ECOLOGICAL MODEL FOR SERAL STAGE CLASSIFICATION AND MONITORING OF NEEDLE AND THREAD/WESTERN WHEATGRASS/ BLUE GRAMA ECOLOGICAL TYPE

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ABSTRACT

A multivariate statistical model (state and transition model) was developed for seral stage classification and monitoring within a needle and thread/western wheatgrass/blue grama (*Hesperostipa comata/ Pascopyrum smithii/Bouteloua gracilis*) ecological type, which occurs in eastern Wyoming, Montana and western North Dakota and South Dakota. These three key plant species provide information required for the model to be used to classify seral stages and monitor trends based on index values (canopy cover (%) x frequency of occurrence (%)) of the three key plant species. The model is not linear and does not require a straight progression through all seral stages (plant phases) but may go through multiple states. Four seral stages (early to late plant succession) were quantitatively identified with an overall accuracy of seral stage assignment of 93%. All seral stages were significantly different (P = 0.001). Measurements of the three key plant species is all that is required for model prediction and classification of seral stages.

Keywords

Ecological type, succession, seral stages, grasslands, disturbance, state and transition, model.

INTRODUCTION

Changes in rangeland ecological status often involve and are reflected by plant species composition following natural and anthropogenic-induced disturbances. State and transition models based on multivariate analyses of plant succession are indicators of plant changes that occur within a vegetation type, and when quantified, these models serve as tools for resource managers to assess the magnitude of vegetation change (Dyksterhuis 1949; Uresk 1990; Benkobi and Uresk 1996; Benkobi et al. 2007; Briske et al. 2005; Uresk et al. 2012). Classification into seral stages provides a framework within which the resource manager can effectively describe potentials and evaluate the impact of disturbance regimes on

ecological systems (Mclendon and Dahl 1983; Uresk 1990, Benkobi and Uresk 1996; Uresk et al. 2012). These seral stages are determined within an ecological type using a multivariate statistical classification and monitoring model. The model is not linear and does not require a linear progression of plant succession through all seral stages of plant succession. This quantitative model can be included in the conceptual and working models of multiple stable states (state and transition models) to describe the dynamics of this ecological type (Bestelmyer et al. 2003; Briske et al. 2005). My model is based on interrelationships from a set of key perennial plant species (quantitative variables) that best predict seral stages within an ecological type. This model allows resource managers the ability to assess the seral status of an area within a seral stage and to use the information as the basis for developing management plans and their assessment. The objectives were: (1) develop a multivariate ecological seral classification and monitoring model for needle and thread (*Hesperostipa comata*), blue grama (*Bouteloua gracilis*) and western wheat grass (*Pascopyrum smithii*) upland ecological type, (2) describe and discuss the defined seral stages, and (3) present application guidelines and management implications.

STUDY AREA

The study was conducted in the eastern area of Thunder Basin National Grassland (TBNG), Wyoming, on the upland grassland steppe within the Cheyenne River Basin (Thilenius et al. 1995). This area encompasses about 86,000 acres of National Forest Service lands.

Soils are predominately aridisols (crushman, forkwood, terro series). Surface textures vary from fine-grayish brown loam (aridisols) to clay loam and grayish sandy loam (entisols) (USDA-SCS 1983; USDA-SCS 1990). The climate of TBNG is interior continental with hot summers and cold winters. Mean annual precipitation over an 87-year period at Dull Center 1 SE weather station, which is located at the southeastern portion of TBNG, ranged from 14 cm to 50 cm with an average of 33 cm (HPRCC 2013). Mean annual temperatures ranged from 0.1 °C to 16.4 °C. The lowest average annual temperature was 6.4 °C and highest was 10.1 °C. Average period of frost-free days is about 120 days (Martener 1986).

Vegetation—The upland mid grass prairie consists of needle and thread, blue grama and western wheatgrass and occurs throughout Thunder Basin grasslands in gently rolling terrain (Thilenius et al. 1995). Common shrubs include prairie sagewort (*Artemisia frigida*) with sparse big sagebrush (*Artemisia tridentata*). Plains pricklypear (*Opuntia polyacantha*) is common throughout the area. The ecological type (needle and thread/western wheatgrass/blue grama) for this study occurs in eastern Wyoming, Montana and some areas of western North Dakota and South Dakota. This ecological type is in Kuchler's (1964) potential vegetation 64. Plant nomenclature followed USDA-NRCS (2013).

METHODS

All data collection and analyses followed procedures developed by Uresk (1990). A ground reconnaissance was conducted in the summer of 1993 to assess the vegetational variability within the study area. We stratified sites into three pre-defined visual seral stages for field sampling (Cochran 1977; Thompson et al. 1998; Levy and Lemeshow 1999). Stratification of sites for sampling began by finding ungrazed sites, some within 40- to 60- year old exclosures (late seral stage), early successional sites, and sites estimated to be in the mid succession status according to vegetational variability.

Sampling was conducted on 106 macroplots (sites). Each macroplot was randomly selected within one of the three perceived seral stages (early, mid, late). Approximately 35 macroplots were sampled within each perceived seral stage. At each macroplot, two parallel 30 m (99 ft) transects were set 20 m (66 ft) apart. Canopy cover and frequency of occurrence were estimated within 0.1 m^2 (20 x 50 cm) (8 x 20 in) microplots (Daubenmire 1959). Plots were placed at 1 m (3.3 ft) intervals along each transect. Cover was estimated for individual plant species, categories (grass-sedge, forbs, shrubs, total plant cover), litter and bare ground. Data by macroplot (60 microplots) were averaged to generate mean percent values for all variables. An index was created based on the site cover mean times the site frequency mean. Index = ((transect 1 cover + transect 2 cover)/2) * ((transect 1 frequency + transect 2 frequency)/2) (Uresk 1990). Data were analyzed by SPSS (1992) and SPSS (2003).

Preliminary data examination removed minor plant species with average index values <1. The remaining plant species were used as variables in a sequence of statistical procedures: data reduction with discriminant analyses on the perceived three seral stages followed by principal component analysis for further data reduction (SPSS 1992; SPSS 2003). A non-hierarchical clustering procedure (ISODATA) defined seral stages (Ball and Hall 1967; del Moral 1975). Clusters were subjected to stepwise discriminant analyses for model development to define key plant variables for predicting seral stages. Misclassification error rates were estimated using SAS (1988) and SPSS (2003) cross-validation procedures. The developed model was field-tested in 1994.

RESULTS

Principal component analysis reduced the number of variables to 9 plant species: western wheatgrass, blue grama, threadleaf sedge (*Carex filifolia*), prairie junegrass (*Koeleria macrantha*), pricklypear, spiny phlox (*Phlox hoodii*), Sandberg bluegrass (*Poa secunda*), scarlet globemallow (*Sphaeralcea coccinea*), and needle and thread grass (*Hesperostipa comata*). Stepwise discriminant analysis further reduced the number of variables to 3 plant species, needle and thread, western wheatgrass and blue grama for model development. These species are referred to as the key plant species for predicting seral stages and monitoring. The clustering procedure, grouped the 106 sites into 4 distinct seral stages and all are significantly different ($P < 0.001$). The distribution patterns of indices and dynamics

Table 1. Mean indices of key plant species for four seral stages in a needle and thread, western wheatgrass, blue grama ecological type

		MEAN INDEX		
Seral	**n**	**Needle and thread**	**Western wheatgrass**	**Blue grama**
Late	35	5271	626	577
Late intermediate	10	3226	3538	1249
Early intermediate	20	2413	347	3730
Early	41	1319	225	1200

n= number of sites

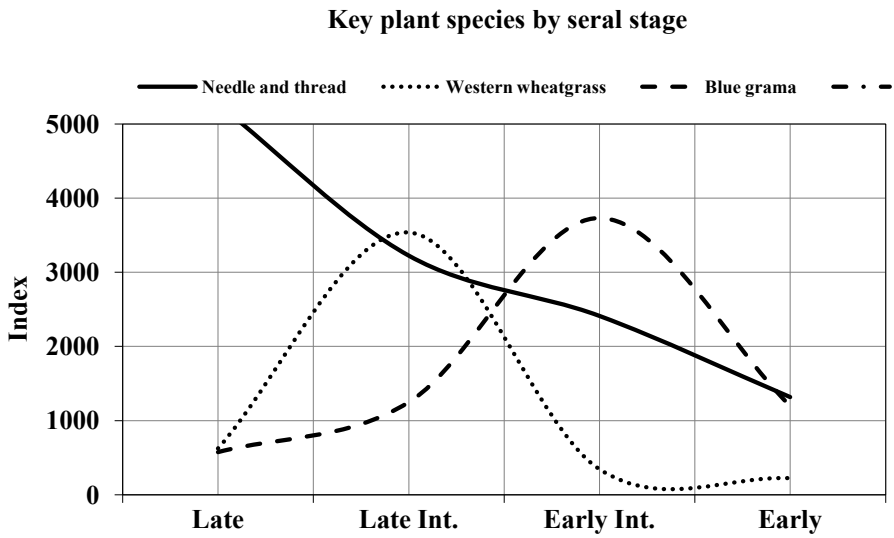

Figure 1. Key plant species with mean index values displayed throughout four seral stages in needle and thread, western wheatgrass and blue grama ecological type. Graph provides a guide for approximate mixtures of plant species at each seral stage.

for the 3 key plant species throughout the 4 seral stages are presented in Figure 1 and Table 1. Needle and thread dominated in the late seral stage, western wheatgrass in the late intermediate stage and blue grama in the early intermediate stage. Lesser amounts of the 3 key plant species are in the early seral stage.

Fisher's classification discriminant functions show the importance of each key plant species among the seral stages and provide model coefficients for predicting seral stages and monitoring within the ecological type (Table 2). Key plant species by seral stage with the greatest coefficients in the stage identify the biotic potential of the plants within the ecological system. An example of new index data for key plants to calculate seral stage assignment is presented in Table 3. To calculate the assignment of the seral stage from Fisher's classification coefficients, multiply site index values for needle and thread grass, western wheatgrass and blue grama for each seral stage (row), and then sum the products for a score. The

greatest score defines the assignment of seral stage (Uresk et al. 2010). When all the products are negative, the least negative score is used for seral stage assignment. New data collected on a site for needle and thread = 2900 (index value), western wheatgrass = 2100, and blue grama = 3600 assign the site to an early intermediate seral stage with a score of 77. Overall, seral stage assignment accuracy was 93%. Specific cross-validation results showed a misclassification rate of less than 2% for the early intermediate, 7% for early, 10% for both late and late intermediate stages. These errors are likely to occur for each seral stage when newly collected field data for a site are inserted into the classification model. Additional information on seral classification and assignment, monitoring trends, data collection, plot establishment and programs for PDA and other computers may be obtained from USDA-Forest Service web site at http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

Table 2. Fisher's discriminant function coefficients for ecological classification model for needle and thread, western wheatgrass, blue grama ecological type.

Species	Late	Late Intermediate	Early Intermediate	Early
Needle and thread	0.00289	0.00223	0.00234	0.00105
Western wheatgrass	0.00216	0.01108	0.00053	0.00056
Blue grama	0.00255	0.00258	0.00739	0.00252
Constants	-10.420	-26.187	-18.152	-3.650

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

	Needle and thread	Western wheatgrass	Blue grama		
Seral	(Coeff[1] * Index)	+ (Coeff * Index) +	(Coeff * Index)	Constant =	Score
Late	(0.00289 * 2900	+ 0.00216 * 2100	+ 0.00255 * 3600)	- 10.420 =	11.677
Late Int[1]	(0.00223 * 2900	+ 0.01108 * 2100	+ 0.00258 * 3600)	- 26.187 =	12.836
Early Int	(0.02340 * 2900	+ 0.00053 * 2100	+ 0.00739 * 3600)	- 18.150 =	77.4302
Early	(0.01050 * 2900	+ 0.00056 * 2100	+ 0.00252 * 3600)	- 3.650 =	**37.048**[2]

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

***Late Seral Stage*—**This seral stage is characterized by a dominance of needle and thread with an average of 56% canopy cover and 95% frequency of occurrence for 35 sites (Table 4, Table 5). Other grasses and sedges include blue grama, western wheatgrass and thread leaf sedge. Cheatgrass (*Bromus tectorum*) was present in lesser amounts. Total grass-sedges made up 80% canopy cover. Shrubs occupied approximately 5% canopy (primarily prairie sagewort) with small-scattered mats of pricklypear at 4%. Forbs (mostly scarlet globemallow and plantains) represent 14% canopy cover (Table 4). Litter cover and bare ground were 11% and 8%, respectively. Plant species richness was 49 forbs, 22 grass-sedges, and 9 shrubs (Figure 2).

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

Species or variable	Late	Late Intermediate	Early Intermediate	Early
Needle and thread				
Hesperostipa comata	55.6(2.1)	52.3(8.9)	34.1(4.2)	20.3(1.5)
Western wheatgrass				
Pascopyrum smithii	13.4(1.3)	39.6(3.6)	10.9(1.4)	8.9(0.9)
Blue grama				
Bouteloua gracilis	15.0(1.4)	25.0(4.7)	41.1(1.8)	19.5(1.4)
Threadleaf sedge				
Carex filifolia	8.6(2.1)	4.2(1.4)	10.3(2.4)	14.8(2.3)
Cheatgrass				
Bromus tectorum	7.5(2.1)	6.6(2.6)	0.7(0.5)	0.5(0.2)
Pricklypear				
Opuntia polyacantha	4.2(0.9)	7.3(3.0)	10.5(2.8)	1.6(0.4)
Scarlet globemallow				
Sphaeralcea coccinea	2.0(0.5)	1.1(0.3)	1.4(0.4)	0.7(0.2)
Prairie junegrass				
Koeleria macrantha	1.9(0.8)	1.6(0.6)	0.64	0.9(0.3)
Prairie sagewort				
Artemisia frigida	1.3(0.1)	1.3(0.7)	1.0(0.7)	2.1(0.5)
Plantain				
Plantago spp.	1.2(0.4)	2.9(1.9)	0.9(0.4)	0.2(0.1)
Total Grass-Sedges	**80.0(1.0)**	**82.2(3.3)**	**75.7(3.1)**	**61.8(2.6)**
Total Forbs	**14.0(1.5)**	**14.8(4.6)**	**16.5(2.9)**	**9.5(1.0)**
Total Shrubs	**4.5(1.0)**	**7.7(3.3)**	**10.9(3.0)**	**1.8(0.5)**
Total Litter	**11.3(1.3)**	**17.4(3.7)**	**4.2(0.9)**	**5.4(0.8)**
Bare Ground	**7.8(0.8)**	**4.6(1.4)**	**14.0(1.5)**	**13.0(1.3)**

Late Intermediate Seral Stage—Index values show needle and thread and western wheatgrass to dominate this seral stage (Figure 1). Needle and thread has an average canopy cover of 52% with a frequency of occurrence of 62% (Table 4, Table 5). Canopy cover and frequency of occurrence for western wheatgrass was 40% and 89%, respectively. Blue grama was present in lesser amounts. Cheatgrass was common in this stage with 7% cover and 37% frequency. Forbs represented less than 2% canopy cover. However, frequency of occurrence for scarlet globemallow was 14% and for plantains 21%. Shrubs, including prairie sagewort, occupied approximately 8% canopy cover, forbs 15%, litter 17%, and bare ground 5%. Plant species richness included 33 forbs, 10 grass-sedges and 5 shrubs (Figure 2).

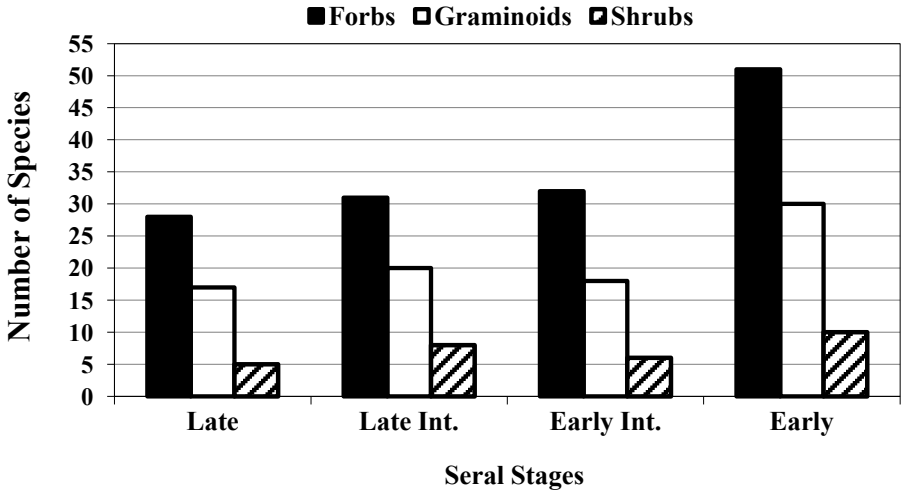

Figure 2. Number of plant species by life form category and seral stages in a needle and thread, western wheatgrass and blue grama ecological type.

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

Species or variable	Late	Late Intermediate	Early Intermediate	Early
Needle and thread				
Hesperostipa comata	94.8(1.1)	61.7(13.4)	67.2(7.1)	65.1(3.4)
Western wheatgrass				
Pascopyrum smithii	46.8(3.9)	89.3(2.4)	30.3(5.8)	25.5(3.6)
Blue grama				
Bouteloua gracilis	38.5(4.0)	50.0(11.4)	94.2(1.3)	61.6(3.9)
Threadleaf sedge				
Carex filifolia	26.1(5.1)	16.2(4.0)	38.3(7.1)	44.2(5.7)
Cheatgrass				
Bromus tectorum	28.7(5.8)	36.9(10.2)	5.4(3.0)	5.3(1.8)
Pricklypear				
Opuntia polyacantha	15.0(3.0)	26.0(10.8)	33.1(7.3)	8.2(1.3)
Scarlet globemallow				
Sphaeralcea coccinea	22.4(3.0)	13.8(3.0)	20.7(3.8)	11.3(1.9)
Prairie junegrass				
Koeleria macrantha	9.4(3.6)	7.5(3.4)	4.31	6.94
Prairie sagewort				
Artemisia frigida	8.0(2.6)	6.7(4.0)	4.6(3.0)	13.48
Plantain				
Plantago spp.	11.7(3.3)	21.3(12.4)	13.8(4.9)	2.59
Field brome				
Bromus arvensis	3.1(1.5)	5.8(4.5)	0.8(0.4)	2.8(1.8)

Early Intermediate Seral Stage—Blue grama dominated this seral stage and exhibited the greatest canopy cover and frequency of occurrence with 41% and 94%, respectively (Table 4, Table 5). This plant exhibited approximately twice the amount of cover and frequency as in the previous seral stages. Needle and thread and western wheatgrass both had cover values of 34% and 11% and frequency of occurrence values of 67% and 30%, correspondingly. Threadleaf sedge and pricklypear, with 10% and 11% cover, 38% and 33% frequency, respectively, increased in cover and frequency compared to late and late intermediate seral stages. Cheatgrass exhibited low cover (1%) and frequency (5%) in this stage. Canopy cover for grass-sedges was 76%, forbs 17% and shrubs 11%, and 1% prairie sagewort. Bare ground was 14% and by litter 4%. Plant species richness was 40 forbs, 18 grass-sedges and 7 shrubs (Figure 2).

Early Seral Stage—All 3 key plant species (needle and thread, western wheatgrass, blue grama) dominated in this seral stage but with lower canopy cover (20%, 9%, and 19% cover, respectively) and frequency than in all previous seral stages (Table 4, Table 5). Threadleaf sedge and prairie sagewort increased in canopy cover (15% and 2%, respectively) and frequency of occurrence in this seral stage compared to all previous stages. Cheatgrass was low in cover and frequency values. Grasses-sedges exhibited 62% canopy cover, forbs 9%, and prairie sagewort, a shrub, 2%, bare ground 13% and litter 5%. Plant species richness was 63 forbs, 25 grass-sedges and 6 shrubs (Figure 2).

DISCUSSION

State and transition models for plant succession have been an approach used for describing ecological processes and dynamics in recent years (Bestelmyer et al. 2003; Briske et al. 2005). Mine is one of these types of models and can be used to describe plant dynamics and transitions between seral stages (plant community phases) within an ecological type. State and transition models are conceptual and may include grazing, burning, climatic changes, and resource management activities. The multivariate model I developed is similar in concept but quantitatively defines the discrete categories or multiple states for the plant community phases. The developed model is not linear and does not go through all stages of plant succession from early to late seral stages. Plant succession may go from early to late by-passing the intermediate stages of succession. The developed model provides discrete stages based on ecological processes involving key plant indicators for transition or plant succession (Stringham et al. 2003; Briske et al. 2005). The multivariate model developed for describing seral stages on the grasslands in Thunder Basin, Wyoming, using coefficients for predicting vegetational change provides resource managers with a powerful management tool. This tool will aid managers in evaluating and monitoring the resource status, which will indicate recovery or deterioration by gazing, burning, and climatic fluctuations with respect to a desired condition at a site (Uresk 1990; Benkobi and Uresk, 1996; Uresk et al. 2012).

Plant seral stages can be defined as management alternatives to be useful in meeting objectives for a desired vegetational condition. However, management for one or two alternatives may result in some plant and animal species being lost and others gained. Resource managers must evaluate these tradeoffs in their conservation plans and management efforts. For example, in selecting the early seral stage with low cover and density to emphasize threatened species such as prairie dogs or mountain plover, we are making a choice that will de-emphasize livestock production (i.e., lower weights). However, livestock grazing can be a tool to regulate changes in seral conditions or status. When the management plan includes livestock production and recreation while maintaining biological diversity, the focus should be the entire range of seral stages (early to late) across the landscape. Because a mosaic of all seral stages provides a full range of plant species that would maximize plant and animal diversity (Vodehnal et al. 2009; Fritcher et al. 2004), approximately 10-15% of the landscape is recommended to be maintained in the early and late seral stages with the remainder in the intermediate seral stages (Kershaw 1973; Mueller-Dombois and Ellenburg 1974).

Based on frequency of occurrence, cheatgrass, an invasive annual plant, was common throughout the study area. Field brome (*Bromus arvensis* = Japanese brome), considered to be an ecological equivalent to cheatgrass, was less common. Both species were most abundant in the late and late intermediate seral stages. These seral stages had approximately 3 times more litter and 2 times less bare ground than in the early intermediate and early seral stages. Whisenant and Uresk (1990) reported that field brome increases as litter increases and that *increases* in litter were related to the lack of grazing and fire. I expect that cheatgrass has the same relationship to litter as field brome. Since livestock graze throughout the area, lighter grazing is expected to increase the abundance of cheatgrass (and field brome). The application of the developed model is limited to the needle and thread/western wheatgrass/blue grama ecological type and requires a minimum of 2 macroplots per section (640 acres or 259 ha) for rangeland seral classification and monitoring. All plots must be located within the ecological type and not randomly located within the section because other ecological types may occur within the section. Canopy cover and frequency of occurrence for the 3 key plants (needle and thread, western wheatgrass, and blue grama) are the only required field measurements. During years with above average precipitations, mid-June to September appears to be a good period for field measurements. Otherwise, the field measurement period could be shorter (early June to mid-August) as identification of plant species becomes difficult. Monitoring trends, based on changes in the 3 key plant species, will require repeated measurements over time on permanent macroplots to estimate changes. Because the three perennial plants required for this model are the most common species within this ecological type and can be identified easily and monitored to determine seral change. Finally, determination of seral stages is accurate and quantitative, thus free of subjective judgments. Additional information may be obtained from USDA-Forest Service web site.

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