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ABSTRACT—Historic herbicide use and grazing have influenced natural diversity and quality of native pasturelands in the Great Plains. Floristic quality assessments are useful to assist agencies in prioritizing conservation practices to enhance native grasslands. The objective of this study was to determine the effects of past land-use practices on the floristic quality of remnant native pastures in eastern South Dakota and southwestern Minnesota. Floristic quality assessments were conducted on 30 native pastures and categorized by past management practices (herbicide application and grazing intensity). Mean coefficient of conservatism ($\overline{C}$) and floristic quality index (FQI) were calculated for each site. Results showed that increased herbicide use and grazing intensity resulted in a lower species richness, forb $\overline{C}$, and FQI. However, grass and grasslike plants were minimally affected. Pastures that were infrequently sprayed with herbicides and lightly grazed consistently had the highest species richness, $\overline{C}$, and FQI. Pastures with no grazing produced similar values to those with moderate grazing. Pastures managed as preserves or wildlife habitat areas had higher FQI than those managed for livestock grazing. The implications of this study should further help ecologists and managers understand the positive and negative effects of grazing practices and herbicide application on tallgrass prairie remnants.

Key Words: tallgrass prairie, floristic quality, species richness, grasses, forbs, grazing, herbicides

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INTRODUCTION

The natural landscape of the eastern Great Plains has been immensely altered since European-American settlement. Large areas of land have been put into agricultural production, and as a result, less than 1% of the native tallgrass prairie remains (Samson and Knopf 1996). Remnant tallgrass prairies display varying degrees of quality due to habitat disturbance and invasion by exotic species (Northern Great Plains Floristic Quality Assessment Panel 2001). Long-term use of herbicides that control broadleaf species has resulted in decreased forb diversity in eastern Nebraska rangelands (Masters et al. 1992; Masters et al. 1994) and in eastern Texas (Hickman and Derner 2007). Exotic cool-season grasses such as smooth bromegrass (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.) have increased greatly in the Great Plains (Weaver and Fitzpatrick 1934; Casler and Carlson 1995). Anthropogenic additions of nitrogen deposition have contributed to the competitiveness of exotic cool-season grasses (Wedin and Tilman 1996; Vinton and Goergen 2006). It is likely that remnant grasslands of the eastern Great Plains have experienced greater grazing intensities since the removal of the bison (*Bison bison*), fencing of pastures, and introduction of domestic livestock (Weaver and Fitzpatrick 1934). Grazing intensity has been shown to decrease the vigor of pasture forage species and increase weedy species (Harker et al. 2000). Therefore, tallgrass prairie remnants are a high priority for conservation by natural resource agencies. The objectives of this study were to determine the effects of past management practices, involving varying levels of herbicide application and grazing intensity, and whether the primary land use (either nature preserve/wildlife production or livestock grazing) has had an impact on floristic quality of native prairies pastures in the Prairie Coteau Ecoregion of eastern South Dakota and southwestern Minnesota. The literature suggests that herbicide use and grazing intensity decrease the floristic quality of native pastures and that prairies managed as nature preserves/ wildlife areas should have higher floristic quality than pastures managed for livestock grazing.

MATERIALS AND METHODS

Thirty native tallgrass prairie pastures in the Prairie Coteau Ecoregion of eastern South Dakota and southwestern Minnesota were sampled for floristic quality, defined by Swink and Wilhelm (1979, 1994) as the assessment of native plants' degree of dependence on intact native plant communities, in the field seasons of 2006 and 2009 (Fig. 1). Pasture size averaged 88 ha and ranged from 12 to 810 ha. Field methodology followed standard protocol for floristic quality index (FQI) assessment (Northern Great Plains Floristic Quality Assessment Panel 2001). Pastures were surveyed in July and August to identify all vascular plant species within a parcel of the pasture until no new species were detected after 10 minutes of additional searching. Once the 10-minute period expired, the surveyor moved to a new location within the pasture. This procedure was repeated until no new species were found within the entire pasture. The average time spent surveying pastures was 5 minutes per hectare. Each plant is assigned a conservatism value as determined by the Northern Great Plains Assessment Panel (2001). Values of conservatism, or coefficient of conservatism, are integral values ranging from 0 to 10, with 0 assigned to species typifying disturbed habitats and 10 assigned to the most conservative species, that is, those occurring strictly in undisturbed habitats. The coefficient of conservatism value thus represents the plant species' ability to indicate or predict the quality of a natural area (Higgins et al. 2001). Exotic species are not assigned a value. Mean coefficient of conservatism ($\overline{C}$) and FQI values were calculated for each pasture based on floristic composition. The mean coefficient of conservatism for a particular land parcel is thus the average of coefficient of conservatism values for all of the native species occurring on the parcel. Floristic quality index is calculated by the following equation:

$$FQI = \overline{C}\sqrt{N},$$

where $\overline{C}$ is the mean coefficient of conservatism for a site and N is the total number of native plant species found. This procedure is not density dependent, and thus $\overline{C}$ and FQI values for a land parcel are stable over time, at least provided that the management does not change, and given the fact that most prairie plants are perennials and are observed during both wet and dry years.

Herbicide use was categorized as frequent if it was broadcast over an entire pasture annually or up to every 3 to 4 years and infrequent if the pasture was only spot sprayed when and where necessary. Grazing intensity was categorized as no grazing, light, moderate, and heavy relative to the recommended stocking rate for South Dakota rangeland and pasture (SDSU 2007) and was based on fall stubble height (Mousel and Smart 2007). Light grazing was usually practiced seasonally (spring or summer) for <4 months to achieve utilization of approximately 25% or

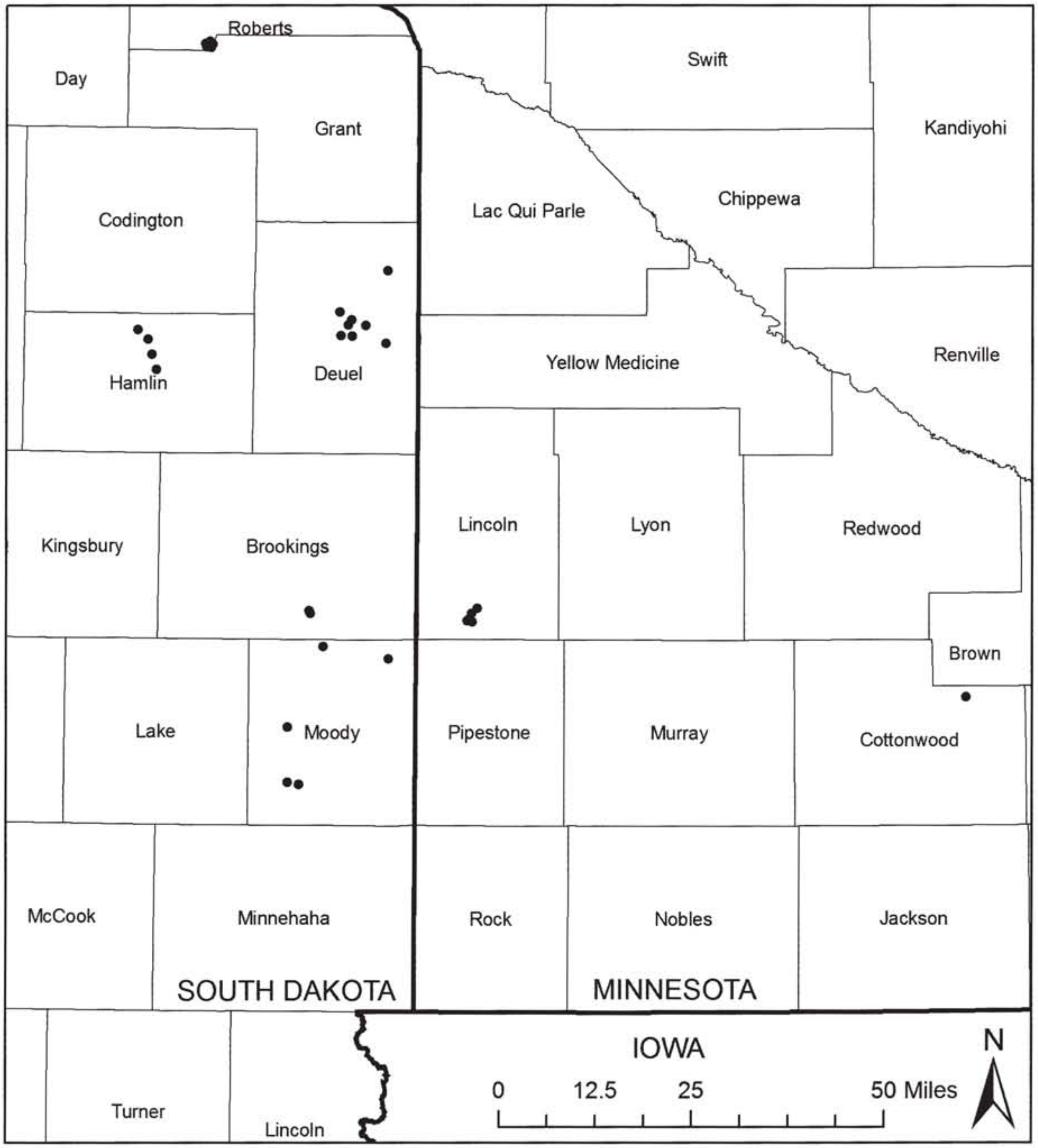

Figure 1. Locations of remnant tallgrass prairie sites (solid circles) in the Prairie Coteau Ecoregion of eastern South Dakota and southwestern Minnesota.

less of the annual herbage production. Moderate and heavy grazing was usually practiced season-long to achieve an approximate utilization of 50% and >65%, respectively. Ranchers and managers verified that land parcels had never been plowed and provided past management information that allowed us to categorize the combined use of herbicides and grazing intensity into six categories: frequent herbicide–heavy grazing ($n = 8$), frequent herbicide–moderate grazing ($n = 6$), infrequent herbicide–heavy grazing ($n = 3$), infrequent herbicide–moderate grazing ($n = 3$), infrequent herbicide–light grazing ($n = 6$), and infrequent herbicide–no grazing ($n = 4$). Primary land use was categorized as either nature preserve/wildlife habitat ($n = 12$) or livestock grazing land ($n = 18$). A one-way analysis of variance was used to compare herbicide–grazing combinations and primary land-use effects using PROC GLM (SAS Institute 2009). Normality of the residuals was verified using the NORMAL and PLOT options in

PROC UNIVARIATE (SAS Institute 2009). The Shapiro-Wilk's test yielded values close to 1 and the normality plots validated the assumptions of normality for all variables. Levene's test and Welch's ANOVA were computed to evaluate equal variances among herbicide–grazing treatments and primary-use treatment groups using the HOVTEST and WELCH options in the MEANS statement of PROC GLM (SAS Institute 2009). When the *P*-value was <0.05, Welch's ANOVA was used instead. Means were separated using the PDIFF option in PROC GLM (SAS Institute 2009) when the *P*-value for the main effect was $P < 0.05$. Preplanned contrast statements were used to separate the effects of herbicide and grazing intensity among the frequent and infrequent herbicide-treated pastures and the heavily and moderately grazed pastures. (We excluded the infrequent herbicide–lightly grazed and infrequent–no grazing pastures).

RESULTS

Herbicide–Grazing Intensity

The number of grass and grasslike species, grass and grasslike $\overline{C}$, and grass and grasslike FQI were not statistically different among herbicide–grazing intensities, although heavily grazed pastures averaged 6.5 fewer species than did moderately grazed pastures (Table 1). The number of forb species, forb $\overline{C}$, and forb FQI were significantly different among herbicide–grazing intensities (Table 2). The number of forb species was highest for pastures that were infrequently sprayed and grazed lightly or moderately. Pastures that were frequently sprayed with herbicide and heavily grazed had the fewest forb species. Forb $\overline{C}$ was not different among pastures where herbicides were infrequently used. Pastures that were frequently sprayed with herbicide and heavily grazed had a lower forb $\overline{C}$ than those that were moderately grazed. Forb FQI was 1.5 times greater on pastures that were infrequently sprayed with herbicide compared to those that were frequently sprayed with herbicide. Prairies where herbicide was infrequently used but grazed lightly had 1.25 times greater forb FQI than those that were not grazed. Moderately grazed pastures had 1.26 times greater forb FQI than those that were heavily grazed.

The overall number of species, overall $\overline{C}$, and overall FQI were significantly different among herbicide–grazing intensities and had rankings similar to the forbs for the different herbicide–grazing intensity combinations (Table 3). The number of exotic grasses and forbs was not statistically different among herbicide–grazing intensities except that frequent use of herbicides averaged 6.8 fewer exotic forbs than pastures that were infrequently sprayed with herbicide (Table 4).

Primary Land Use

Preserves/wildlife habitat areas were similar to areas managed for livestock grazing in the number of grass and grasslike species, grass and grasslike $\overline{C}$, and grass and grasslike FQI (Table 5). Pastures managed primarily for livestock grazing averaged 57.7 fewer forb species, had a 14% lower forb $\overline{C}$, and a 41% lower forb FQI (Table 5). Overall number of species, overall $\overline{C}$, and overall FQI were 1.8, 1.1, and 1.5 times greater, respectively, for pastures managed as preserves/wildlife habitat compared to those managed for livestock grazing (Table 5). Pastures managed for livestock grazing averaged 2.1 more exotic grasses and 10.7 fewer forbs than areas managed as preserves/wildlife habitat areas (Table 5).

DISCUSSION

Herbicide–Grazing Intensity

There are several reasons why herbicide use did not affect grass diversity as much as it affected forb diversity (Tables 1 and 2). The most frequently used herbicides on pasturelands in the Prairie Coteau Ecoregion of eastern South Dakota and southwestern Minnesota are those that control broadleaf plants (Darrel Deneke, South Dakota State University, integrated pest management coordinator, pers. comm., 2010). State noxious weed laws require the control of invasive species such as leafy spurge (*Euphorbia esula* L.) and Canada thistle (*Cirsium arvense* [L.] Scop.), and these species have high infestation rates in counties of this region (South Dakota Department of Agriculture 2009). In addition, the forb $\overline{C}$ was higher on lands that were infrequently sprayed with herbicides, suggesting that rare and more sensitive forbs are not able to survive frequent herbicide treatment.

It is well documented that increased grazing intensity decreases floral diversity on native rangelands (Lauenroth et al. 1999), and our study found likewise. However, grass and grasslike FQI was not significantly different among grazing intensities (Table 1). The reason for this was that the grass and grasslike $\overline{C}$ was not different between grazing intensities even though heavy grazing averaged 6.5 fewer grass and grasslike species compared to moderately grazed pastures. Numerous stocking rate studies show that taller and midsize grasses are replaced

TABLE 1

NUMBER OF GRASS AND GRASSLIKE SPECIES (*N*), GRASS AND GRASSLIKE MEAN COEFFICIENT OF CONSERVATISM ($\overline{C}$), AND GRASS AND GRASSLIKE FLORISTIC QUALITY INDEX (FQI) FROM 30 NATIVE PASTURES

	Grass and grasslike species		
Herbicide–grazing intensity	**N** $\bar{x}$ **(SE)**[1]	$\overline{C}$ $\bar{x}$ **(SE)**	**FQI** $\bar{x}$ **(SE)**
Frequent–heavy	18.1 (2.24)	4.70 (0.16)	19.5 (1.27)
Frequent–moderate	23.7 (2.59)	4.84 (0.18)	23.6 (1.47)
Infrequent–heavy	16.0 (3.66)	5.28 (0.26)	21.1 (2.08)
Infrequent–moderate	23.3 (3.66)	4.69 (0.26)	22.5 (2.08)
Infrequent–light	27.2 (2.59)	4.95 (0.18)	25.5 (1.47)
Infrequent–none	20.0 (3.17)	4.74 (0.22)	21.1 (1.80)
P-value	0.1011	0.1293	0.2650
Contrasts[2]			
Frequent vs. infrequent	0.6957	0.3305	0.8624
Heavy vs. moderate	0.0490	0.3369	0.1347
Interaction	0.7754	0.1063	0.4590

Note: Pastures were surveyed from 2006 to 2009 in eastern South Dakota and southwestern Minnesota.
[1]SE indicates standard error of the mean.
[2]Contrasts do not include infrequent—light and infrequent—none pastures.

TABLE 2

NUMBER OF FORB SPECIES (*N*), FORB MEAN COEFFICIENT OF CONSERVATISM ($\overline{C}$), AND FORB FLORISTIC QUALITY INDEX (FQI) FROM 30 NATIVE PASTURES

	Forb species		
Herbicide–grazing intensity	**N** $\bar{x}$ **(SE)**[1]	$\overline{C}$ $\bar{x}$ **(SE)**	**FQI** $\bar{x}$ **(SE)**
Frequent–heavy	40.1 (8.26) d[2]	4.01 (0.14) c	25.4 (2.77) d
Frequent–moderate	66.3 (9.54) c	4.46 (0.16) b	36.3 (3.20) c
Infrequent–heavy	75.3 (13.49) bc	5.03 (0.22) a	43.6 (4.52) b
Infrequent–moderate	105.7 (13.49) ab	4.96 (0.22) ab	50.7 (4.52) ab
Infrequent–light	132.8 (9.54) a	5.23 (0.16) a	59.9 (3.20) a
Infrequent–none	87.5 (11.68) bc	5.16 (0.19) a	47.9 (3.92) b
P-value	0.0001	0.0001	0.0001
Contrasts[3]			
Frequent vs. infrequent	0.0033	0.0005	0.0003
Heavy vs. moderate	0.0209	0.3331	0.0275
Interaction	0.8584	0.1769	0.6294

Note: Pastures were surveyed from 2006 to 2009 in eastern South Dakota and southwestern Minnesota.
[1]SE indicates standard error of the mean.
[2]Means followed by different letters are significantly different ($P < 0.05$).
[3]Contrasts do not include infrequent—light and infrequent—none pastures.

TABLE 3
NUMBER OF OVERALL SPECIES (N), OVERALL MEAN COEFFICIENT OF CONSERVATISM ($\overline{C}$), AND OVERALL FLORISTIC QUALITY INDEX (FQI) FROM 30 NATIVE PASTURES

	Overall species		
Herbicide–grazing intensity	**N** $\bar{x}$ **(SE)**[1]	$\overline{C}$ $\bar{x}$ **(SE)**	**FQI** $\bar{x}$ **(SE)**
Frequent–heavy	58.3 (9.35) d[2]	4.23 (0.11) c	32.0 (2.66) d
Frequent–moderate	90.0 (10.80) c	4.56 (0.12) bc	43.3 (3.07) c
Infrequent–heavy	90.7 (15.27) bc	5.12 (0.17) a	48.6 (4.34) bc
Infrequent–moderate	129.0 (15.27) ab	4.91 (0.17) ab	55.5 (4.34) ab
Infrequent–light	160.0 (10.80) a	5.19 (0.12) a	65.4 (3.07) a
Infrequent–none	107.5 (13.22) bc	5.09 (0.15) a	52.4 (3.75) bc
P-value	0.0001	0.0001	0.0001
Contrasts[3]			
Frequent vs. infrequent	0.0109	0.0003	0.0006
Heavy vs. moderate	0.0123	0.6911	0.0213
Interaction	0.8014	0.0813	0.5532

Note: Pastures were surveyed from 2006 to 2009 in eastern South Dakota and southwestern Minnesota.
[1]SE indicates standard error of the mean.
[2]Means followed by different letters are significantly different ($P < 0.05$).
[3]Contrasts do not include infrequent—light and infrequent—none pastures.

by shorter species (Lauenroth et al. 1999). The low standard error of the grass and grasslike $\overline{C}$ indicates that the most commonly found species have similar C values (Northern Great Plains Floristic Quality Assessment Panel 2001). In addition, the computation of FQI is not density dependent, meaning an area could have a substantial reduction in species diversity without reducing its FQI. Grazing intensity had a significant impact on forb FQI because numerous forb species are sensitive to overgrazing (Johnson and Larson 1999).

PRIMARY LAND USE

The desire for ecosystem goods and services (i.e., an economic benefit such as beef production or a service providing habitat for flora and fauna) dictates management decisions regarding herbicide use and grazing intensity. Our data set represents the common pastureland uses in this region, and our findings of higher FQI values for forbs and for overall species on areas managed as preserves/wildlife habitat areas compared to pastures managed for livestock grazing (Table 5) was similar to previous findings. Higgins et al. (2001) surveyed 63 tallgrass prairie remnant sites in eastern South Dakota and found that private land had an FQI of 39 compared to 57 for preserves. In northeastern Kansas, Jog et al. (2006) found warm-season hay meadows had an FQI of 32 and warm-season pastures managed for livestock grazing had an FQI of 21. Landowners whose primary objective is livestock grazing tend to use herbicides for weed control more frequently and stock heavier than managers of preserves. To conserve the floristic diversity of remaining native prairie tracts, the cultural and economic incentives behind these management decisions must be understood.

Livestock producers tend to accept exotic grasses whereas managers of preserves dislike exotic grasses because they reduce native species biodiversity. Our data showing 2.1 more exotic grass species on pastures managed for livestock grazing versus areas managed as preserves/wildlife areas (Table 5) support this view. Exotic forbs are a real concern for producers and managers. Pastures that were frequently sprayed had fewer exotic forb species, and producers that managed land for livestock grazing also had fewer exotic forb species (Table 5). These data suggest that cultural factors such as "what the neighbors think," along with legal obligations to control

TABLE 4
NUMBER OF EXOTIC GRASSES AND FORBS FROM 30 NATIVE PASTURES CATEGORIZED BY HERBICIDE–GRAZING INTENSITY

	Grasses	Forbs
Herbicide–grazing intensity	$\bar{x}$ (SE[1])	$\bar{x}$ (SE)
Frequent–heavy	7.1 (0.65)	11.4 (2.43)
Frequent–moderate	7.8 (0.75)	14.3 (2.81)
Infrequent–heavy	6.0 (1.07)	19.0 (3.97)
Infrequent–moderate	6.0 (1.07)	20.3 (3.97)
Infrequent–light	5.3 (0.75)	26.2 (2.81)
Infrequent–none	4.5 (0.92)	17.3 (3.44)
P-value	0.0809	0.0942
Contrasts[2]		
Frequent vs. infrequent	0.1152	0.0545
Heavy vs. moderate	0.6990	0.5303
Interaction	0.6990	0.8115

Note: Pastures were surveyed from 2006 to 2009 in eastern South Dakota and southwestern Minnesota.
[1]SE indicates standard error of the mean.
[2]Contrasts do not include infrequent—light and infrequent—none pastures.

noxious weeds, are likely responsible for the fewer exotic forbs found on lands where livestock grazing is the primary objective.

Judicious use of herbicide application should be practiced instead of frequent broadcast applications. Fuhlendorf et al. (2009) showed that broadcast application of herbicides on Oklahoma rangeland, where forbs comprised 23% of the herbage production, did not increase grass and beef production. Their work suggests that a higher economic threshold of weedy broadleaf plants exists. Such thresholds are unknown in the Prairie Coteau Ecoregion, but historic climax-plant-community theory for this region would indicate that forbs make up approximately 5% to 15% of the plant community in terms of biomass (NRCS 2010b). The perception that broadleaf plants reduce grass production in this region may be incorrect.

Economic incentives from conservation agencies need to focus on reducing the stocking rate to a light grazing intensity in order to maintain or increase plant diversity. Such incentives exist through the Natural Resources Conservation Service's Conservation Stewardship Plan. Practices such as deferred grazing and rotational grazing with proper stocking rates pay producers

TABLE 5
NUMBER OF GRASS AND GRASSLIKE, FORB, AND OVERALL SPECIES (N), GRASS AND GRASSLIKE, FORB, AND OVERALL MEAN COEFFICIENT OF CONSERVATISM ($\overline{C}$), AND GRASS AND GRASSLIKE, FORB, AND OVERALL FLORISTIC QUALITY INDEX (FQI) FROM 30 NATIVE PASTURES

	Grass and grasslike species			Forb species			Overall species		
Primary land use	N $\bar{x}$ (SE)[1]	$\overline{C}$ $\bar{x}$ (SE)	FQI $\bar{x}$ (SE)	N $\bar{x}$ (SE)	$\overline{C}$ $\bar{x}$ (SE)	FQI $\bar{x}$ (SE)	N $\bar{x}$ (SE)	$\overline{C}$ $\bar{x}$ (SE)	FQI $\bar{x}$ (SE)
Preserve/wildlife habitat	23.3 (1.99)	4.90 (0.13)	23.4 (1.13)	114.9 (8.09)	5.20 (0.13)	55.4 (2.73)	138.1 (9.38)	5.16 (0.10)	60.2 (2.70)
Livestock grazing	20.4 (1.62)	4.80 (0.11)	21.4 (0.92)	57.2 (6.61)	4.36 (0.11)	32.8 (2.23)	77.7 (7.66)	4.50 (0.08)	39.3 (2.20)
P-value	0.2697	0.5789	0.1826	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Note: Pastures were surveyed from 2006 to 2009 in eastern South Dakota and southwestern Minnesota.
[1]SE indicates standard error of the mean.

TABLE 6
NUMBER OF EXOTIC GRASSES AND FORBS FROM 30 NATIVE PASTURES CATEGORIZED BY PRIMARY LAND USE

	Grasses	Forbs
Primary land use	$\bar{x}$ (SE)[1]	$\bar{x}$ (SE)
Preserve/wildlife habitat	5.1 (0.52)	23.8 (1.86)
Livestock grazing	7.2 (0.42)	13.1 (1.52)
P-value	0.0041	0.0001

Note: Pastures were surveyed from 2006 to 2009 in eastern South Dakota and southwestern Minnesota.
[1]SE indicates standard error of the mean.

who qualify (NRCS 2010a). These payments are necessary to offset economic drivers to graze heavy. Dunn et al. (2010) reported that the net profit from grazing mixed-grass prairie at three different range-condition classes was significantly greater at good and low to fair range conditions compared to excellent range condition in western South Dakota, because excellent range condition could not be stocked as heavily. Thus, ranchers have no economic incentive to improve rangeland, but it also means there should be no incentive to overstock rangeland that is currently in good condition. Smart et al. (2010) showed, using data from Hart et al. (1998), that greater efficiencies occur at heavy stocking rates and optimum returns per hectare were between moderate and heavy stocking. Therefore, if society desires the benefits of improved range condition (higher plant diversity, quality wildlife habitat, etc.), then lower stocking rates must be incentivized (Dunn et al. 2010).

On the other hand, managers of preserves/wildlife production areas should be aware of the benefits of using livestock to apply periodic disturbances. Pastures that were infrequently sprayed with herbicide and lightly grazed had the highest species richness and highest $\overline{C}$ and FQI (Tables 1–3). As long as grazing is kept at a light intensity (<25% utilization of annual herbage production) and applied at the right time, it can be a useful tool to reduce competition of exotic cool-season grasses.

In summary, floristic quality assessments provided useful insight into the effects of past management practices, such as grazing intensity and herbicide application. Floristic quality index values for grasses and grasslike plants were less affected by herbicide use and grazing intensity than those for forbs. Lightly grazed pastures had higher FQI values and greater species richness than pastures that were grazed moderately, heavily, or ungrazed. Frequent use of herbicides reduced FQI values for forbs to a much greater extent than it did for grasses. Finally, pastures managed as preserves/wildlife production areas had higher FQI values than pastures managed for livestock grazing. If conservation is aimed at improving the floristic quality of remaining native prairies in this region, economic incentives should be promoted to reduce stocking rates and encourage judicious use of herbicides.

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