Ecological Model for Seral Stage Classification and Monitoring with Key Plants on Sandy Ecological Sites in Nebraska and South Dakota

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Abstract

The objectives were to develop a multivariate model (state and transition) to define and classify seral stages with capabilities that enable us to monitor vegetation changes with three key plant species within a sandy ecological site located in the Sand Hills of Nebraska and South Dakota. Three key plant species, prairie sandreed (*Calamovilfa longifolia*) /little bluestem (*Schizachyrium scoparium*)/sun sedge (*Carex inops*) provided inputs for the model to classify seral stages and to monitor vegetation transitions based on index values (canopy cover (%) x frequency of occurrence (%)) from field measurements within the full range of natural variability. The model does not require a straight progression through all seral stages or plant phases but may go through multiple stages or remain at a steady state. Four seral stages that represent early to late succession provided an assignment accuracy of 90 percent. Seral stages were significantly different (P<0.05) from each other. Application of the model to predict seral stages and vegetation monitoring is accurate, quantitative and free of subjective judgments.

Keywords: Succession, range, sand hills, state and transition

Introduction

The public has placed greater demands on our rangelands for multiple uses in recent years. Livestock grazing has been a common use of the rangeland resources while the importance of wildlife, recreation and water use has increased. Over the past few decades, to maintain a sustainable rangeland for multiple uses, vegetation classification and monitoring based on plant succession and communities have been important inputs for resource management (Dyksterhuis 1949, Dyksterhuis 1985). The succession and community framework has provided resource managers methods to evaluate vegetation changes occurring from natural events as well as from management activities.

Recently, state and transition conceptual models based on subjective judgments and observations have received much attention (Bestelmyer et al. 2003, Briske et al. 2005). These models are qualitative (Twidwell et al. 2013). Subjective observations and interpretations of vegetation status and trends are highly variable among observers (Kershaw 1973, Block et al. 1987). Various multivariate non linear models have been developed based on plant succession and communities for evaluating the magnitude of vegetation change and to maintain a sustainable resource system. (Huschle and Hironaka 1980, Mclendon and Dahl 1983, Uresk 1990, Benkobi et al. 1996, Uresk et al. 2010, Uresk et al. 2012). Multivariate models provide discrete categories based on ecological processes (plant succession) based on key plant variables to determine changes or transitions in steady states within an ecological site. The objectives in this study were: (1) develop a multivariate ecological model based on the range of vegetation variability that best describes the ecological site with discrete seral stages or community phases and states providing the ability to implement quantitative monitoring, (2) describe and discuss the defined discrete classification of seral stages (community phases) and (3) present application guidelines for sampling protocol and monitoring.

Study Area

The study was conducted on the Nebraska National Forest in the Sand Hills of central Nebraska. This region encompases approximately 5 million hectares (19,300 miles^2) in southern South Dakota and Central Nebraska (Bleed and Flowerday 1990). Study areas included the Samuel R. McKelvie District that encompasses 46,280 hectares (115,700 acres) and the Bessey District with 36,183 hectares (90,456 acres). The two areas are separated by 80 kilometers (50 miles).

Climate is semi-arid (Burzlaf 1962), with a mean annual precipitation (HPRCC 2013a) of 53 cm (21 in) at Halsey, NE (1903 to 1990) and 48 cm (19 in) at Valentine NE (1948 to 2013) (HPRCC 2013b). Eight to 78 percent of the precipitation falls during the growing season (April-September) as short duration intense thunderstorms. Average monthly temperature ranged from a low of -13° C (8° F) in the winter to a high of 32° C (89° F) in the summer.

Sand Hills flora has been described numerous times since the late 1800's. An overall review of the Sand Hills for the ecology of flora and fauna, soils, livestock grazing, climate, geology, hydrology, streams lakes and history of the area is presented by Bleed and Flowerday (1990). Burzlaff (1962) defined the vegetation of the Nebraska sandhills into three range sites, dry valleys, rolling sands and choppy sands. Each of the range sites were characterized by plant species cover as a measure of forage production and soils. Topography is important in the distribution of plants within these range sites (Barns and Harrison 1982). This study focused on flat valleys, between choppy and rolling sand hills, also known as dry valleys or sandy range sites (Bleed and Flowerday 1990, USDA-NRCS 2014). Dominant plant species include prairie sandreed (*Calamovilfa longifolia*), sand bluestem (*Andropogon hallii*), little bluestem (*Schizychyrium scoparium*), big bluestem (*Andropogon gerardii*), blue and hairy grama (*Bouteloua gracilis* and *B. hirsuta*), needle and thread grasses (*Hesperostipa comata* and *H. spartea*), sedges (*Carex inops*) and switchgrass (*Panicum virgatum*). The forb, common ragweed (*Ambrosia psilostachya*) and shrub, prairie rose (*Rosa arkansana*) were common on the ecological site (Burzlaff 1962, Barnes and Harrison 1982, USDA-NRCS 2014). Plant nomenclature followed USDA_NRCS (2013).

Methods

Data collection for canopy cover and frequency of occurrence followed Daubenmire (1959) and experimental designs and statistical analyses followed Uresk's (1990) procedures. Data were collected on 29 macroplots (sites) during the summer of 1989 and 1990. Each macroplot was randomly selected within one of three perceived seral stages of early, mid and late plant succession (Cochran 1977, Thompson et al. 1998, Levy and Lemeshow 1999). At each macroplot, 2, 30 m (99 ft) parallel transects were set 20 m (66 ft) apart. Canopy cover and frequency of occurrence in 0.1 m^2 (20 x 50cm) plots of individual plant species, total gramoinds, forbs, shrubs, percentage of plant litter and bare ground (Daubenmire 1959) were recorded . Daubenmire cover classes were transformed to mid-point values. However, the mid points for interpretation are based on the assumption that the actual values tend to be symmetrically dispersed around the mid points (Bonham 1989). Analyses were based on transect means (percentages); not individual microplots with mid point classes or ordinal data. These microplots were placed at 1 m (3.3 ft) intervals along each transect. All macroplot data (60 microplots) for each site were averaged for canopy cover and frequency of occurrence for individual plant species and litter, bare ground and life forms (grasses, forbs, shrubs) by site for analyses. An index for plant species, per site, was created based on canopy cover means multiplied by frequency means: Index = ((transect 1 cover + transect 2 cover)/2) X ((transect 1 frequency + transect 2 frequency)/2) (Uresk 1990). To determine the overall mean index, individual site indices were averaged for the area. Note, averaging canopy cover and frequency of occurrence over several sites and then multiplying the two variables will not provide the exact overall mean index. Data were analyzed with SPSS (1992) and SPSS (2003). Sample size estimates (macroplots) were estimated to be within 20 percent of the mean at 80 percent confidence (Cochran 1977).

Stepwise discriminant analyses were used for the initial reduction of variables on the three perceived seral stages (early, mid, late) (Uresk 1990). This initial procedure for data reduction produced a data set that was employed for all subsequent analyses. Principal component analyses on data from the initial data reduction were useful for further data reduction with fewer variables. We used the extraction method and examined the component score coefficient matrix for each of the variables after initial data reduction (Uresk 1990, SPSS 2003).

The reduced data were analyzed with ISODATA, a non-hierarchical cluster analyses (Ball and Hall 1967, del Moral 1975). Discriminant analyses on cluster groups identified key variables for seral stage classification and provided a quantitative model for classification and monitoring ($P< 0.05$). Misclassification error rates were estimated with cross validation procedures of leaving one site out (SPSS 2003, SAS 1988). Assumptions for multivariate modeling were examined by Q-Q plots for normality, multicollinearity between predictor variables and independence of variables (SPSS 2003). Homogeneity of variances was analyzed by Levene's test. Means of means approach a normal distribution (Steel and Torrie 1980). All assumptions were acceptable for multivariate modeling.

The model was field tested in 1991. Field testing of the model for a new macroplot was first evaluated biologically based on plant species composition, followed by evaluating the classification of the site to a seral stage.

Results

Cluster analyses (ISODATA) grouped the 29 sites into 4 distinct seral stages ($P<0.05$). Stepwise discriminant analysis for model development defined 3 key plant species (prairie sandreed, little bluestem, sun sedge), as the best predictive variables for seral stage classification and monitoring transitions within this ecological site. The distributions of indices for each key plant species showed the biological dynamics throughout the seral stages or plant phases (Fig. 1, Table 1). Prairie sandreed and sun sedge dominated the late seral stage. Little bluestem and sun sedge were most abundant in late intermediate and early intermediate stages.. Lesser amounts of all three key plant species described the early seral stage. Each key plant species individually and collectively characterized the vegetation dynamics of the model within this ecological site.

Fisher's discriminant functions (SPSS 2003) provided model coefficients and biotic potential of key plant species for predicting and classifying plant and seral stage dynamics (multistates) within this ecological site (Table 2). An example of using Fisher's discriminant functions and applying the coefficients to a new index data collected in the field (pasture or allotment) for key plant species is presented in Table 3. These coefficients when computed with the new index values provide the seral stage assignment. Mathematical calculations are as follows: Multiply the site index values for each of the key plant species by seral stage (row) and then sum the products for the score. The greatest value of the four scores is the seral stage assignment. If all products are negative; the least negative score is the seral stage assignment. Site index values for prairie sandreed = 317, little bluestem = 2067 and sun sedge = 1529 assigned the site

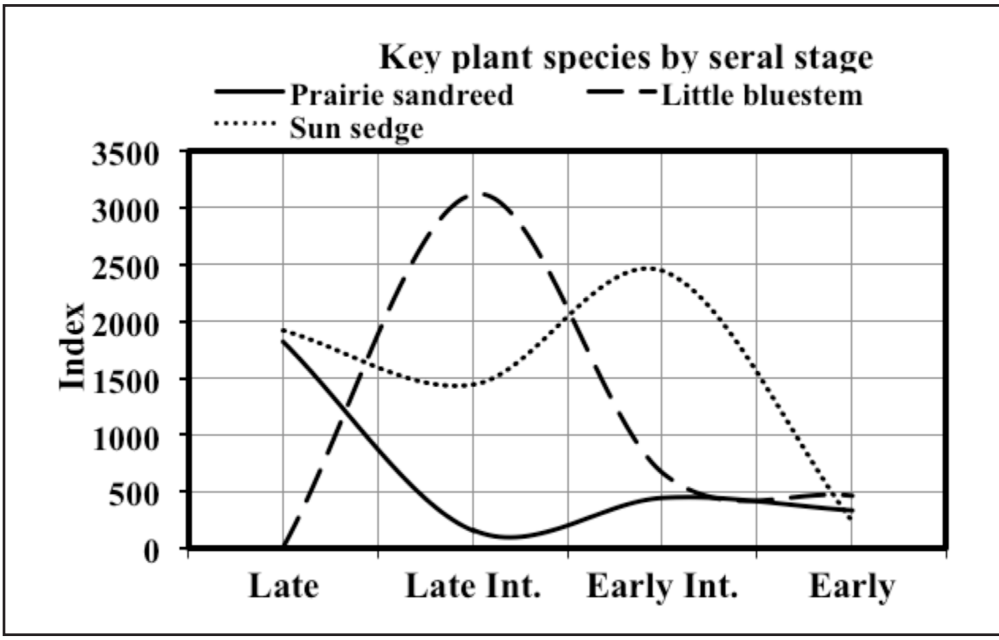

Figure 1. Key plant species with mean index values (canopy cover (%) x frequency of occurrence (%)) throughout the four seral stages in sandy sites in Nebraska and South Dakota.

Table 1. Mean indices of key plant species through four seral stages within the sandy ecological site in Nebraska and South Dakota.

Seral	n	Prairie sandreed	Little bluestem	Sun sedge
Late	5	1810	4	1921
Late intermediate	7	157	3122	1448
Early intermediate	9	449	665	2445
Early	8	387	468	237

n= number of sites

Table 2. Fisher's classification discriminant function coefficients for classification of seral stages with key species in a sandy ecological site in Nebraska and South Dakota.

Species	Late	Late intermediate	Early intermediate	Early
Prairie sandreed	0.01642	-0.00093	0.00367	0.00314
Little bluestem	-0.00172	0.00465	0.00032	0.00041
Sun sedge	0.00168	0.00068	0.00191	0.00014
Constant	-17.864	-9.061	-4.658	-2.107

to late intermediate seral stage with a score of 1.30 (Table 3). Cross validation results showed the overall accuracy of the model was 90 percent.

Additional information on seral stage classification, monitoring, trend monitoring, data collection, plot establishment and programs for personal digital assistant (PDA) and other computer programs can be obtained from USDA-Forest Service web site at: http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

Table 3. An example of assigning seral stages by using Fisher's discriminant coefficients with new index data collected from the field using sites in Nebraska and South Dakota.

	Prairie sandreed		Little bluestem		Sun sedge				
Seral	(Coeff[1] X Index)		+ (Coeff X Index) +		(Coeff X Index)		Constant =		Score
Late	(0.01642 X 317	-	0.00172 X 2067	+	0.00168 X 1529)	-	17.864	=	-13.65
Late Int[2]	(-0.00093 X 317	+	0.00465 X 2067	+	0.00068 X 1529)	-	9.061	=	**1.30**[3]
Early Int	(0.00367 X 317	+	0.00032 X 2067	+	0.00191 X 1529)	-	4.658	=	0.09
Early	(0.00314 X 317	+	0.00041 X 2067	+	0.00014 X 1529)	-	2.107	=	-0.05

[1] Coeff = function coefficients used for classification
[2] Int = Intermediate
[3] Assigned seral stage

Late Seral Stage

Prairie sandreed and sun sedge (Table 4, Table 5 and Fig. 1) equally dominated the late seral stage with an average canopy cover of 21 percent and 22 percent and frequency of occurrence 87 percent and 78 percent. Blue grama was the most common perennial grass in the late seral stage with 45 percent canopy cover and 82 percent frequency of occurrence (Table 4, Table 5). Other common grasses included sand bluestem, sand dropseed (*Sporobolus cryptandrus*) and switchgrass. Total graminoids made up 76 percent canopy cover. Forb and shrub canopy cover was 5 percent and 4 percent. Litter and bare ground cover was 76 percent and 25 percent.. Plant species richness in the late seral stage consisted of 29 forbs, 18 graminoids and 3 shrubs (Fig. 2) with 17 plant families.

Late Intermediate Seral Stage

Little bluestem and sun sedge dominated the late intermediate seral stage (Fig. 1, Table 1). Little bluestem had an average canopy cover of 36 percent and 85 percent frequency of occurrence (Table 4, Table 5). Average canopy cover for sun sedge was 19 percent with 96 percent frequency of occurrence. Other common grasses were blue grama, sand bluestem, switchgrass, hairy grama, needle and thread and prairie junegrass. Graminoid cover was 84 percent. Forb and shrub canopy cover was 9 percent and 5 percent. Litter cover was 83 percent and and bare ground 16 percent. Plant species richness consisted of 44 forbs, 18 graminoids and 3 shrubs (Fig. 2). A total of 18 plant families were identified in the late intermediate seral stage.

Early Intermediate Seral Stage

Sun sedge dominated the early intermediate seral stage (Fig. 1) with a mean canopy cover of 26 percent and frequency of occurrence 96 percent (Table 4, Table 5). Prairie sandreed and little bluestem exhibited canopy cover 6 percent, 12 percent and frequency of occurrence 52 percent, 29 percent, respectively. Common grasses included blue grama, sand bluestem, switchgrass, hairy grama, needle and thread and Kentucky bluegrass (*Poa pratensis*). Total forb and shrub canopy were 7 percent and 6 percent, respectively. Litter cover was 79 percent and bare ground 22 percent. Plant species richness included 46 forbs, 27 graminoids and 5 shrubs that included 22 plant families in this seral stage (Fig. 2).

Early Seral Stage

In the early seral stage, key plant species (prairie sandreed, little bluestem, sun sedge) showed similar indices (Fig. 1, Table 1). Mean canopy cover ranged between 6-9 percent and frequency ranged between 23-57 percent (Table 4, Table 5). Sand bluestem and switchgrass showed greater mean cover in the early seral stage with 12 percent

Table 4. Canopy cover (%) and standard error (in parentheses) of common plant species by seral stage in sandy sites in Nebraska and South Dakota.

Species or variable	Late	Late Intermediate	Early Intermediate	Early
Prairie sandreed *Calamovilfa longifolia*	20.8(2.0)	3.2(0.8)	6.3(1.6)	6.1(2.2)
Little bluestem *Schizachyrium scoparium*	0.4(0.3)	35.6(3.6)	11.6(4.2)	9.0(4.3)
Sun sedge *Carex inops*	21.7(6.8)	18.8(2.6)	25.5(4.7)	8.8(4.3)
Blue grama *Bouteloua gracilis*	44.6(9.0)	8.2(4.1)	13.6(5.4)	3.7(1.9)
Sand bluestem *Andropogon halli)*	9.6(3.6)	4.6(1.7)	4.2(1.3)	12.1(4.9
Sand dropseed *Sporobolus cryptandrus*	7.7(2.4)	1.5(0.9)	1.2(0.4)	1.7(0.6)
Switchgrass *Panicum virgatum*	6.8(3.1)	11.6(1.9)	6.9(2.6)	17.6(7.0)
Western wheatgrass *Pascopyrum smithii*	1.9(1.9)	0.2(0.1)	0.9(0.5)	3.8(3.7)
Hairy grama *Bouteloua hirsuta*	1.0(0.6)	4.8(2.0)	4.0(1.9)	0.9(0.5)
Needle and thread grass *Hesperostipa comata*	2.4(0.5)	3.9(0.9)	2.6(0.9)	4.6(2.6)
Prairie junegrass *Koeleria macrantha*	0.6(0.3)	3.7(1.1)	1.1(0.4)	0.7(0.3)
Heller's rosette grass *Dichanthelium oligosanthes*	0.1(0.1)	1.8(1.4)	1.6(0.7)	2.4(0.9)
Kentucky bluegrass *Poa pratensis*	0(0)	<0.1)(<0.1)	2.1(1.6)	2.7(2.6)
Cuman ragweed *Ambrosia psilostachya*	0.8(0.6)	1.9(0.8)	0.4(0.2)	1.8(0.6)
Prairie rose *Rosa arkansana*	3.0(1.2)	2.0(0.9)	2.9(1.2)	2.8(1.0)
Graminoid cover	**76.5(9.2)**	**83.5(1.4)**	**75.0(3.5)**	**79.1(4.6)**
Forb cover	**5.0(1.5)**	**9.2(1.1)**	**7.4(1.1)**	**10.4(2.3)**
Shrub cover	**4.3(1.0)**	**4.5(0.8)**	**6.4(1.0)**	**5.9(1.2)**
Litter cover	**75.6(5.2)**	**82.8(2.2)**	**79.1(7.6)**	**73.5(10.0)**
Bare ground	**24.8(5.5)**	**15.7(2.3)**	**21.5(7.3)**	**22.8(9.6)**

Table 5. Percent frequency (%) and standard error (in parentheses) of common plant species by seral stage in sandy sites in Nebraska and South Dakota .

Species	Late	Late Intermediate	Early Intermediate	Early
Prairie sandreed *Calamovilfa longifolia*	87.2(2.4)	39.3(6.0)	52.2(10.6)	41.5(11.7)
Little bluestem *Schizachyrium scoparium*	2.3(1.5)	84.8(3.6)	28.9(9.6)	22.5(8.5)
Sun sedge *Carex inops*	78.3(10.7)	95.7(1.3)	95.7(2.6)	57.1(13.6)
Blue grama *Bouteloua gracilis*	81.7(11.4)	26.2(12.3)	40.6(13.1)	11.9(6.1)
Sand bluestem *Andropogon halli*	34.0(11.7)	42.6(7.8)	34.6(11.0)	37.7(11.2)
Sand dropseed *Sporobolus cryptandrus*	35.7(9.9)	12.6(6.1)	14.1(5.4)	16.0(6.7)
Switchgrass *Panicum virgatum*	20.3(7.5)	66.9(5.5)	35.0(8.3)	46.0(10.9)
Western wheatgrass *Pascopyrun smithii*	12.3(11.9)	4.1(2.3)	15.6(8.6)	12.3(9.3)
Hairy grama *Bouteloua hirsuta*	4.3(2.2)	32.1(10.1)	24.4(11.5)	5.6(1.5)
Needle and thread grass *Hesperostipa comata*	18.0(3.8)	32.6(6.3)	24.8(7.2)	20.2(10.7)
Prairie junegrass *Koeleria macrantha*	5.3(3.1)	39.8(8.2)	16.7(4.9)	10.0(4.5)
Heller's rosette grass *Dichanthelium oligosanthes*	0.1(1.3)	17.9(12.0)	20.7(8.0)	21.5(6.0)
Kentucky bluegrass Poa pratensis	0(0)	0.5(0.3)	8.9(5.7)	12.9(12.5)
Cuman ragweed *Ambrosia psilostachya*	7.3(5.0)	28.8(10.6)	10.4(4.2)	24.6(8.3)
Prairie rose *Rosa arkansana*	23.0(8.5)	13.3(4.5)	22.6(9.0)	22.3(7.9)

and 18 percent than the key plant species. Western wheatgrass, needle and thread grass and blue grama were each approximately 4 percent cover. Other common grass species were Heller's rosette grass (*Dichanthelium oligosanthes*) and Kentucky bluegrass. Average forb cover was 10 percent and shrub cover 6 percent. Shrub cover was dominated by prairie rose (*Rosa arkansana*). Litter cover was 74 percent and bare ground 23 percent. Forty six forbs, 25 graminoids and 3 shrubs (Fig. 2) represented plant richness. Nineteen plant families were identified in this seral stage.

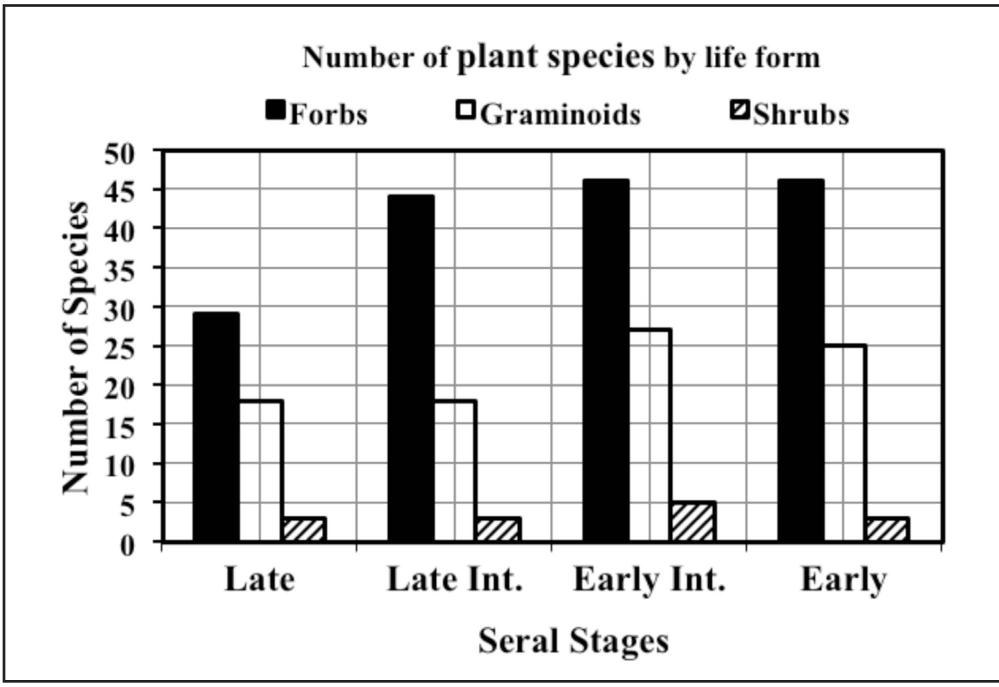

Figure 2. Number of plant species by life form throughout the four seral stages within the sandy ecological site in Nebraska and South Dakota.

Discussion

State and transition models are conceptual models for rangeland assessments and classification of multiple states within an ecological site. The conceptual state and transition model defined for this ecological site (Fig. 2 State-and-Transition Diagram) is reported in USDA-NRCS (2014), sands ecological site description. These models are based on expert qualitative opinion without scientific evaluation to determine their quantitative usefulness (Twidwell et al. 2013). Our developed model is quantitative and can be used to describe the plant dynamics and transitions between and among seral stages (plant community phases) using three key plant species. This model can be used for identifying transitions by sampling permanent macroplots within pastures or allotments yearly or once every few years to determine plant trends for transitions between and among seral stages. When permanent macroplots are established within the ecological type to assess the vegetational trend of a site, re-sampling and comparing the previously assigned seral stage to the current stage provides information about succession or retrogression. Model coefficients developed for this ecological site may be incorporated into the conceptual state and transition model for the ecological site description. Our model is linear but the key plant species are not linear when they progress through all four plant phases of plant succession.. Plant succession may go from early to late successional phase bypassing the intermediate phases or a site may be static for many years (Samuel and Hart 1994). This multivariate model provides resource managers a tool to define discrete stages or plant phases with only three key plant indicators to identify state and transition shifts within the ecological site. Evaluation and monitoring trends of the vegetation resource can be validated and documented for recovery or deterioration affected by herbivore grazing, fire, soil erosion, yearly and climatic changes for resource management areas (Uresk 1990, Benkobi et al. 1996, Uresk et al. 2010, Uresk et al. 2012). Canopy cover of perennial graminoids and litter cover offer the greatest potential for soil protection against wind or water erosion of soils within this ecological site (Malakouti et al. 1978, Mergen et al. 2001).

Management for all seral stages optimizes plant and animal species richness in this ecological site. A mosaic of seral stages (plant phases) with sufficient land area across the landscape is considered optimal for increased plant and animal species diversity (Rumble and Gobeille 1995, Fritcher et al. 2004, Vodehnal et al. 2009, Uresk et al. 2012). One individual seral stage might not be practical for multiple-use management, however; the entire range from early to late seral would accommodate greatest plant species diversity, wildlife diversity, livestock production and recreation. The late and intermediate seral stages may be more important for specific wildlife species. An example is sharptailed grouse and their association with late and intermediate seral stages for nesting cover (Prose et al. 2002, Vodehnal et al. 2009). Bird species diversity varied among seral stages on the mixed grass prairie in central South Dakota (Fritcher et al. 2004). To meet species diversity for both plant and animals, wildlife habitat, a recommendation of 10 - 15 percent of the landscape would be in early and late seral stages with the remainder within early intermediate and later intermediate stages or plant phases as a mosaic (Kershaw 1973, Mueller-Dombois and Ellenberg 1974).

Livestock grazing can be used as a management tool to provide a mosaic of seral stages across the landscape and to produce changes in seral condition. An adjustment of timing of livestock grazing, number of animals and time of grazing can be a management tool to achieve the desired landscape of mosaic seral stages and maintain livestock production (Severson and Urness 1994). The developed quantitative model can quantify changes in plant species composition and spatial distribution of seral stages over the landscape. Prairie sandreed and green needlegrass are considered highly palatable perennial grasses and these grasses often decrease when subjected to overgrazing (Lang 1973, Lewis et al. 1956, Uresk and Voorhees 2013). Little bluestem is considered more tolerant of grazing than prairie sandreed. Sun sedge decreases with intense grazing.

The developed model can be used to monitor and classify seral stages or plant phases based on prairie sandreed, little bluestem and sun sedge with an accuracy of 90 percent. Data collection for canopy cover and frequency of occurrence for each of the key species are the only field requirements. These data provide inputs to the model that predicts seral classification and for monitoring plant changes over time. The recommendation is to establish 1 macroplot per section (640 acres or 259 ha) within the same ecological site because other ecological sites may be present within the section. See aforementioned web site for additional information and methodology. Depending on yearly climatic conditions, data collections may be from mid-June through mid-September. In dry years, the sampling period may be shorter. Data may be collected yearly or every few years, depending upon management objectives.

The model developed for this ecological site can be used to quantify relationships between grazing intensities, wildlife, plant succession and to maintain a desired management objective. Additional information on rare plant and animal species, soil erosion as related to seral stages or plant phases may be included in resource management plans. Application of the model to predict seral stages and monitoring transitions is accurate, quantitative and free of subjective judgments.

Summary

A multivariate statistical model was developed based on prairie sandreed, little bluestem and sun sedge to classify seral stages (plant phases) and to monitor transitions on sandy ecological sites in Nebraska and South Dakota. Four resource categories (seral stages) were derived from discrete groupings with vegetation index values based on canopy cover and frequency of occurrence. Range and wildlife resource managers will be able to use this model to monitor the vegetation and evaluate management actions. Monitoring and evaluating vegetation is a process to improve existing management objectives. It will allow resource managers the ability to develop management plans and refine their assessment for multiple uses. Overall, it is equally important to understand the ecological system to maintain sustainable resources for both plants and animals over the landscape.

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