Western North American Naturalist

Volume 64 | Number 2 Article 9

4-30-2004

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Recommended Citation

Pokorny, Monica L.; Sheley, Roger L.; Svejcar, Tony J.; and Engel, Richard E. (2004) "Plant species diversity in a grassland plant community: evidence for forbs as a critical management consideration," *Western North American Naturalist*: Vol. 64 : No. 2 , Article 9.
Available at: https://scholarsarchive.byu.edu/wnan/vol64/iss2/9

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Western North American Naturalist 64(2), ©2004, pp. 219–230

PLANT SPECIES DIVERSITY IN A GRASSLAND PLANT COMMUNITY: EVIDENCE FOR FORBS AS A CRITICAL MANAGEMENT CONSIDERATION

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ABSTRACT.—This study quantified species and functional group diversity in a grassland plant community in southwestern Montana. Specific objectives were to measure the richness and density of functional groups within the grassland community, measure the biomass of each functional group, and calculate diversity indices for each functional group. We hypothesized that diversity would be greater than previous descriptions for the *Festuca idahoensis/Agropyron spicatum* habitat type because our multiple-season method would recognize seasonal and environmental variations in community composition. Of the species present, we hypothesized that forb functional groups account for the majority of richness and biomass of this grassland plant community. Species richness and density were measured during spring, summer, and fall of 2000, and biomass was collected during spring, summer, and fall of 2001. Species richness was measured by counting all species present on 4-m^2 plots. We measured forb density per 4-m^2 plot and determined grass density by counting tillers per species within a 0.2 × 0.5-m frame. Diversity indices were calculated for each functional group. Biomass by functional group was clipped from three 0.2 × 0.5-m frames per 4-m^2 plot. Data support the hypothesis that multiple-season sampling recognizes greater species diversity at one location because both sites were more diverse plant communities than previously described for this habitat type. We documented 14 graminoids and 69 forbs from just 2 sites. Total diversity of a 4-m^2 plot averaged 42 species, consisting of 5 grasses, 12 deep-rooted forbs, and 25 shallow-rooted forbs. Our data also support the hypothesis that forb functional groups represent the majority of the richness and biomass of the grassland community. Forbs account for 83% of species richness in this research. In addition, forbs represent a greater proportion of plant biomass than grasses on our sites. Functional group diversity and forb diversity should be a larger consideration in *Festuca idahoensis/Agropyron spicatum* grassland management decisions. We recommend that land managers recognize forb species and forb functional group diversity in grassland classifications. Maintaining diversity should be a primary objective of land managers because increased diversity has been found to increase community stability and productivity, and decrease the risk of invasion by undesired species. To encourage land managers to put more resources into monitoring diversity, a simple and repeatable sampling procedure applicable to both community and landscape scales needs to be developed.

Key words: grasslands, community composition, species richness, species diversity, functional group diversity, forbs.

Grasslands are the largest biome on earth, comprising 24% of the world's vegetation and about 125 M ha in the United States (Sims and Risser 2000). Near the start of the 20th century, descriptions of grasslands focused on understanding the value of species for livestock grazing, and few quantitative data were used to describe plant community productivity or species composition and function in the system (Kearney et al. 1914, Shantz and Piemeisel 1924). Grasslands soon began to be described by their particular climax plant community. Clements (1920) classified and described grasslands of the western United States as 1 of 5 grassland formations. Since Clements, ecologists have recognized and described finer level classifications of the grasslands. Stoddart and Smith (1943) described 18 range types, based on presence and abundance of characteristic plant species. More recent classifications of grassland habitat types in the northwestern United States identify major grassland vegetation types, seral stages of each type, and response to grazing management practices (Daubenmire 1970, Mueggler and Stewart 1980). A common trend of these classification systems is the vegetative type's grass species nomenclature and emphasis on managing grass for livestock production (Stoddart and Smith 1943, Daubenmire 1970, Mueggler and Stewart 1980, Willoughby et al. 1998).

While forb species are listed as diverse components of grassland communities (Daubenmire 1970, Sims et al. 1978, Mueggler and Stewart 1980, Jensen et al. 1988b, Hogg et al. 2001), they have not been a primary focus in

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classification and land management practices (Willoughby et al. 1998, Fuhlendorf and Engle 2001), perhaps because forb species composition varies with environmental and biological factors (MacCracken et al.1983), or because forbs have the greatest production variability within habitat types (Jensen et al. 1988a). Conversely, year-to-year and site-to-site variation of forbs may be a function of methodology limitations in these classifications. Vegetative classifications have historically documented species composition only once during the growing season (Stoddart and Smith 1943, Daubenmire 1970, Mueggler and Stewart 1980, Jensen et al. 1988b). Depending on annual variation in climate, early- or late-developing forbs may have been missed in data collection for classification descriptions. Measuring diversity once at peak standing crop does not account for diversity of spring or fall forbs. To estimate actual community diversity and diversity of forbs within a site, we believe periodic field sampling must occur.

Ecologists and land managers have recognized the importance of diverse plant communities in maintaining healthy ecosystems (Darwin 1859, Elton 1958, MacArthur and Wilson 1967, Goodman 1975, Pimm 1991). It is possible that forbs, or groups of forbs with similar characteristics, are important management groups and play a vital role in ecosystem functions such as invasion resistance and nutrient cycling (Symstad 2000, Dukes 2001, Tilman et al. 2001, Pokorny 2002). Despite the potential role of forbs in plant community processes, only limited attention is given to their composition in grasslands during management practices.

The purpose of this research was to quantify species and functional group diversity in a grassland plant community in southwestern Montana. Specific objectives included identifying plant species richness, density, and biomass within a *Festuca idahoensis*/*Agropyron spicatum* grassland habitat type using a multiple-season sampling method, identifying various functional groups based on their morphology, and comparing richness with previously described diversities of this habitat type. We hypothesized that species richness would be greater than previous descriptions of habitat type of a given location because of our multiple-season method of quantifying the community. Of the species present we hypothesized that forb functional groups account for the majority of richness and biomass of a grassland plant community.

METHODS

Study Areas

This study was conducted on 2 sites within the *Festuca idahoensis*/*Agropyron spicatum* habitat type (Mueggler and Stewart 1980). This habitat type lies at the cool-wet end of grassland habitat types and can be found at elevations ranging from 1400 m to 2300 m. Predominant indigenous perennial grasses include Idaho fescue (*Festuca idahoensis* Elmer) and bluebunch wheatgrass (*Agropyron spicatum* Pursh). The proportion of forbs to graminoids varies with location and increases with precipitation for this habitat type (Mueggler and Stewart 1980). Some predominant indigenous forbs include prairie sage (*Artemisia ludoviciana* L.), arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt), and lupine (*Lupinus* spp.). Medium shrubs are absent from this habitat type unless it has been severely disturbed. We chose the *Festuca idahoensis*/*Agropyron spicatum* habitat type because it is widely distributed throughout the mountain grasslands in southwestern Montana and the western United States and provides a model system for applied ecological research.

Sites were located on the Flying D Ranch approximately 70 km west (45°34′N, 111°34′W) of Bozeman, Montana. Sites lie on an east–northeast aspect of a 20° slope at 1624 m elevation. Our specific sites were chosen because they were near enough to one another to be considered similar and appeared to represent the late seral stage within the *Festuca idahoensis*/*Agropyron spicatum* habitat type. Annual average precipitation is 41 cm and annual average temperature is 6.5°C (Fig. 1).

Prior to plot establishment, we tested soils for presence of picloram (4-amino-3,5,6-trichloropicolinic acid, potassium salt) and nutrient availability to minimize the risk that site characteristics and plant community composition were influenced by herbicide applications or differing resource availability. Picloram was not detected at the 0.01 $mg \cdot kg^{-1}$ level. At depths of 0–15 cm, mass water content, total N, NH_4-H, K, total soil C, and C:N did not differ between sites 1 and 2. Site 1 had higher NO_3-H and S levels and lower P levels in the shallow soils than site 2. The only difference between sites

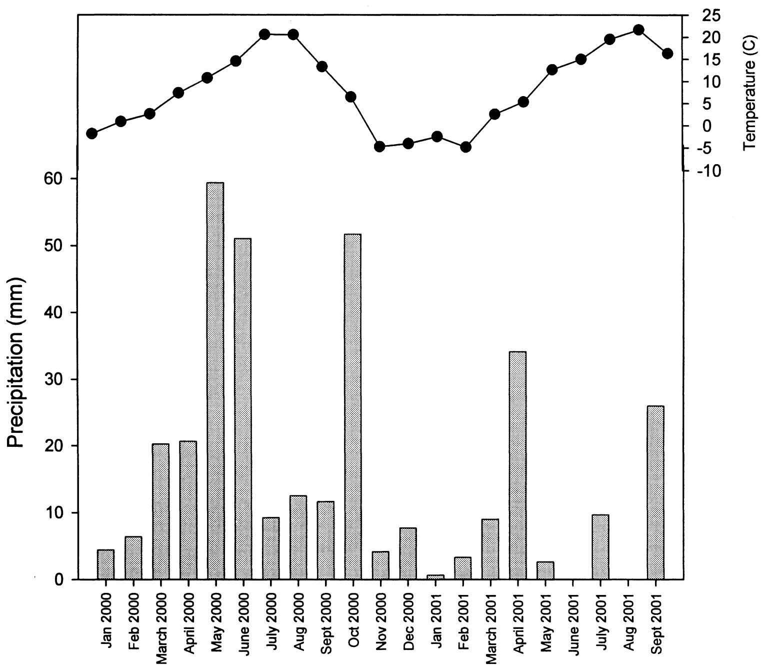

Fig. 1. Average monthly precipitation and temperature gathered from the Red Bluff Experimental Station, approximately 4 km from the study sites.

in nutrient concentration at depths of 15–40 cm was NO_3-N, which was higher on site 1 than site 2.

Soil classifications indicated site 1 soils are loamy-skeletal, mixed, frigid, active Typic Haplocryolls (Haplo Cryic Mollisol), and site 2 soils are coarse-loamy, mixed, frigid, active Typic Haplocryolls (Haplo Cryic Mollisol). Soil profile descriptions for each site showed small variations in the structure, material, and pH of the A and Bw horizons. Main differences in soil profiles were depth of the A horizon (22 cm verses 12 cm, site 1 and 2, respectively) and presence of a Bw horizon at site 2. The Bw horizon structure, which contributed substantially to total profile depth, had larger, blockier soil aggregates than the A or Bk horizons of each site.

The area has been grazed for decades, and in some years of its recent history (50–60 years) it has been heavily grazed by either cattle (*Bos taurus*) or bison (*Bison bison*). Bison grazing during the past 10 years has been sporadic. Windblown slopes are prime winter habitat for wildlife. In the study area winter use by elk (*Cervus elaphus*) has steadily increased as herd size has increased during the past 20 years. In general, site disturbances have been low and the plant communities are in a late seral stage.

Plot Design, Treatments, and Measurements

This study was part of a larger research project aiming to achieve multiple objectives. Describing the treatments for the larger experiment is essential for understanding why sample sizes differ in the data collected for this portion of the research. Species of grass, forbs, and spikemoss were combined into functional groups based on morphological similarities. Forbs were further divided into 2 functional groups based on average rooting depth of each species, determined by careful excavation of each species to determine root structure and rooting depth. The distinction between a shallow and a deep depth was based on a natural break within the roots sampled, which occurred at about 15 cm. In cases where the average root depth was close to 15 cm, species with primarily fibrous roots were considered shallow-rooted, while taproots were grouped with deep-rooted forbs.

Treatments were arranged in a randomized, complete-block design with 4 replications on each of 2 sites. Treatments were applied by removing a functional group or groups in combination from the 2 × 2-m plots. This study consisted of 7 removal treatments: (1) shallow-rooted forbs, (2) deep-rooted forbs, (3) all forbs, (4) grasses, (5) all plant material, (6) nothing (control), and (7) moss, lichens, and spikemoss (collectively referred to as spikemoss throughout the paper). While removing functional groups in spring, summer, and fall of 2000, we recorded species richness and density for all species removed as well as for all species on the control plots (nothing removed). Spring sampling occurred when the majority of spring ephemeral forbs were in bloom, summer sampling coincided with peak standing crop, and fall sampling occurred after 95% of the vegetation was senescent. To measure species richness we counted all species present on the plot, and for forb density we counted the number of plants per species in the plot. Grass density was determined by counting the number of tillers per species within a 0.2 × 0.5-m frame. A single frame was placed randomly in each plot. For the spikemoss functional group, percent foliar cover was estimated within a 0.2 × 0.5-m frame for each species representing ≥1% of the plot area. Forbs and *Selaginella* species were identified using Dorn (1984) while grasses follow the nomenclature in Cronquist et al. (1977). We used Flowers (1973) and McCune (1995) to identify mosses and lichens.

Aboveground biomass of shallow-rooted forbs, deep-rooted forbs, and grasses was collected during spring, summer, and fall of 2001 from all plots where their biomass was not removed as a treatment. Thus, there are different sample sizes for each group. Plots were divided into 3 subplots that were randomly assigned to each of the 3 sample periods to prevent sampling the same area twice. Plants were clipped to ground level within three 0.2 × 0.5-m frames randomly placed in each subplot. Plant aboveground biomass was separated by functional group as it was clipped. As part of the treatments, we removed spikemoss from 2 plots in each block. All plant tissues were oven-dried (40°C, 160 hours) to a constant weight. We then weighed them and recorded their biomass.

Data Analysis

Species frequency of occurrence in the 4-m^2 plots was calculated for each site to determine species distribution between sites. Frequency of occurrence was calculated as number of plots a species occurred in divided by total number of plots. Species richness per seasonal sample period was calculated as a percentage of total species richness. Richness, biomass, and density were summarized for shallow-rooted forb, deep-rooted forb, and grass functional groups individually and for the plot as a whole (hereafter referred to as "overall plot"). Biomass was averaged over the 3 seasons for this comparison. For the spikemoss functional group, mean percent cover, richness, and biomass were summarized. Richness was always summarized per plot (4 m^2) while density, biomass, and percent cover were averaged per m^2. Both the Simpson and Shannon-Weaver diversity indices were calculated for each functional group. The Simpson diversity index is defined as $D = 1/(\text{sum}[Pi^2])$ where Pi is the proportion of the ith species (Begon et al. 1990). The Shannon-Weaver index is defined as $H = -\text{sum}(Pi[\ln Pi])$ (Begon et al. 1990). To further describe the habitat type and variation in plant species richness, density, and biomass within this habitat type, data comparisons between the 2 sites were conducted using the Student's *t* test in SPSS software (SPSS version 10.0 1999). We used ANOVA to investigate the degree of seasonal variability of functional group biomass. In this case, functional group, season, and block were all main effects and functional group × season was the interaction term. Tukey's multiple comparisons were calculated in SAS when *P*-values were ≤0.05 (SAS 1990).

RESULTS

Frequency, Density, Biomass, and Cover

Twenty-four plant families were represented in 4 functional groups on the study sites. Plant families most often encountered were Asteraceae (16 taxa), Fabaceae (7 taxa), and Poaceae (14 taxa). In total, 84 vascular plants, 2 nonvascular plants, and 4 lichens were identified in this grassland system (Table 1). Of those species, 47 were shallow-rooted forbs, 22 were deep-rooted forbs, 14 were grasses, 4 were lichens, 1 was a spikemoss, and 2 were mosses. Shallow-rooted forbs (0–15 cm roots) consisted of annual, short-lived perennials, and perennial species with bulbs, rhizomes, fibrous roots and/

or shallow taproots. Deep-rooted forbs (15–40 cm roots) were primarily perennial taprooted plants with varying lateral root lengths and depths. Idaho fescue and bluebunch wheatgrass were the most commonly occurring grasses. Arrowleaf balsamroot, lupine, prairie milkvetch (*Astragalus adsurgens* Pallas), and blazing star (*Liatris punctata* Hook) are deep-rooted forbs that occurred on nearly every plot. Shallow-rooted forbs were dominated by both spring ephemeral forbs, including death camas (*Zigadenus venenosus* Wats.) and yellowbell (*Fritillaria pudica* Pursh), and midsummer bloomers, including penstemon (*Penstemon eriantherus* Pursh) and blanketflower (*Gaillardia aristata* Pursh). A single species of spikemoss, resurrection plant (*Selaginella densa*), accounted for 99% of the cover and biomass of the spikemoss group, while mosses and lichens were rarer in occurrence and distribution.

Twenty-four species had ≥75% frequency of occurrence on both sites (Table 1). While most species were evenly distributed over both sites, there were some exceptions. *Iris missouriensis* had a frequency of occurrence of 90% at site 1 and was absent from site 2. Eight species had at least 3 times the frequency of occurrence on site 1 than site 2. Sixteen species were present on site 1 in low frequencies while absent from site 2. *Carex filifolia* and *Cladonia pyxidata* occurred on site 2 with at least 3 times the frequency of site 1. Five species were present on site 2 in low frequencies while absent from site 1. The percent of plant species that could be identified varied by season. Of the total number of species present on the sites, 52%, 76%, and 44% were able to be identified in spring, summer, and fall samplings, respectively.

Mean overall plot species density was 22.9 plants · m^{-2} and 45.3 plants · m^{-2} on sites 1 and 2, respectively (Table 2). Grass tillers were about twice as dense on site 2 (434.6 tillers · m^{-2}) as on site 1 (187.6 tillers · m^{-2}). This probably accounted for greater overall density on site 2. While shallow-rooted forbs generally had a lower frequency of occurrence on site 2 than on site 1, their density was about one-third greater on site 2 (3.3 plants · m^{-2}) than on site 1 (2.6 plant · m^{-2}).

Site 1 had a greater overall plot biomass (89.1 g · m^{-2}) than site 2 (74.8 g · m^{-2}; Table 2). Shallow-rooted forbs accounted for 23.5 g · m^{-2} (26%) and deep-rooted forbs for 47.5 g · m^{-2} (53%) of the plant community biomass at site 1. Site 2 had a greater biomass of grasses than site 1. Site 2 also had twice as much biomass of the spikemoss functional group as site 1 did (Table 3). *Selaginella densa* formed an almost continuous layer on the soil at site 2 (66% cover), surrounding the base of bunchgrasses, and had vascular vegetation growing through and within its foliage. In comparison, site 1 had more bare ground.

We were interested in natural variability and distribution of functional group biomass over the 3 seasons in diverse grassland communities and found that biomass at site 1 varied among functional groups and with season (Table 4). Deep-rooted forbs had a greater biomass (48 g · m^{-2}) than shallow-rooted forbs (24 g · m^{-2}) and grass (27 g · m^{-2}) at site 1 (Table 5). The highest functional group biomass occurred in the fall while biomass of functional groups was lowest during spring (Table 5). On site 2 the amount of biomass depended on functional group, season, and a functional group × season interaction (Table 4). All 3 functional groups yielded similar biomass in spring (Fig. 2). In summer, grasses (30 g · m^{-2}) and deep-rooted forbs (36 g · m^{-2}) had a greater biomass than shallow-rooted forbs (16 g · m^{-2}). Deep-rooted forbs produced more biomass (65 g · m^{-2}) than either of the other 2 functional groups in the fall. Fall biomass for grass and shallow-rooted forbs was 36 g · m^{-2} and 23 g · m^{-2}, respectively. Deep-rooted forbs was the only group whose biomass varied seasonally with an increase in biomass from spring (20 g · m^{-2}) to summer (60 g · m^{-2}). Biomass of spikemoss on plots was not used for the analysis of variance because it does not represent the group's seasonal biomass (Mueggler and Stewart 1980, van Tooren et al. 1990).

Species Diversity

Overall plot mean species richness within a 4-m^2 plot was 43.6 and 39.4 for sites 1 and 2, respectively (Table 2). Site 1 had greater species richness of shallow-rooted forbs (26.9), grasses (5.5), and spikemoss (2.6) than what was recorded for site 2. Site 2 (12.3) had a greater richness of deep-rooted forbs than site 1 (10.8).

Two diversity indices were calculated for each site because the indices have different meanings of equitability (Table 2). For both indices, equitability increases with an increase in the index. According to the Simpson index, the equitability of shallow- and deep-rooted

TABLE 1. Species functional group assignment, average root depth, and frequency in 4-m^2 plots on site 1 and site 2, respectively. The shallow-rooted forb, deep-rooted forb, grass, and the spikemoss functional groups are represented by S, D, G, and M, respectively.

Species	Common name	Functional group	Average root depth (cm)	Frequency of occurrence
Achillea millefolium L.	Yarrow	S	10	0.28 / 0.21
Allium cernuum Roth.	Nodding onion	S	5	0.97 / 1.00
Alyssum alyssoides L.	Alyssum	S	3	0.06 / 0.00
Antennaria parvifolia Nutt.	Small leaf pussytoes	S	11	0.65 / 0.66
Arabis nuttallii Robinson	Nuttall rockcress	S	5	1.00 / 0.34
Arenaria congesta Nutt.	Ballhead sandwort	S	4	0.97 / 1.00
Arnica sororia Greene	Arnica	S	10	0.28 / 0.25
Artemisia campestris L.	Common sagewort	S	12	0.09 / 0.00
Artemisia dracunculus L.	Green sagewort	S	3	0.06 / 0.00
Artemisia frigida Willd.	Fringed sage	S	14	1.00 / 0.40
Artemisia ludoviciana L.	Man sage	S	3	0.31 / 0.28
Astragalus agrestis Dougl. ex Hook	Field milkvetch	S	10	0.00 / 0.09
Besseya wyomingensis (A. Nels.) Rydb.	Kittentail	S	12	0.97 / 0.91
Castilleja pallescens (Gray) Greene	Pale Indian paintbrush	S	7	1.00 / 1.00
Cerastium arvense L.	Chickweed	S	8	1.00 / 0.94
Chenopodium leptophyllum Nutt.	Lambsquarter	S	7	0.09 / 0.03
Comandra umbellata (L.) Nutt.	Bastard toadflax	S	4	1.00 / 0.90
Dodecatheon conjugens Greene	Shooting star	S	6	0.97 / 0.90
Douglasia montana Gray	Mountain douglasia	S	9	1.00 / 0.88
Erigeron caespitosus Nutt.	Tufted fleabane	S	13	0.90 / 0.90
Erysimum asperum Nutt DC.	Plains wallflower	S	5	0.16 / 0.00
Erysimum inconspicuum (Wats.) MacM.	Wallflower	S	6	0.09 / 0.00
Fritillaria pudica Pursh	Yellow bell	S	6	0.97 / 1.00
Gaillardia aristata Pursh	Blanketflower	S	6	1.00 / 1.00
Galium boreale L.	Bedstraw	S	3	0.22 / 0.00
Gaura coccinea Nutt. ex Pursh	Gaura	S	3	0.09 / 0.03
Gutierrezia sarothrae Britt. & Rusby	Broom snakeweed	S	6	0.63 / 0.72
Haplopappus acaulis Nutt.	Goldenweed	S	7	0.00 / 0.03
Heterotheca villosa Pursh	Golden aster	S	6	0.59 / 0.75
Iris missouriensis Nutt.	Bearded iris	S	11	0.90 / 0.00
Linum lewisii Pursh	Flax	S	8	0.97 / 1.00
Lesquerella alpina (Nutt.) Wats.	Alkaline bladderpod	S	7	0.19 / 0.00
Lomatium cous Coult. & Rose	Mountain lomatium	S	12	0.94 / 0.75
Musineon divaricatum Pursh	Musineon	S	10	0.13 / 0.06
Nothocalais cuspidata (Pursh) Greene	Cuspidate nothocalais	S	14	1.00 / 1.00
Nothocalais troximoides (Gray) Greene	Nothocalais	S	8	0.56 / 0.97
Penstemon eriantherus Pursh	Penstemon	S	4	1.00 / 1.00
Sedum borschii Clausen	Stone crop	S	3	0.03 / 0.00
Senecio canus Hook	Woolly groundsel	S	8	0.94 / 0.66
Sisyrinchium montanum Greene	Blue eye grass	S	5	0.97 / 0.72
Vicia americana Mahl. ex Willd.	American vetch	S	10	0.97 / 0.88
Viola nuttallii Pursh	Yellow violet	S	4	0.72 / 0.84
Viola nuttallii var. vallicola A. Nels.	Yellow violet	S	4	0.03 / 0.03
Zigadenus venenosus Wats.	Death camas	S	6	1.00 / 1.00
Unknown forb 1	Unknown forb	S	5	0.03 / 0.00

forbs did not differ statistically between sites. Site 1 (D = 3.11) had a greater Simpson index for grass than site 2 (D = 1.66); therefore, grass species were more evenly distributed at site 1 than at site 2. Overall plot species diversity for site 1 (D = 4.28) was >2 times greater than diversity at site 2 (D = 1.78). The Shannon-Weaver diversity index indicated that equitability of species within functional groups and the overall plot differed between sites. At site 1, grasses, shallow-rooted forbs, and overall species per plot were more evenly distributed than at site 2. Evenness values ranged from H = 1.27 for grass, to H = 2.81 for shallow-rooted forbs, and to H = 1.86 for the overall plot total. As with the Simpson index, site 2 (H = 1.99) had greater evenness of deep-rooted forbs than site 1 (H = 1.85).

TABLE 1. Continued.

Species	Common name	Functional group	Average root depth (cm)	Frequency of occurrence
Unknown forb 2	Unknown forb	S	6	0.03 / 0.00
Unknown forb 3	Unknown forb	S	3	0.03 / 0.00
Anemone multifida Poir.	Ball anemone	D	19	0.06 / 0.00
Anemone patens L.	Pasque flower	D	26	0.50 / 0.97
Astragalus adsurgens Pallas	Prairie milkvetch	D	30	1.00 / 0.94
Astragalus crassicarpus Nutt.	Plum milkvetch	D	20	0.41 / 0.84
Balsamorhiza sagittata (Pursh) Nutt	Arrowleaf balsamroot	D	35	1.00 / 0.78
Clematis hirsutissima Pursh	Vase flower	D	24	0.25 / 0.03
Crepis acuminata Nutt.	Hawksbeard	D	16	0.19 / 0.06
Crepis occidentalis Nutt.	Hawksbeard	D	20	0.59 / 0.66
Frasera speciosa Dougl. ex Griseb	Green gentian	D	30	0.56 / 0.84
Geum triflorum Pursh	Prairie smoke	D	19	0.13 / 0.06
Geranium viscosissimum Fisch	Sticky geranium	D	20	0.00 / 0.03
Heuchera parviflora Nutt.	Littleleaf allumroot	D	20	0.44 / 0.00
Ipomopsis spicata Nutt. (Grant)	Spike ipomopsis	D	27	0.56 / 0.88
Liatris punctata Hook	Blazing star	D	19	1.00 / 0.97
Lithospermum ruderale Dougl. ex. Lehm	Puccoon	D	35	0.63 / 0.84
Lupinus sericeus Pursh	Lupine	D	35	0.97 / 0.97
Mertensia oblongifolia (Nutt.) G. Don	Bluebell	D	20	0.09 / 0.00
Phlox albomarginata Jones	Phlox	D	16	0.41 / 0.66
Oxytropis lagopus Nutt.	Haresfoot loco	D	20	0.06 / 0.13
Oxytropis sericea Nutt.	White pointloco	D	20	0.50 / 0.81
Taraxacum officinale Weber	Common dandelion	D	18	0.97 / 1.00
Tragopogon dubius Scop.	Goatsbeard	D	18	0.41 / 0.69
Agropyron spicatum Pursh	Bluebunch wheatgrass	G	15	1.00 / 0.96
Aristida longiseta L.	Red three-awn	G	15	0.25 / 0.04
Bouteloua gracilis H.B.K. Lag	Blue grama	G	5	0.79 / 0.38
Carex filifolia Nutt.	Threadleaf sedge	G	10	0.08 / 0.29
Carex rossii Boott	Ross sedge	G	11	0.00 / 0.17
Festuca idahoensis Elmer	Idaho fescue	G	10	1.00 / 1.00
Festuca ovina L.	Sheep fescue	G	10	0.00 / 0.08
Helictotrichon hookeri (Scribn.) Henr.	Spike oat	G	11	0.75 / 0.25
Koeleria nitida Nutt.	Junegrass	G	9	0.38 / 0.21
Poa cusickii Vasey	Cusick bluegrass	G	7	0.50 / 0.33
Poa pratensis L.	Kentucky bluegrass	G	7	0.21 / 0.00
Poa secunda Presl.	Sandbergs bluegrass	G	10	0.46 / 0.08
Stipa comata Trin. & Rupr.	Needle and thread	G	12	0.08 / 0.17
Agropyron spp.	Wheatgrass	G	8	0.04 / 0.04
Selaginella densa Rydb.	Compact spikemoss	M	n/a	0.84 / 1.00
Xanthoparmelia wyomingica	Rockfrog	M	n/a	0.36 / 0.02
Peltigera rufescens	Felt pelts	M	n/a	0.20 / 0.07
Cladonia chlorophaea	Peppered pixie-cup	M	n/a	0.75 / 0.61
Cladonia pyxidata	Pixie-cup	M	n/a	0.09 / 0.27
Tortula ruralis	Hairy screw moss	M	n/a	0.07 / 0.09
Bryum caespiticum	Moss	M	n/a	0.25 / 0.04

DISCUSSION

Species diversity of both sites was high (Daubenmire 1970, Mueggler and Stewart 1980). Sampling over time allowed us to document greater species richness than previously suggested for this habitat type (Daubenmire 1970, Mueggler and Stewart 1980). In their classification description of the *Festuca idahoensis/Agropyron spicatum* habitat type in Montana, Mueggler and Stewart (1980) documented a total of 27 species of graminoids and 69 forb species from 45 sites. In comparison, we documented 14 graminoids and 69 forbs from just 2 sites. It is hard to quantify the richness per site from Mueggler and Stewart; however, based on the average constancy of each life-form, 25% of the 27 grass species (7) and 24% of the 69 forb species (17) occurred on each of their 45 sites. Similarly, Daubenmire (1970) documented an average of 3 grasses, 9 annual forbs, and 8 perennial forbs per 4 m^2 in

TABLE 2. Means and *P*-values generated from independent *t* tests for species richness, density, Simpson diversity index, and Shannon-Weaver index at both sites.

Functional group	Site	*n*	Density (m^2)	Biomass ($g \cdot m^{-2}$)	Richness (4 m^2)	Simpson diversity index	Shannon-Weaver diversity index
Grass	1	24	187.6	27.3	5.5	3.11	1.27
	2	24	434.6	29.7	4.0	1.66	0.65
	df		46	40	46	46	46
	P-value		<0.0001	0.303	<0.0001	<0.0001	<0.0001
Deep-rooted forbs	1	32	1.9	47.5	10.8	4.95	1.85
	2	32	1.9	40.3	12.3	5.35	1.99
	df		62	32	62	62	62
	P-value		0.813	0.266	0.001	0.236	0.008
Shallow-rooted forbs	1	32	2.6	23.5	26.9	12.56	2.81
	2	32	3.3	17.2	23.2	11.69	2.59
	df		62	32	62	62	62
	P-value		<0.0001	0.017	<0.0001	0.536	<0.0001
Overall plot	1	16	22.9	89.1	43.6	4.28	1.86
	2	16	45.3	74.8	39.4	1.78	0.99
	df		30	30	30	30	30
	P-value		<0.0001	0.053	0.017	<0.0001	<0.0001

TABLE 3. Mean richness, biomass, and percent cover of moss, lichen, and spikemoss on both sites. Sample size per site was 56 for richness and percent cover and 8 for biomass.

Functional group	Site	Richness (4 m^2)	Biomass ($g \cdot m^{-2}$)	Percent cover (m^2)
Moss / Lichen / Spikemoss	1	2.6	168	46
	2	2.1	366	66
	df	110	14	110
	P-value	0.009	0.002	<0.0001

the *Agropyron spicatum*/*Festuca idahoensis* habitat type of Washington. Our grassland description documented 39–44 species per 4-m^2 plot which consisted of 4–6 grasses, 11–12 deep-rooted forbs, and 23–27 shallow-rooted forbs. We documented an average canopy cover of moss/spikemoss/lichen of 46%, 66% of which comprised 2–3 species. In comparison, Mueggler and Stewart (1980) estimated bryophytes to be 5%–24% ground cover but did not identify species.

Our data support the hypothesis that forb functional groups represent the majority of the richness and biomass of this grassland community. Forbs accounted for 83% of vascular species richness in our research. Similarly, Mueggler and Stewart (1980) and Daubenmire (1970) found 72% and 93% of total species recorded for this habitat type to be forbs. Sims et al. (1978) found grasslands to be composed of 3 to 4 times the number of forb species as grasses. In addition, forbs represented a greater proportion of plant biomass than the grasses on our sites. This was consistent with Mueggler and Stewart (1980), who found forbs account for approximately 1.5 times more biomass than grasses. Biomass of forb functional groups would be equal to, or greater than, biomass of grasses in the plant community throughout the growing season. Robust, deep-rooted forbs dominated the biomass on site 1 and were a large contributor to overall community biomass in all 3 seasons on site 2. Biomass of the shallow-rooted forbs in this grassland community appears to have been underestimated by ecologists and managers in grassland community descriptions and management practices. This group is typically characterized as small, spring ephemeral plants. Our data suggest that although small, these species are ubiquitous enough to comprise roughly one-fourth of the total biomass on both sites. Furthermore, shallow-rooted forb biomass was well represented throughout the entire growing season, and these plants were not merely spring ephemeral forbs.

TABLE 4. ANOVA results for functional group, season, and block effects on functional group biomass at sites 1 and 2.

		Site 1		Site 2	
Source	df	Mean square	*P*-value	Mean square	*P*-value
Functional group	2	1467.1	<0.0001	1156.5	<0.0001
Season	2	1312.2	<0.0001	1226.2	<0.0001
Block	3	20.7	0.834	30.4	0.408
F group* Season	4	54.9	0.548	284.2	<0.0001
Error	300	71.8	n/a	31.4	n/a

TABLE 5. Mean separations for biomass main effects at site 1. Letters represent significant differences at the $\alpha \leq 0.05$ level. Functional group biomass was averaged over seasons. Seasonal biomass is the average of the grass, shallow-, and deep-rooted forb functional groups.

				95% confidence interval	
Dependent variable		Biomass ($g \cdot m^{-2}$)	Standard error	Lower bound	Upper bound
Functional group	Grass	27.34a	1.80	23.78	30.89
	Shallow-rooted forbs	23.55a	1.89	19.80	27.30
	Deep-rooted forbs	47.52b	4.60	38.39	56.64
Season	Spring	19.18a	1.55	16.10	22.26
	Summer	36.67b	3.36	29.00	42.34
	Fall	42.29b	3.45	35.45	49.14

The term “grasslands” is misleading to the actual composition of this biome because grasses typically comprise ≤20% of total plant species richness (Sims and Risser 2000). Although 3 to 4 grass species may comprise a large portion of biomass in grasslands, forbs contribute more to community diversity (Sims et al. 1978, Sims and Risser 2000). Because maintaining functional group diversity is suggested for maintaining optimum plant community functioning (Levine and D’Antonio 1999, Dukes 2001), we suggest more emphasis be placed on managing grasslands for forb functional group diversity.

Our results indicate that greater species richness coincides with greater overall biomass or productivity. This finding is consistent with other research suggesting increased diversity is positively correlated with increased community productivity and stabilization (Naeem et al. 1994, Tilman et al. 1997, Tilman et al. 2001, Anderson and Inouye 2001) due to the more complete use of resources (Tilman 1997, Carpinelli 2001). Lower availabilities of resources have been suggested to decrease invasibility of the community by undesired species (McNaughton 1993, Robinson et al. 1995). Recent research implies that functional diversity is equally or more important to resisting invasion than species diversity alone (Symstad 2000, Dukes 2001, Tilman et al. 2001, Pokorny 2002) because of resource preemption (Tilman 1997, Davis and Pelsor 2001, Dukes 2001). Therefore, species number alone may not be as important as species present with different ecosystem roles (Walker 1992, Sala et al. 1996, Sheley et al. 1996, Diaz and Cabido 2001), which suggests that ecosystem functioning may be sensitive to functional diversity.

Our dissection of the grassland plant community into functional groups was a means to investigate diversity of forbs in the community. Dissection into functional groups was also a means to investigate the role of groups in plant community dynamics and management. We classified forbs into functional groups based on morphology because it is thought to reflect the life history strategies of species (Lauenroth et al. 1978, Gitay and Noble 1997) and can be useful in predicting ecosystem dynamics, such as response to disturbance or changes in nutrient composition (Connell and Slatyer 1977, Pickett et al. 1987, Shaver et al. 1997). Maintaining functional groups is essential for long-term persistence of biota within a plant community

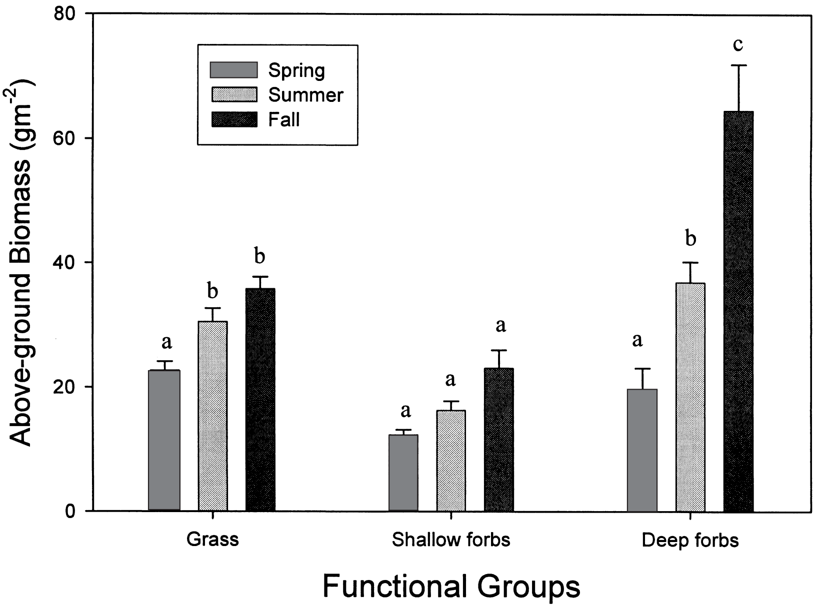

Fig. 2. Seasonal functional group biomass collected during the 2001 growing season at site 2. Letters represent biomass differences ($P < 0.05$) among functional groups comparable within a given season. Error bars are 1 standard error of the mean.

(Walker 1992) and may be more feasible than individual species-based management. Classification into functional groups allows the defining mechanism of the group to be monitored more directly and provides a link between life history strategies at the plant level and processes at the ecosystem level (Chapin 1993, Westoby and Leishman 1997). Separating plants into functional groups is essential for understanding the direction of change within the plant community because groups can be a stronger determinate of ecosystem processes than individual species diversity (Tilman et al. 1997). Furthermore, maintaining plant functional group diversity may be more important to ecological integrity than simply maintaining plant species diversity (Hooper and Vitousek 1997, Tilman et al. 1997, Mack and D'Antonio 1998), because altering functional group diversity could cause large effects on ecosystem processes.

MANAGEMENT AND RESEARCH IMPLICATIONS

We recommend that land managers recognize forb species and forb functional group diversity in grassland classifications. Periodic field sampling during the growing season provides (1) a better understanding of plant community composition and (2) a target plant community for management. As a minimum, we recommend quantifying species diversity twice during the growing season. By sampling once in the spring when spring forbs are beginning to bloom, and once in the summer at peak standing crop, land managers should be able to capture approximately 95% of the diversity in the *Festuca idahoensis/Agropyron spicatum* habitat type. In comparison, a maximum of 76% of community diversity was recorded with a single summer field sampling.

We also recommend land managers establish and maintain forb species and forb functional group diversity in land management decisions. Intermediate levels of disturbance have been proposed to maintain the highest levels of diversity (Connell 1978). In land management intermediate levels of disturbance can be obtained by regulating grazing timing and intensity and through periodic prescribed burning. Diversity can also be maintained through careful planning of herbicide applications. When using herbicides, we recommend carefully calibrating herbicide rates to minimize effects on off-target plants, applying herbicides when the most indigenous vegetation is senescent, spot-spraying areas (versus areawide broadcast spraying) to maintain diversity where individual weedy plants exist, and reseeding competitive grasses and forbs after herbicide application.

Maintaining functional group diversity should be a primary objective of land managers because increased functional group diversity correlates with increased stability and productivity through niche differentiation and resource acquisition. Increasing functional diversity also decreases the risk of invasion by undesired species. Indigenous forb functional groups use resources similarly to nonindigenous forb invaders and are a critical component in community invasion resistance. Besides their contribution to ecosystem function, functional groups are a simpler unit for managing diversity than a species-based approach because the goal is to establish and maintain multiple species that respond similarly to change and collectively resist invasion.

Several research needs were identified in the study. First, a simple, repeatable sampling procedure that can be applied at community and landscape scales needs to be developed. A simple method could encourage land managers and management agencies to put more resources into monitoring if a simple effort could produce a greater return in data collected and handled. Next, areas on the landscape most susceptible to invasion need to be identified as focal points for maintaining diversity and invasion resistance. Research also must address the level of diversity, or functional group diversity, that is needed to maintain a diverse, invasion-resistant, and properly functioning ecosystem. Finally, techniques for native plant propagation, establishment, and revegetation need to be improved and further developed.

ACKNOWLEDGMENTS

We greatly appreciate technical assistance from Catherine Zabinski, and field and lab assistance from Tracy Cashman, Shelly Grossi, Julian Calabrese, Steve Laufenberg, Kristi McKinnon, Jennifer Anderson, Erin Bard, Jane Mangold, Jim Hafer, and Kirk Denny. We thank Catherine Seibert and Dr. Sharon Eversman for assisting with vegetative identification. Funding was provided by the Turner Foundation and the Tribal Colleges Research Grant Program, USDA. Special thanks to the Flying D Ranch and Turner Enterprises, Inc., for assisting with this research.

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Received 4 November 2002
Accepted 3 April 2003