderate to high stocking rates or harvested for hay annually, as described in a previous article for J. Clark Salyer and Des Lacs NWRs (Murphy and Grant 2005). Suppression of wildfire continued during this same period.

After acquisition by the Service, native prairies generally were managed with no grazing or light, season-long grazing, and, rarely, with fire. By the mid 1960s, Service-owned prairies were rested with increasing frequency to emphasize dense, undisturbed nesting cover for prairie ducks and upland game birds. Prescribed fire came into use during the 1970s and 1980s, though sparingly (Figure 2). Since the early 1990s, however, prescribed fire has been more frequently and extensively applied, particularly at Des Lacs and J. Clark Salyer Complexes. The extent and frequency of prescribed grazing also have increased; prescriptions generally focus on short-term (2- to 4-week) grazing periods instead of season-long grazing.

Our data support the assertion by two of our authors in an earlier work that the nature and extent of invasions by introduced plant species and some species of native shrub may be in part an unforeseen consequence of rest, the management approach most typical of Service lands until recently (Murphy and Grant 2005). Invasive plants have been recognized for decades as a substantial threat to Service-owned prairies in North Dakota and South Dakota. For example, Cosby (1975) recognized that eliminating grazing and fire does not protect prairie but instead degrades it due to litter accumulation and invasion by introduced grasses. He gave examples of deteriorating vegetation on Service-owned lands in North Dakota, including notes on smooth brome invasion. However, the scope, scale, and implications of such invasions have been underestimated, and until now, have not been quantified. The Service has usually lacked staff, funding, and direction for basic inventory and monitoring of prairies. Without such assessments, individual managers have been unable to understand how their management actions contribute to long-term changes in prairie vegetation (Murphy and Grant 2005).

Our data indicate that smooth brome and Kentucky bluegrass are the most significant invaders of Service-owned prairies in North Dakota and South Dakota. Neither species has received attention in the scientific community comparable to that invested for control of weedy forbs such as leafy spurge, Canada thistle (*Cirsium arvense*), yellow toadflax (*Linaria vulgaris*), and wormwood (*Artemisia absinthium*). Smooth brome and Kentucky bluegrass are still widely cultivated in the Great Plains for hay, pasture, and renovation of disturbed sites (Sather 1987, Otfinowski et al. 2007). These rhizomatous grasses often escape cultivation and rapidly displace native grasses and forbs, especially under extended periods of rest (Lura et al. 1988, Romo et al. 1990, Bragg 1995, Cully et al. 2003, Otfinowski et al. 2007). Indeed, some Service-owned prairies already are so thoroughly invaded by smooth brome and Kentucky bluegrass that restoration of native-dominated flora seems unlikely (Murphy and Grant 2005). Remedial management of remaining prairies will require swift and effective actions that integrate strategies to mimic processes that shaped and maintained native prairie prior to Euro-American settlement.

A Plan for Action Based on Managing Adaptively

Attempts to suppress smooth brome, Kentucky bluegrass, and other introduced cool-season grasses have met with poor or inconsistent success in northern prairies where the dominant native species are also cool-season grasses (Willson and Stubbendieck 2000), particularly where management has been passive and mainly consisting of rest (Murphy and Grant 2005). Restoration and maintenance of prairies in the northern Great Plains will require an improved understanding of factors contributing to current ecosystem dysfunction and those necessary for restoring ecosystem health. Chief among these factors are formative processes that shaped the region's ecology (e.g., drought, fire, herbivory; Samson et al. 2004). Few prairies in the northern Great Plains are managed such that defoliation by fire or grazing mimics the conditions (i.e., frequency, timing, and extent of disturbances) to which native plant communities are adapted. We define an approach that does this as "process-oriented management." As management focus strays from a process-oriented approach, maintenance and restoration of Service-owned prairies becomes more expensive and less successful. In particular, the cost of restoration for badly degraded prairies (if they can be restored at all) will far exceed that for maintenance of prairies that are floristically intact. We require a comprehensive, long-term evaluation of prospective strategies aimed at reducing introduced plants, especially smooth brome and Kentucky bluegrass, in native prairies. Evaluation of strategies applied across broad physiographic and climatic gradients is crucial to understanding their effects within a region of extreme environmental variability.

Under historical conditions, the frequency, duration, and intensity of important disturbance events (e.g., fire and grazing) in native prairies likely varied with environmental conditions such as temperature, precipitation, soils, slope, and aspect, but these variations are not completely understood. In contemporary prairies, invasion by introduced plants is an additional source of variation. Collectively, these sources of variability represent uncertainties that will determine the success or failure of prairie restorations. By following the adaptive management principles of recognizing and understanding these uncertainties before and during restorations (Walters 1986), restorationists can simultaneously pursue management objectives and systematically acquire information that will improve future management. Accordingly, we describe a three-phase approach for restoration and maintenance of prairies on Service lands in the northern Great Plains.

Phase I: Inventory All Service-Owned Native Prairies in North Dakota and South Dakota

Extensive inventories that address the most pressing management questions of prairie restorationists can be accomplished using tools, such as the belt transect method we used, that focus on plant groups of special management interest, rather than intensive, species-level approaches (Grant et al. 2004). This paper summarizes basic inventory results only for prairies on five Service complexes in North Dakota and South Dakota. Results from ongoing inventories of remaining Service-owned prairies in the region will be available by 2009. These data will then be used to group prairies based on similar proportions of intact plant assemblages or degree and nature of invasion for use in management experiments described in Phases II and III. The inventories also will provide baseline data for future monitoring and for development of process-oriented goals and objectives for restoration of Service-owned prairies. Furthermore, these data should support more detailed analyses of plant invasion patterns based on tract size, management history, edge/interior ratios, latitude/longitude, soils, slope, or aspect, because many of these attributes vary among prairies tracts or across complexes in North Dakota and South Dakota (e.g., Table 1). Patterns of invasion may suggest underlying mechanisms that influence competition among native and introduced plants, and this knowledge will be important in continued development of effective restoration strategies.

Phase II: Develop an Adaptive Management Process to Guide Restoration of Service-Owned Prairies

The primary focus of this phase is to identify and describe strategies most likely to enhance native plants in prairies variably invaded by introduced grasses, weedy forbs, and woody vegetation. The Service's long-term goal is restoration of plant communities representative of those found in the region prior to Euro-American settlement. We expect to identify key uncertainties that can lead to unexpected results in the Service's efforts to restore these prairies. Chief among these uncertainties is competition among native and introduced plants; plant community response to management is expected to vary by degree of invasion and by the particular plant species (both native and introduced) present. Competition also is expected to vary in response to the type (e.g., prescribed fire), duration, intensity, and frequency of management. Similarly, plant response likely varies with geographic location and gradients of climate, soil, or slope and aspect. Sources of variation like these translate into uncertainties in plant response (i.e., competition) that can be couched as working hypotheses in an adaptive management framework. Hypotheses may be expressed as simple models that can be investigated in an applied setting. For example, both Kentucky bluegrass and smooth brome increase in prairies under rest (see Murphy and Grant 2005 for a review and citations). However, Kentucky bluegrass also increases with grazing but may decrease with fire. In contrast, smooth brome may be sensitive to repeated grazing and likely is unaffected or may increase with fire. These dissimilar responses to fire and grazing support development of simple models involving prescribed fire and grazing that could be evaluated in the field. By comparing model projections to actual outcomes, evidence is acquired to support or refute a particular hypothesis (e.g., fire and grazing effects on smooth brome and Kentucky bluegrass), and thus inform future management (Walters 1986, Starfield 1997). A key component of this phase will be the identification of metrics expected to encapsulate prairie responses to management (i.e., how does the Service measure attributes of the vegetation community or abiotic environment that are most indicative of restoration success or failure?).

To this end, in March 2006, the Service hosted a two-day meeting of biologists and managers from federal and state agencies, universities, and the private sector with expertise on prairie management (Grant 2006). Discussions focused on the exchange and synthesis of information, particularly on the ecology and control of smooth brome, because brome is thought to be among the most significant threats to Service-owned prairies in the region. Participants discussed a broad range of potential strategies, including prescribed fire, grazing, clipping, chemicals, and combinations thereof. Uncertainties related to timing, frequency, and duration of management were discussed. Participants also considered the appropriate size for experimental units and suitable metrics (e.g., Brudvig et al. 2007) for assessing management effectiveness in the context of projected staffing and funding levels during the implementation phase (*Phase III* below). Specifics of these strategies will be refined over several years, resulting in development of hypotheses/models suitable for restoration of Service-owned prairies.

Phase III: Implement the Project on a Sample of Prairie Tracts; Evaluate Hypotheses and Refine Future Management Based on Results of Monitoring

The primary focus of this phase is to assess the efficacy of restoration strategies derived from Phase II. Experimental tracts will have broad spatial coverage and be chosen based on results of inventories (Phase I) and logistical constraints. Restoration strategies will reflect uncertainties specific to each experimental tract (e.g., degree of invasion, type of invasive species, geographic location, soils, etc.). For example, strategies for managing a prairie tract occurring on level loamy soils and only nominally invaded by Kentucky bluegrass (10% frequency of occurrence) are likely to differ from those for managing a similar tract significantly invaded by smooth brome (40% frequency) and Kentucky bluegrass (20% frequency). Management prescriptions and/or hypotheses will be periodically refined based on principles of adaptive management (Walters 1986). Strategies that prove effective on experimental areas are candidates for broader implementation on Service-owned prairies in the northern Great Plains.

A second focus of Phase III is determination of degradation thresholds for those prairies already compromised by invasive plants. Some of these prairies may already be so extensively degraded that restoration may be impractical (Murphy and Grant 2005). Other prairies may be almost pristine, requiring less effort to maintain their condition. Many prairies may require 30–50 years to recover and decades of study may be necessary to gain reliable information on strategies most effective in restoring these prairies. The determination of degradation thresholds represents an uncertainty that is especially critical for allocating restoration efforts when resources are limited (e.g., Bestelmeyer 2006). Should patterns of invasion be identified during the analysis of inventory data collected in Phase I, the specific factors influencing those patterns may be used to identify and prioritize tracts with greater restoration potential (and conversely tracts that have little to no chance of restoration). Phase III is scheduled to begin in 2009.

Conclusions

Our data suggest that protection of prairies has not preserved or enhanced the quality of native plant communities on many Service-owned lands in North Dakota and South Dakota. Despite 40–70 years of protection, the integrity of many prairies held in public trust continues to decline, primarily because of invasion by cool-season, introduced plants (Murphy and Grant 2005, this study) and woody vegetation (Grant and Murphy 2005). Our study further demonstrates the pitfalls of managing disturbance-dependent prairies as relatively static, late-successional systems over many decades. We demonstrate an approach, founded on principles of adaptive management, that should yield valid and robust recommendations for restoring prairies on Service-owned lands and elsewhere in the northern Great Plains.

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