# Seral Stage Classification and Monitoring Model for Big Sagebrush/Western Wheatgrass/Blue Grama Habitat

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Abstract-An ecological classification model for seral stages was developed for big sagebrush *(Artemisia tridentata)* shrub steppe habitat in Thunder Basin National Grassland, Wyoming. Four seral stages (early to late succession) were defined in this habitat type. Ecological seral stages were quantitatively identified with an estimated 92% level of accuracy when this model was applied in the field. The number of plant species was greater in the early seral stage and decreased throughout to the late seral &age. This model will assist range managers to monitor and evaluate management alternatives by assessing changes in species composition and trends over time within and between seral stages. Canopy cover (%) and frequency of occurrence (%) for big sagebrush, western wheatgrass *(Agropyron* smithii), and blue grama *(Bouteloua gracilis)* are the only required variables to measure in the field to determine and monitor seral stages. The developed model may only be applied to this habitat type, and caution is expressed when applying it beyond Thunder Basin National Grassland.

Determination of proper management alternatives in sagebrush communities is important but difficult when managing for multiple-use objectives. The ability to identify a range of alternatives and relate them to prescribed management activities is essential to achieve a desired condition (Dyksterhuis 1985; Uresk 1990; UCT 1995). Determination of seral stages using multivariate statistical models of plant succession allows managers to monitor prescribed practices. Plant succession has been used for rangeland monitoring for many years (Sampson 1919; Humphrey 1949; Dyksterhuis 1949; MacCracken and others 1983; Hanson and others 1984; Dyksterhuis 1985; Hoffman and Alexander 1987; Girard and others 1989; Westoby and others 1989; Uresk 1990). However, accurate and repeatable quantitative procedures that do not rely on subjective interpretations are often lacking.

Over the last few decades, the rangeland condition classification concept has provided resource managers a framework for evaluating vegetation changes in response to natural events (weather, fire) and management practices (Dyksterhuis 1949; Westoby and others 1989; Smith 1988; Holechek and others 1989). Range classification methods used by the Forest Service (USDA-USFS 1968) and Soil Conservation Service (USDA-SCS 1976) have not been sensitive enough to detect slow plant succession in arid rangeland (Tausch and others 1993; Samuel and Hart 1994). Other multivariate and ordination techniques (Mueller-Dombois and Ellenberg 1974; del Moral 1975; Foran 1986; McLendon and Dahl 1983; Mosely and others 1986) have refined vegetation classification, but did not provide simple practical tools, such as quantitative equations or models, for range managers to determine successional course using measurements of vital vegetation attributes as variables.

The use of range condition based on climax plant communities as a management tool has been strongly criticized (Pendleton 1989; Friedel 1991; Tausch and others 1993; Borman and David 1994; National Research Council 1994; UCT 1995) because of (1) difficulty of determination of the climax vegetation in some habitat types and (2) replacement of climax community by other disclimax plant associations after major disturbances. While the above is true, this research effort provides a classification model that does not require identification of climax vegetation nor does it rely on the comparison of present vegetation to climax vegetation as defined by the USDA-SCS's (1976) procedures. The developed procedure evaluates the full range of plant succession from early to late seral stages within a habitat type that is present today (Uresk 1990). The purpose of this study was to develop an ecological classification tool which will be used by range managers to determine seral stages can be used to decide management alternatives. The objectives were to (1) develop and test an ecological classification model for big sagebrush shrub steppe habitat type and(2) delimit possible applications for the classification model outside Thunder Basin National Grassland.

## Study Area

The study was conducted in Thunder Basin Mational Grassland (TBNG), Wyoming, on the upland big sagebrush shrub steppe habitat type (Thilenius and others 1994). This area encompasses about 380,000 acres of National Forest Service lands.

Soils are predominately aridisols (crushman, forkwood, terro series) and entisols (grummit, samday, shingle, tassel series). Surface textures vary from fine-grayish brown loam (aridisols) to clay loam and grayish sandy loam (entisols) (USDA-SCS 1983, 1990). Elevations in TBNG range from

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3,937 ft (1,200 m) at the southeast corner to a maximum of 5,250 ft (1,600 m) on the surface of the Rochelle Hills. The maximum elevation at the northern part (Spring Creek) is about 4,265 ft (1,300 m) (von Ahlefeldt and others 1992). Climate of TBNG is interior continental with hot summers and cold winters. Strong winds, often up to 40 mph (66 km/h), occur any time of the year. Mean annual precipitation ranges from 12 inches (30 cm) in central TBNG to 16 inches (40 cm) in the northern part (Spring Creek). Mean annual temperatures range from 43 °F (6 °C) to 47 °F (8 °C). The highest temperatures range from 104°F(40°C)to 110°F(44°C) and the lowest temperatures range from -36 to -44°C. Frost free period averages 120 days (Martener 1986).

## Methods

Data collection and analyses followed Uresk (1990). A preliminary ground reconnaissance of the entire TBNG upland big sagebrush shrub steppe habitat began in mid-June of 1993. The ground reconnaissance was conducted to assess the vegetation variability of the study area. Sites were selected so that the range natural variability of the vegetation would be explained by the sampling. Plots that had been excluded from grazing for 50 years were also included in the sampling. Plant nomenclature followed Flora of the Great Plains (Great Plains Flora Association 1986).

Data were collected on 121 macroplots (sites). Each macroplot was randomly selected within one of three perceived seral stages (early, mid, late). A total of 121 macroplots were permanently established throughout the entire big sagebrush shrub steppe habitat in 1993. At each macroplot, 2 parallel 99 ft (30 m) transects were set 66 ft (20 m) apart. Sampling of canopy cover and frequency of occurrence for each plant species occurring within each microplot, 8 x 20 in (20 x 50 cm), was completed at 3.28 ft (1 m) intervals along each transect (Daubenmire 1959). Plant litter, rock cover, and bare ground were also estimated. All macroplot data (60 microplots) for each site were averaged for each plant species (variable). Average canopy cover (%) was multiplied by frequency of occurrence (%) to produce an index value for the analyses (Uresk 1990).

Preliminary data examinations removed minor plant species that were highly variable. Twenty variables (from a total of 150) were subjected to further analyses. Principal component analysis (SAS Institute 1988) further reduced the number of variables to 6 major plant species: big sagebrush, western wheatgrass, blue grama, threadleaf sedge *(Carex filifolia),* prairie junegrass *(Koeleria cristata),* and needle-and-thread *(Stipa comata).* A non-hierarchical clustering procedure, ISODATA (Ball and Hall 1967; del Morel 1975), grouped the 121 sites into 4 distinct clusters (seral stages). Then stepwise discriminant analysis (Norusis/SPSS Inc. 1992) at 0.05 entry level selected big sagebrush, western wheatgrass, and blue grama as the best predictive variables to be used for seral stage classification and monitoring. Misclassification error rates were estimated using cross-validation procedures (SAS Institute 1988). The developed model was subjected to field testing by collecting additional data during the second year (1994).

## Results

Four distinct seral stages (early to late) were defined in the TBNG sagebrush shrub steppe habitat. Stepwise discriminant analysis showed significant differences among these seral stages ($P < 0.05$). The developed model consisted of 3 variables (plant species) and 4 Fishers discriminant functions that define the seral stages (table 1). Variables were heavily weighted at individual seral stage, reflecting the biotic potential of each key plant species in predicting dynamics of the vegetation within the ecological system (fig. 1). Big sagebrush is dominant in late seral stage, western wheatgrass in late intermediate, and blue grama in early intermediate (table 2). All 3 plant species showed low percent covers and frequency of occurrences in early seral stage. Big sagebrush, western wheatgrass, and blue grama were the best indicators of seral stages.

This model classifies seral stages by multiplying index values associated with the 3 key plant species by the discriminant coefficients of each seral stage and then summing the products for each seral stage. The greatest of the four discriminant scores indicates assignment of the seral stage. An example of seral stage determination is presented in table 3: a site where the index value for big sagebrush = 4730,

**Table** l-Fisher's discriminant coefficients for classification of seral stages in Thunder Basin National Grasslands sagebrush shrub steppe habitat type.

| | Seral Stages | | | |
|---|---|---|---|---|
| **species** | Late | Late Int.[1] | Early Int. | **Early** |
| Big sagebrush | 0.00551 | 0.00154 | 0.00095 | 0.00113 |
| Western wheatgrass | 0.00241 | 0.01146 | 0.00505 | 0.00240 |
| Blue grama | 0.00216 | 0.00399 | 0.00932 | 0.00262 |
| Constant | -15.000 | -14.070 | -15.643 | -3.1503 |

[1]Int. = intermediate.

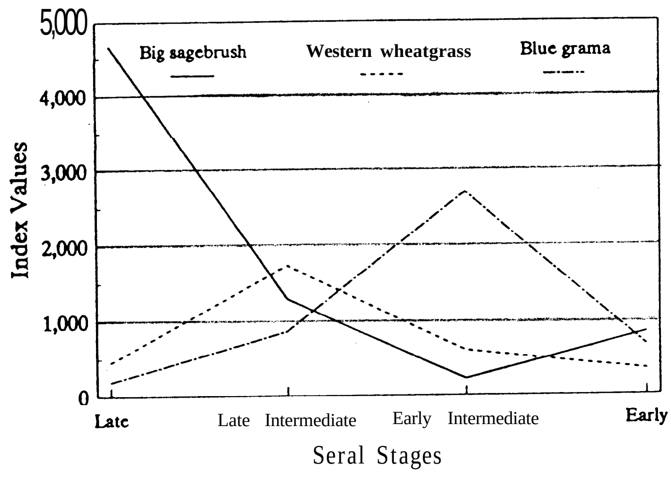


**Figure** 1-Key plant species with index values (canopy cover (5) x frequency of occurrence (%)) distributed throughout all seral stages in Thunder Basin National Grasslands sagebrush shrub steppe habitat.

**Table 2**—Canopy cover ($\bar{x} \pm$ SE) and frequency of occurrence ($\bar{x} \pm$ SE) for the key plants throughout the defined seral stages in Thunder Basin National Grassland sagebrush shrub steppe.

| Seral stages | n | Big sagebrush | Western wheatgrass | Blue grama |
|---|---|---|---|---|
| | n | Canopy cover (%) | | |
| Late | 25 | 55 ± 2.1 | 8 ± 1.2 | 6 ± 0.8 |
| Late intermediate | 23 | 22 ± 3.1 | 20 ± 1.0 | 14 ± 1.7 |
| Early intermediate | 21 | 7 ± 0.9 | 8 ± 1.3 | 30 ± 1.8 |
| Early | 52 | 17 ± 1.6 | 7 ± 0.6 | 12 ± 0.9 |
| | n | Frequency of occurrence (%) | | |
| Late | 25 | 85 ± 1.6 | 60 ± 4.9 | 32 ± 2.3 |
| Late intermediate | 23 | 60 ± 4.8 | 85 ± 1.7 | 61 ± 4.7 |
| Early intermediate | 21 | 27 ± 2.8 | 63 ± 5.9 | 87 ± 2.6 |
| Early | 52 | 51 ± 2.8 | 50 ± 2.6 | 57 ± 2.7 |

n = sample size

western wheatgrass = 976, and blue grama = 120 would be assigned to the late seral stage. In this example, 13.67 is the greatest score and is associated with the late seral stage. Monitoring of a site over time will show any changes in seral stages when the above procedures are applied.

Overall application accuracy, obtained from cross-validation procedures (SAS Institute 1988), was 92%. Specific cross-validation results showed classification errors that are likely to occur for each seral stage during applications of the developed model. These errors for each seral stage were less than 1% for late, 4% for late intermediate, 5% for early intermediate, and 10% for early.

The early seral stage had the greatest number of plant species with 74 forbs, 30 graminoides, and 11 shrubs. The number of plants decreased throughout to the late seral stage which had 38 forbs, 18 graminoides, and 5 shrubs (fig. 2).

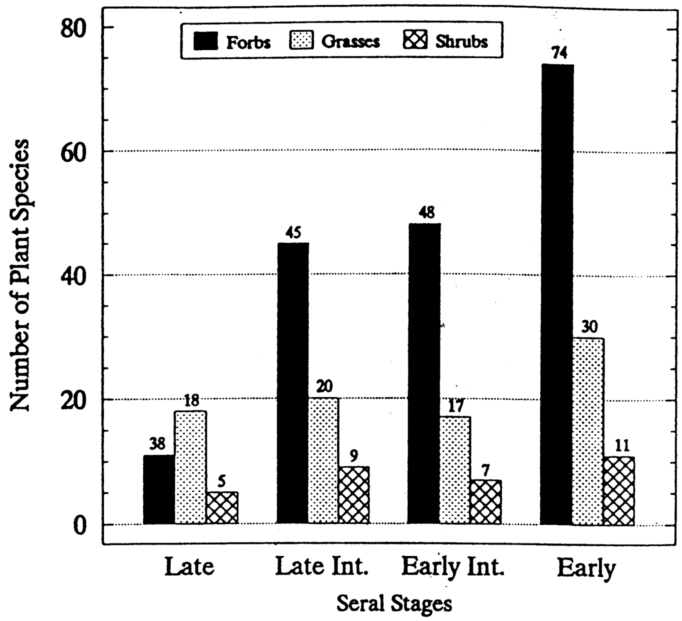


**Figure 2**—Number of plant species by category throughout all seral stages in the Thunder Basin National Grasslands sagebrush shrub steppe habitat type.

## Discussion

The developed seral classification and monitoring model was based on ecological concepts of plant succession (Clement 1916; Sampson 1919; Humphrey 1947; Dyksterhuis 1949; Daubenmire 1968). However, plant succession in this study is not used as defined by USDA-SCS's (1976) procedures that use percentage of climax to determine current range condition. With the developed model, successional status is obtained from using multivariate quantitative equations. These equations consist of interrelationships from a set of plant species occurring throughout the defined four seral stages. Thus, the developed model determines seral stages regardless of hypothetical past or future climax vegetation. It is difficult to predict long term (100 years or more) past or future climax conditions; at best such prediction becomes an ecological guess. Knowledge of hypothetical climax vegetation is not required when applying the developed model to determine seral stages because: (1) vegetation data that were used to develop the quantitative model were collected over a range of natural variation on a habitat type that is present today and (2) every plant species sampled occurring in the habitat type was included as a variable in a sequence of multivariate statistical analyses to determine the set of key plant species (perennial or annual) that best characterize the habitat type.

Although sagebrush steppe appears to be common on western rangelands, the application of the developed model

**Table 3**—An example of estimating the assigned seral stage using Thunder Basin National Grasslands Fisher's discriminant coefficients and data collected for the 3 plant species on a site.

| | Big sagebrush Coeff[1]. | Big sagebrush Index | Western wheat. Coeff. | Western wheat. Index | Blue grama Coeff. | Blue grama Index | Const. | Score |
|---|---|---|---|---|---|---|---|---|
| Late | (0.00551 • | 4730 + | 0.00241 • | 976 + | 0.00216 • | 120) – | 15.00 | = 13.67 |
| Late Int. | (0.00154 • | 4730 + | 0.01146 • | 976 + | 0.00399 • | 120) – | 14.07 | = 4.88 |
| Early Int. | (0.00095 • | 4730 + | 0.00505 • | 976 + | 0.00932 • | 120) – | 15.64 | = –5.10 |
| Early | (0.00113 • | 4730 + | 0.00240 • | 976 + | 0.00262 • | 120) – | 3.15 | = 4.85 |

[1]Coeff. = Fisher's discriminant classification coefficient, Const. = constant values in Fisher's discriminant model, Int. = intermediate.

is limited to this specific habitat type. When applying this classification model outside TBNG, care must be taken to ensure that big sagebrush is the dominant shrub. Western wheatgrass and blue grama are the dominant grass species (table 2). Subspecies of big sagebrush were not differentiated in our study. However, Johnson (1979) reported that Wyoming big sagebrush *(Artemisia tridentata wyomingensis)* was the most dominant subspecies in this area. Kuchler (1964) limited this habitat type to southeastern Montana and Wyoming while Bailey (1980) limited it to Wyoming Basin Province only. However, Johnson (1979) stated that the northeastern Wyoming sagebrush steppe was consistent with mixed grass prairie elsewhere, except for a greater dominance of sagebrush.

## Management Implications

Rangelands with different seral stages may require several management strategies to maintain biodiversity. For instance, an adjustment in the level or timing of livestock grazing can change the seral stage to a preferred management alternative. As seral stages change, some plant species will be lost and others gained. These are trade-offs which can be evaluated. To maintain biological diversity, all defined seral stages must be maintained. The question is how much of each seral stage and where must it be maintained?

Managing for one particular seral stage does not meet multiple-use objectives. For instance, the early intermediate seral stage appears to be superior to the late seral stage for livestock production because of the abundance of palatable graminoides in this habitat type. Other seral stages may be more important to certain species of wildlife, such as sage grouse, which require an early seral stage for booming and a late seral stage for nesting. Samuel and Hart (1994) reported that biological diversity was greater in early seral stage sites that were not dominated by blue grama when they conducted a biological survey in northeastern Wyoming. We found that the early seral stage had a greater number of plant species which decreased throughout to the late seral stage (fig. 2).

Managers concerned with biological diversity must maintain all defined seral stages. The entire range, from late to early, is necessary for multiple use, such as livestock and wildlife production and recreation (Bowns and Bagley 1986; Uresk 1990; Samuel and Hart 1994). However, an early seral condition, where bare ground is high, may require additional considerations because of potentially high soil erosion (Benkobi and others 1994). The developed model provides a tool for range managers that can determine vegetation changes in response to management alternatives.

The developed classification model can also quantify the effect of various grazing intensities on secondary succession in order to determine grazing levels that will maintain, restore, or change the successional status of the vegetation for a management alternative. In addition, useful information about wildlife species' activities, livestock and wildlife interactions, and their relationships to seral stages in plant communities can be demonstrated (MacCracken and others 1983; Uresk and Paulson 1988; Uresk 1990; Rumble and Gobeille 1995).

Application of the developed model requires field measurements of index values (canopy cover (96) x frequency of occurrence (%)) for the three key plant species (big sagebrush, western wheatgrass, blue grama). Field measurements of canopy cover should follow Daubenmire's (1959) six cover classes. For each site sampled, two 99 ft (30 m) parallel transects should be established 66 ft (20 m) apart. Along each transect, sampling should be conducted at 3.3 ft (1 m) intervals, using an 8 x 20 inch (20 x 50 cm) quadrat frame. The obtained index values are applied to the classification model (table 1) as demonstrated in table 3. Variability in the data led to an estimate of 2 macroplots per section (640 acres) as a minimum requirement for seral stage classification and monitoring. Monitoring requires repeated measurements of the 3 key plant species over time on permanent plots to oversee management changes.

## Conclusions

A classification and monitoring tool (model) of plant succession was developed for TBNG sagebrush shrub steppe habitat. Key plant species for classification and monitoring were defined by multivariate statistical methods. Percent cover and percent frequency of occurrence for big sagebrush, western wheatgrass, and blue grama can be used to measure succession or retrogression in this habitat type. The consistent overall accuracy (92%) of this classification system suggests wider applications for this model in management, conservation, and research.

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