Ecological Model for Classifying and Monitoring of Green Needlegrass/Western Wheatgrass/Blue Gramma/Buffalograss Ecological Type

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Abstract

A multivariate statistical model was developed to classify plant seral stages and to monitor succession of the green needlegrass (*Nassella viridula* (Trin.) Barkworth), western wheatgrass (*Pascopyrum smithii* (Rydb.) Á Löve), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths), buffalograss (*Bouteloua dactyloides* (Nutt.) J.T. Columbus) ecological type on grasslands of North and South Dakota, eastern Montana and Wyoming. Seral stages are objectively derived groupings of vegetation composition based on the range of natural variability within the current grassland ecological type. The model developed in this paper can be used by range and wildlife managers to evaluate management objectives by monitoring changes in plant species cover and composition within and among seral stages and community phases. Four ecological seral stages representing early to late succession were quantitatively identified with an estimated 98 percent accuracy. Three common perennial grasses provide the information to assign seral stages and monitor trends based on index values (canopy cover (%) x frequency of occurrence (%)) for western wheatgrass, buffalo grass and green needlegrass. Estimates of canopy cover and frequency of occurrence of these three plant species are all that is required for the model. The four defined seral stages provide resource managers with options to quantitatively evaluate management alternatives and objectives associated with state and transition community phases. The developed model for this ecological type is simple to use, reliable, repeatable, accurate and cost effective to meet management objectives and monitoring plans.

Keywords: Succession, seral stages, diversity, monitoring, mixed-grass, grassland, management, state and transition.

Introduction

The ecological status of grasslands undergoes changes, over time following natural and human induced disturbances. Knowledge of the various patterns of grassland dynamics provide an ecological framework to evaluate influences associated with natural events and resource management. State and transition models have received much attention in recent years (Briske et al. 2005) and provide a framework to understand natural and human induced disturbances. These models are conceptual based on expert opinion, personal judgments that are essentially qualitative (Twidwell et al. 2013). However, subjective data and interpretations are highly variable among observers (Kershaw 1973, Block et al. 1987) and often make it difficult to obtain consistent interpretations to determine vegetation trends and steady states of succession.

State and transition models can be quantified using multivariate statistical modeling that depicts vegetation change related to weather, fire, grazing, management and plant succession. These multivariate models can provide an approach for predicting ecological processes of vegetation change (Uresk 1990, Mclendon and Dahl 1983, Huschle and Hironaka 1980, Friedel 1991, Benkobi et al. 2007, Uresk et al. 2012). Multivariate models with cluster analyses provide discrete categories based on ecological processes that are related to key plants distributed among seral stages associated with ecological types (Uresk 1990, Benkobi et al. 2007, Uresk et al. 2012). Multivariate models of plant succession allow resource managers to easily obtain quantitative measurements and evaluate current range conditions. The approach outlined in this paper could be equally applied to quantitatively differentiating community phases within state and transition models incorporated into updated interagency ecological site descriptions (Bestelmeyer et al. 2010).

Ecological types and sites are similar and both are used to describe differences in ecological capability and response on rangelands. Ecological type is the classification system used by the USDA-Forest Service. More recently, ecological site is a classification used by Natural Resource Conservation Service (NRCS). Both systems of plant classification are based on conceptual or distinctive landscape elements. These elements include climate, geology, landform, soils and distinctive vegetation or potential vegetation that differs from other kinds of vegetation. The vegetation within a type or site responds similarly to management and natural disturbances (Winthers et al. 2005, USDI and USDA 2013a).

An overall purpose of this research study was to develop a quantitative model based on the interrelationships of plant species, past management practices that best characterize the ecological type throughout the progression of plants between and among seral stages. The objectives were: (1) provide managers a tool for assessment and monitoring ecological change (2) provide a classification of seral stages and (3) to produce a sampling protocol for monitoring.

Study Area

The study was conducted on Fort Pierre National Grassland in central South Dakota. This grassland is comprised of approximately 46,400 ha (116,000 ac) of federal lands with private lands intermixed. The Fort Pierre National Grassland is located west of the Missouri River, within the Pierre Hills physiographic region (Johnson et al. 1995). Topography was characterized as upland flats dissected by intermittent drainages and swales with gently undulating plains. Elevation ranged from 427 m to 701 m. Soils were primarily clays derived from the Cretaceous Pierre formation and the ecological site description is clayey rangeland (Gries 1998, USDA-NRCS 2008). The dominant grasses were green needlegrass (*Nassella viridula* (Trin.) Barkworth), western wheatgrass (*Pascopyrum smithii* (Rydb.) Á Löve), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths) and buffalograss (*Bouteloua dactyloides* (Nutt.) J.T. Columbus). Common forbs included scarlet globemallow (*Sphaeralcea coccinea* (Nutt.) Rydb.), western yarrow (*Achillea millefolium* L.) and prairie coneflower (*Ratibida columnifera* (Nutt.) Woot. & Standl.). The ecological type, wheatgrass-needlegrass, for this study occurs in western North and South Dakota, eastern Montana and Wyoming and is in Kuchler's (1964) potential vegetation type 66. Plant nomenclature followed USDA-NRCS (2013b).

The mean annual precipitation (1964-2012) was 42.4 cm and ranged from 16.3 cm to 60.5 cm (HPRCC 2013). Seventy-three percent of the precipitation falls during the spring and summer as short duration intense thunderstorms. The average monthly temperature ranged from 31°C in the summer to 2° C in the winter.

Methods

Experimental design, data collection and analyses follow procedures developed by Uresk (1990). A field reconnaissance was conducted to assess the ecological type variability of the study area based on Soil Conservation Service range site description, currently described as ecological site description for clayey soils (USDA-NRCS 2008). Site selection encompassed the entire grasslands to include the full range of natural variability. Sites were stratified into three pre-defined (USDA-NRCS 2008) visual seral stages, early, mid and late based on key plant species and their changes through succession by professional range ecologists (Cochran 1977, Thompson et al. 1998, Levy and Lemeshow 1999).

Data were collected on 57 sites (macroplots) during the summer of 1991. Each site was randomly selected within one of three perceived seral stages based on major plant species abundance defined for each seral stage by experienced range professionals (USDA-NRCS 2008). First, an area was located within a perceived seral stage for site selection. Once the area was located, a random direction and a random number of paces were established prior to actual site location for establishment of transects. This procedure was repeated for all sites. However, some late seral stage sites were located in long-term exclosures. At each site, two, 30 m parallel transects were established 20 m apart. Canopy cover (six cover classes) and frequency of occurrence of plant species were estimated within 0.1 m^2 (20 x 50 cm) quadrats (Daubenmire 1959). These quadrats were located at 1 m intervals along each of the two transects for a total of 60 quadrats. Total plant cover, litter cover and bare ground were estimated within each quadrat. Once all data were collected for the site, it was assigned a seral stage. All data were averaged by transect. The two transect means were then averaged for each site to generate a grand mean for data analyses. An index for plant species was created based on canopy cover means time the frequency means: Index = ((transect 1 cover + transect 2 cover)/2) X ((transect 1 frequency + transect 2 frequency)/2) (Uresk 1990). Conversely, averaging canopy cover and frequency of occurrence over several sites and then multiplying the two variables will not provide the exact overall indices.

Uresk (1990) defined the Index as follows: "The cover-frequency index combines estimates of two important vegetation characteristics. Frequency relates to the number of times a species occurs in a given number of small sample plots and is a measure related to density (Mueller-Dombois and Ellenberg 1974). Canopy cover, the vertical projection of the shoot area of plants, is of greater ecological significance than density in the measurement of plant distribution (Mueller-Dombois and Ellenberg 1974) and gives a better indirect measure of plant biomass than the number of individuals. Cover values may change due to year differences, but multiplied with frequency to form an index, changes in an ecological stage are less likely when a change may not exist; frequency values are less likely to change abruptly on a yearly basis. However, if high frequency paired with low cover is equivalent to low frequency paired with high cover for a species, then the index is flawed. The likelihood of both situations occurring in the vegetation type is highly unlikely". Data were analyzed with SPSS (1992) and SPSS (2003) software.

Preliminary data examinations of the overall index mean for the ecological type removed minor plant species (variables) from analyses with mean index values of <1. The remaining plant species were used as variables for analyses in the following sequence (Uresk 1990): 1) Variable reduction with discriminant analyses for 57 sites with each site assigned to one of the perceived three seral stages as grouping variables. 2) The variables remaining after reduction by discriminant analyses were analyzed by principal component analyses for further variable reduction. Principal component analyses were useful after initial data reduction by discriminant analyses only with fewer plant variables. We used the extraction method and examined the component matrix, component scores coefficient matrix and the mean index value for each variable. There were no further analyses with principal component procedures. 3) A non-hierarchical cluster analysis (ISODATA) defined groupings based on the five variables for seral stages (Ball and Hall 1967, del Morel 1975). Stepwise discriminant analysis was used again to estimate compactness of the cluster and identify key variables that accounted for the differences between and among clusters and to develop Fisher classification coefficients (SPSS 2003, Uresk 1990). Discriminant analyses identified three key variables for model development and for classifying seral stages and monitoring. Misclassification error rates were estimated with SAS (1988) and SPSS (2003), a cross validation using a jackknife or "leave one site out" procedure. In the cross validation procedure, each site was classified by the discriminant functions derived from all other sites other than the site left out. This was repeated for each of the sites and gave a true hold out prediction for each of the sites. The developed model was field tested the following year.

Assignment of a seral stage was achieved by applying Fisher's classification discriminant functions (SPSS 2003) to a new set of data. The Fisher discriminant function coefficients indicated the significance of each key plant species among seral stages. Key plant species with the greatest coefficients by seral stage expressed the indicator value of plants within the ecological type. To determine the seral stage assignment from Fisher's coefficients, we multiplied site index values for green needlegrass, western wheatgrass and buffalograss for each seral stage (row) and then summed the products (+ and -) including the constant for a score. The greatest positive score or the least negative score when all scores were negative assigned the seral stage. Additional information for this ecological type with programs may be downloaded for personal data assistants (PDAs) and personal computers that will directly assign the seral stage at USDA-Forest Service website: http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

Results

A total of 99 plant species (variables) and total cover for graminoids, forbs, litter and bare ground were sampled on 57 sites. After initial reduction of 99 plant species with index values <1, discriminant analysis reduced the variables to 11 plant species. Principle component analysis further reduced the 11 variables to five plant species: green needlegrass, western wheatgrass, blue grama, buffalograss and threadleaf sedge (*Carex filifolia* Nutt.) and explained 62 percent of the variation. These five variables evaluated by non-hierarchical cluster analysis (ISODATA) resulted in four groupings defined as seral stages. Stepwise discriminant analysis estimated compactness of the groupings that resulted in three variables, green needlegrass, western wheatgrass and buffalograss for the model. These three plant species were defined as key species for classification and monitoring of seral stages.

The clustering procedure grouped the 57 sites (3,420 quadrats (micro-plots), 114 transects) into four distinct seral stages ($P < 0.001$). Index values for the three plant species illustrated the dynamics throughout the four seral stages in this ecological type (Fig. 1, Table 1). Green needlegrass dominated the late seral stage followed by western wheatgrass for late intermediate and early intermediate stages, while buffalograss was dominant in the early seral stage. Each key plant species characterized the vegetation dynamics within this ecological type (Fig. 1).

Fisher's classification discriminant functions showed the significance of each key plant species among seral stages and provided coefficients for classifying seral stages and monitoring within this ecological type (Table 2). Key plant species with the greatest coefficients by seral stage expressed the indicator value of plants within the ecological type. Blue grama was common within the ecological type but was not a significant variable for classifying seral stages. An example of calculating seral stage assignment with Fisher's classification coefficients for key plant species indices collected from a site is presented in Table 3. When the index data are multiplied by the Fisher coefficients and summed accounting for the constants, the site is assigned to early intermediate

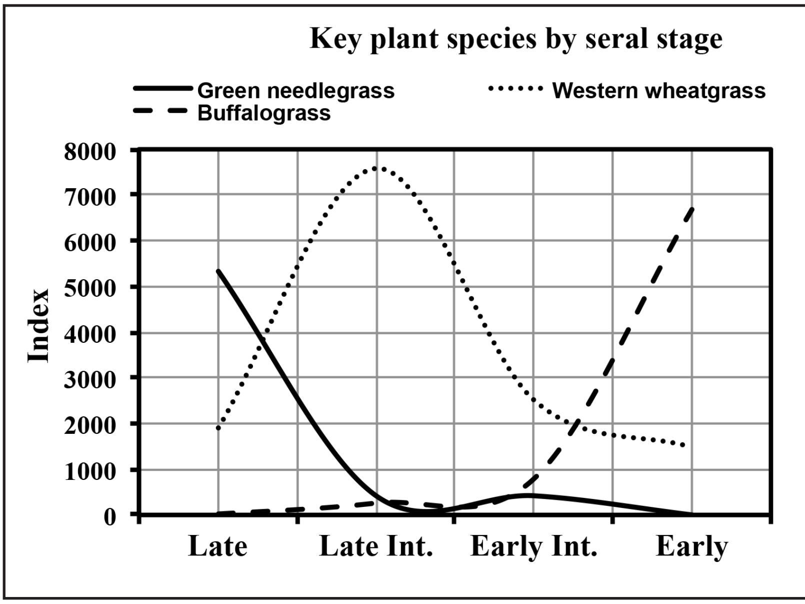

Figure 1. Key plant species with mean index values displayed throughout the four seral stages in a green needlegrass, western wheatgrass, blue grama and buffalograss ecological type. Graph provides an approximate mixture of plant species at each seral stage.

Table 1. Mean indices of key plant species for four seral stages in the ecological type. Indices were calculated as a product of ((transect 1 cover + transect 2 cover)/2)* ((transect 1 frequency + transect 2 frequency)/2).

		MEAN INDEX		
Seral	**n**	**Green needlegrass**	**Western wheatgrass**	**Buffalograss**
Late	10	5318	1927	1
Late intermediate	22	221	7580	259
Early intermediate	18	219	2514	790
Early	7	0	1480	6682

n = number of sites

Table 2. Fisher's discriminant function coefficients and constants for ecological classification model for key variables within the ecological type by seral stage (SPSS 2003).

Species	Late	Late intermediate	Early intermediate	Early
Green needlegrass	0.01128	0.00063	0.00062	0.00103
Western wheatgrass	0.00113	0.00412	0.00138	0.00089
Buffalograss	0.00083	0.00040	0.00087	0.00679
Constant	-32.458	-17.122	-3.529	-24.742

Table 3. An example of assigning seral stages by using Fisher's discriminant coefficients and constants (SPSS 2003) with new index data collected from the field for a site. Indices were calculated as a product of ((transect 1 cover + transect 2 cover)/2) X ((transect 1 frequency + transect 2 frequency)/2).

	Green needlegrass	Western wheatgrass	Buffalograss		
Seral	**(Coeff[1] X Index +**	**Coeff X Index +**	**Coeff X Index)**	**Constant =**	**Score**
Late	(0.01128 X 84 +	0.00113 X 3290 +	0.00083 X 430)	- 32.458 =	-27.436
Late Int[1]	(0.00063 X 84 +	0.00412 X 3290 +	0.00040 X 430)	- 17.122 =	- 3.342
Early Int	(0.00062 X 84 +	0.00138 X 3290 +	0.00087 X 430)	- 3.529 =	**1.437**[2]
Early	(0.00103 X 84 +	0.00089 X 3290 +	0.00679 X 430)	- 24.742 =	-18.808

[1] Coeff = coefficient, Int = Intermediate
[2] Assigned seral stage

seral stage with a score of 1.44. Cross validation (jackknife procedure) results by seral stage showed a misclassification rate of 1 percent for late and early seral stages, 2 percent for late intermediate and 4 percent for early intermediate seral stage (SAS 1988). Overall accuracy of the model based on cross validation was 98 percent. Additional information on seral stage classification, monitoring, trend monitoring, data collection, plot establishment and programs for PDA's and other computers may be obtained from USDA-Forest Service web site at http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

Late seral stage

Late seral stage was dominated by green needlegrass with a mean of 60 percent canopy cover (SE = 4) and 89 percent frequency of occurrence (SE = 3) for 10 sites (Table 4, Table 5). Western wheatgrass, field brome (*Bromus arvensis* L., an annual also known as Japanese brome) and blue grama were the next three most common grasses present. The forb component was dominated by four species with canopy cover between 2-3 percent and frequency of occurrence 8-12 percent. Scarlet globemallow, sweet clover (*Melilotus officinalis* (L.) Lam.), prickly lettuce (*Lactuca serriola* L.) and field bindweed (*Convolvulus arvensis* L.) represented the dominant forbs. Canopy cover of graminoids was 90 percent (SE = 3), forbs 13 percent (SE = 4), litter 23 percent (SE = 9) and bare ground 6 percent (SE = 3). Plant species richness of the late seral stage consisted of 23 forbs and 19 graminoids and no shrubs (Fig. 2). Approximately 80 percent of the plants were perennial species and 20 percent annual-biennial species (Fig. 3).

Late Intermediate seral stage

Western wheatgrass dominated the late intermediate seral stage with a mean of 76 percent canopy cover (SE = 3) and 99 percent frequency of occurrence (SE = < 1) for 22 sites (Table 4, Table 5). Blue grama and field brome were the next most common grasses each with canopy cover of 20 percent (SE = 4, 6) and frequency of 41 (SE = 7) and 43 percent (SE = 9), respectively. Green needlegrass, buffalograss, needleleaf sedge (*Carex duriuscula* C.A. Mey.) and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) were the next most common plants with an average of 5-6 percent canopy cover. Canopy cover for the forb component was dominated by sweet clover and curlycup gumweed (*Grindelia squarrosa* (Pursh) Dunal) with 4 percent and 3 percent cover. Canopy cover of graminoids was 92 percent (SE = 1), forbs 15 percent (SE = 3), litter 26 percent (SE = 7) and bare ground 11 percent (SE = 4). Plant species richness consisted of 52 forbs, 23 graminoids and 1 shrub (Fig. 2). Seventy percent of the plants were perennial and 30 percent annual-biennials (Fig.3).

Table 4. Average canopy cover (%) and standard errors (in parentheses) of common plant species and other variables by seral stages.

Species or variable	Late[1]	Late Intermediate	Early Intermediate	Early
Green needlegrass *Nassella viridula*	59.6(3.6)	6.2(1.9)	5.5(2.5)	0.0(0)
Western wheatgrass *Pascopyrum smithii*	26.1(5.1)	76.3(2.5)	29.3(3.3)	19.3(5.8)
Blue grama *Bouteloua gracilis*	13.4(6.2)	20.4(4.1)	8.8(3.8)	5.8(7.2)
Buffalograss *Bouteloua dactyloides*	<1(0.5)	5.2(2.5)	14.7(3.7)	69.6(6.0)
Purple threeawn *Aristida purpurea*	3.4(1.7)	<1(0.7)	5.4(3.5)	1.3(1.7)
Sideoatsgrama *Bouteloua curtipendula*	1.2(0.7)	5.0(2.2)	5.2(3.5)	5.8(2.7)
Needleleaf sedge *Carex duriuscula*	<1(0.8)	5.4(2.3)	3.0(1.4)	5.0(3.8)
Field brome *Bromus arvensis*	14.9(8.2)	19.5(5.8)	21.1(6.3)	15.2(9.6)
Crested wheatgrass *Agropyron cristatum*	3.4(1.6)	0.1(0.1)	7.7(4.2)	0.1(0.1)
Scarlet globemallow *Sphaeralcea coccinea*	2.0(1.3)	1.1(0.3)	1.7(0.4)	2.5(0.4)
Yellow sweet clover *Melilotus officinalis*	2.7(1.6)	4.1(2.4)	4.4(2.6)	<1(2.9)
Curlycup gumweed *Grindelia squarrosa*	0.1(0.1)	2.6(1.5)	3.5(1.6)	0.2(0.1)
Prickly lettuce *Lactuca serriola*	2.1(1.2)	1.7(0.8)	0.7(0.4)	0.1(0.1)
Field bindweed *Convolvulus arvensis*	2.7(1.8)	0.2(0.1)	1.3(1.1)	0.0(0.0)
Graminoid cover[2]	90.0(3.2)	91.8(0.9)	76.4(4.5)	88.4(2.2)
Forb cover[2]	12.5(4.1)	14.9(3.1)	23.4(3.9)	9.8(1.1)
Litter cover	22.5(9.2)	26.3(6.7)	17.6(7.0)	18.0(12.7)
Bare ground	6.2(3.4)	11.2(4.3)	10.2(3.8)	10.2(7.4)

[1] Sample size: Late=10; Late Intermediate=22; Early Intermediate=18; Early=7

[2] Two dimension cover and not the sum of the individual plant species.

Table 5. Frequency of occurrence averages (%) and standard errors (in parentheses) of common plant species and other variables by seral stages.

Species or variable	Late	Late Intermediate	Early Intermediate	Early
Green needlegrass *Nassella viridula*	88.5(3.4)	15.3(3.6)	10.2(4.1)	0(0)
Western wheatgrass *Pascopyrum smithii*	60.3(9.4)	99.3(0.3)	80.5(3.9)	61.7(10.8)
Bluegrama *Bouteloua gracilis*	24.5(10.1)	41.2(6.8)	19.6(6.8)	2.7(19.3)
Buffalograss *Bouteloua dactyloides*	<1(0.5)	9.9(4.0)	29.3(6.3)	95.5(1.8)
Purple threeawn *Aristida purpurea*	7.0(3.3)	<1(0.5)	10.7(5.5)	4.5(4.0)
Sideoatsgrama *Bouteloua curtipendula*	2.7(1.7)	12.0(5.0)	8.2(4.9)	19.3(8.5)
Needleleaf sedge *Carex duriuscula*	<1(0.8)	18.0(6.9)	7.8(3.2)	20.7(12.3)
Field brome *Bromus arvensis*	27.3(10.5)	42.5(8.5)	41.6(10.7)	34.1(15.6)
Crested wheatgrass *Agropyron cristatum*	9.3(4.2)	0.2(0.1)	15.9(6.2)	1.0(1.0)
Scarlet globemallow *Sphaeralcea coccinea*	8.2(4.0)	8.7(2.1)	14.0(3.1)	27.6(4.7)
Yellow sweet clover *Melilotus officinalis*	15.6(9.5)	11.4(5.7)	11.0(5.7)	<1(2.9)
Curlycup gumweed *Grindelia squarrosa*	0.7(0.5)	7.8(3.5)	13.4(5.0)	4.3(3.3)
Prickly lettuce *Lactuca serriola*	9.8(5.8)	8.9(3.1)	5.2(2.5)	0.5(0.5)
Field bindweed *Convolvulus arvensis*	11.5(7.7)	0.8(0.5)	3.8(3.0)	0.0(0.0)

Early Intermediate seral stage

Early intermediate seral stage was dominated by western wheatgrass with a canopy cover 29 percent (SE = 3) and frequency of occurrence 81 percent (SE = 4) for 18 sites (Table 4, Table 5). Field brome, buffalograss, blue grama and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) were the next most common grasses with canopy cover 21 percent (SE = 6), 15 percent (SE = 4), 9 percent (SE = 4) and 8 percent (SE = 4) and frequency 42 percent (SE = 11), 29 percent (SE = 6), 20 percent (SE = 7) and 16 percent (SE = 6). The forb component based on canopy cover was dominated by scarlet globemallow (2%), sweet clover (4%) and curlycup gumweed (4%). The intermediate seral stage included seven additional forb species with 1 percent or greater canopy

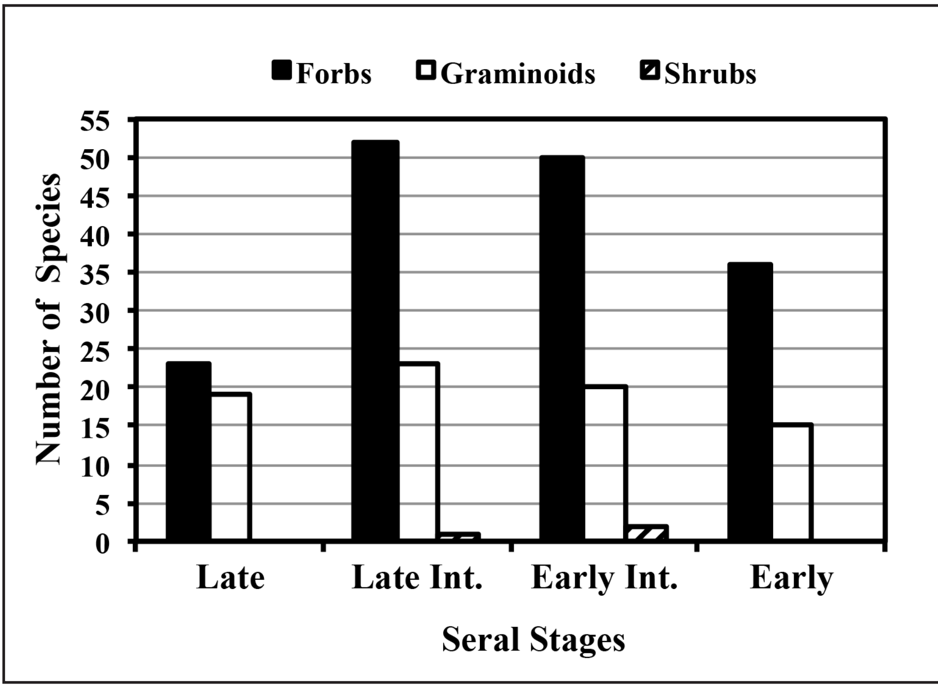

Figure 2. Number of plant species by life form category and seral stages in a green needlegrass, western wheatgrass, blue grama and buffalograss ecological type.

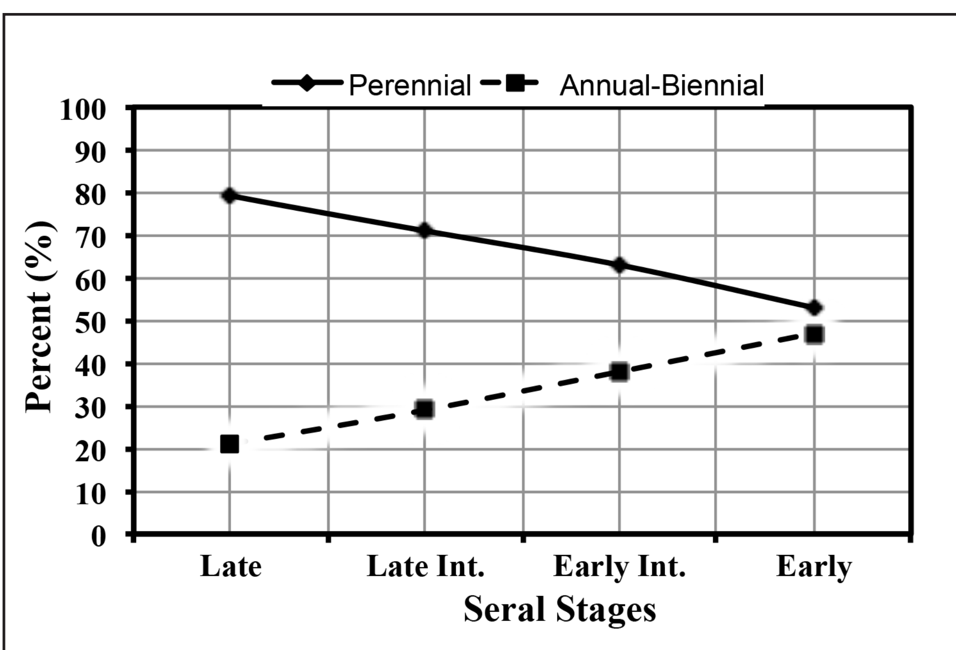

Figure 3. Percent perennial and annual-biennial categories expressed from total plant species throughout the four seral stages.

cover. These forbs included field bindweed, American vetch (*Vicia americana* Muhl. ex Willd.), common dandelion (*Taraxacum officinale* F.H. Wigg.), woolly plantain (*Plantago patagonica* Jacq.), prairie spiderwort (*Tradescantia occidentalis* (Britton) Smyth.), common yarrow (*Achillea millefolium* L.) and snow on the mountain (*Euphorbia marginata* Pursh). Graminoid cover was 76 percent (SE = 5), forbs 23 percent (SE = 4), litter 18 percent (SE = 7) and bare ground 10 percent (SE = 4). Plant species richness included 50 forbs, 20 graminoids and 2 shrubs (Fig. 2). Approximately 63 percent of the plants were perennial and 37 percent were annuals-biennials (Fig. 3).

Early seral stage

Buffalograss was widely distributed and dominant in the early seral stage with 70 percent canopy cover (SE = 6) and 96 percent frequency of occurrence (SE = 2) for 7 sites (Table 4, Table 5). Canopy cover and frequency of occurrence for western wheatgrass was 19 (SE = 6) and 62 percent (SE = 11). Blue grama was a minor component in the early seral stage. Annual field brome had 15 percent canopy cover (SE = 10) and a 34 percent frequency of occurrence (SE = 16). Field brome is an invasive non-native species. Scarlet globemallow was the only forb with greater than 2 percent canopy cover. Canopy cover of graminoids was 88 percent (SE = 2), forbs 10 percent (SE = 1), litter 18 percent (SE = 13) and bare ground 10 percent (SE = 7). Thirty-six forbs, 15 graminoids and no shrubs were represented in the early seral stage (Fig. 2). Perennial plant species represented 53 percent with 47 percent annual-biennials (Fig. 3).

Discussion

The multivariate model developed for this study can be used to describe plant dynamics and species changes between and among seral stages within this ecological type. Disturbances such as grazing, fire and climatic changes can move plant species association or abundance from an early seral stage to a late seral stage or other discrete pathways within the wheatgrass-needlegrass ecological type. State and transition models for plant succession have been a conceptual approach for describing ecological succession and dynamics (Bestelmyer et al. 2003, Briske et al. 2005). The developed model with key plant species and coefficients can be easily incorporated into state and transition models for the ecological type and ecological sites. This model can be used to quantify the differences between and among seral stages and to identify key plants that are indicators of potential shifts. Currently, state and transition models are qualitative and result from personal judgments and observations (Twidwell et al. 2013). The developed model provides resource managers a powerful tool for monitoring resource status resulting from grazing, fire and climatic changes as managers attempt to meet or maintain a desired seral stage at a site (Uresk 1990, Benkobi and Uresk 1996, Zweig and Kitchens 2009, Uresk et al. 2012). Our model was based on data collected from a full range of vegetation values over the landscape (canopy cover and frequency of occurrence) representing natural variation and can be used to determine seral stages regardless of hypothetical past and future climax vegetation.

The seral stages identified in this study limit the number of management objectives to four. These four stages represent a continuum over the landscape, but allow land managers discrete categories for management at different spatial scales. For example, land managers can easily determine seral condition for each pasture within each grazing allotment. Depending upon the land management objectives, livestock grazing can be used for regulating seral stages (Severson and Urness 1994). Livestock grazing can be adjusted (increased or decreased) to modify plant succession or transition from a non-preferred stage toward a planned objective, a desired seral stage.

By using characteristics of grasses, seral stages can be adjusted. For example, western wheatgrass and green needlegrass are cool season, palatable perennial grasses that often decrease when subjected to overgrazing (Lewis et al. 1956). Buffalograss and blue grama are palatable warm season grasses that are more tolerant of grazing and increase under more intense grazing. Western wheatgrass increased and buffalograss decreased with light grazing on the Cottonwood Range Field Station located west of Fort Pierre National Grassland in South Dakota (Lewis et al. 1956).

Managing for all four seral stages may be a management alternative. Inclusion of multiple seral stages increases plant and animal diversity over the landscape. Because one individual seral stage is not practical for multiple-use management across the landscape, the entire seral range (from early to late) is needed to accommodate greatest plant species diversity, wildlife diversity, livestock production and recreation (Uresk 1990, Vodehnal et al. 2009, Fritcher et al. 2004, Benkobi and Uresk 1996, Uresk et al. 2012). The developed model provides resource managers with a cost effective, accurate and repeatable tool that can be applied across allotments and the landscape. A recommendation of 10-15% of the landscape should be in each early and late seral stages with the remainder in the two intermediate stages (Kershaw 1973, Mueller-Dombois and Ellenberg 1974). This would provide a mixture of seral stages across the landscape to provide for both plant and animal diversity and livestock production.

The developed classification and monitoring system used multivariate statistical methods to define key plant species that would classfy seral stages within a green needlegrass, western wheatgrass, blue grama, buffalograss ecological type. Although blue grama is common in this ecological type, it was not selected through statistical procedures as a key plant for classifying seral stages. As a result, four seral stages with three key plant species were quantitatively identified with an accuracy of 98 percent. Canopy cover and frequency of occurrence for the key plants for the index are the only required field data to determine seral stage classification and monitoring. Indices must be calculated for each individual site (See methods). To obtain an overall mean of several sites, each site index is averaged. Data collection may be conducted yearly or once every few years with a minimum of two macroplots per section (640 acres) within the ecological type. See USDA-Forest Service website for additional information: http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

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