CLASSIFICATION AND MONITORING PLAINS COTTONWOOD ECOLOGICAL TYPE IN THE NORTHERN GREAT PLAINS

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ABSTRACT

A multivariate statistical model was developed for the plains cottonwood (Populus deltoides) ecological type to classify seral stages and to monitor succession based on three key variables. Four ecological seral stages representing early to late succession were identified quantitatively with a classification accuracy of 95%. All seral stages were significantly different (P < 0.001). Information required to predict seral stages within 0.2 acre or 0.08 ha macroplots by the model includes DBH of plains cottonwood trees >1 inch, stem number <1 inch and tree number. These are the only measurements required for seral stage classification and monitoring. Resource managers will be able to use this model to evaluate management actions by monitoring changes within and among seral stages. This model is simple to use, reliable, repeatable, accurate, and cost effective to meet resource management objectives and monitoring plans.

Keywords
Woodlands, succession, seral stages, ecological type, riparian, monitoring

INTRODUCTION

Increasing demands for intensive management and mitigation of public lands require improved and efficient methodologies to counter the effects of disruptions by the natural environment on our renewable biological resources. Baseline studies of grassland and wooded vegetation types, and associated wildlife habitats are important in that they provide the basis for needed mitigation actions, restoration, and management. Long-term studies on the Missouri River riparian system have shown considerable changes since 1892 to recent times (Rumble et al. 1998; Johnson et al. 2012; Dixon et al. 2012). Recent years have seen declines in age and structural diversity of cottonwood stands to old decadent stands from limited regeneration along the river system. This is the result, in part, of large dams in place on the Missouri River (Johnson et al. 2012; Dixon et al. 2012). Declines of cottonwoods are related to limited water flows and minimum or restricted scouring needed to create new sandbars for regeneration of trees. However, for the plains cottonwood (Populus deltoides) ecological type (Girard et al.
1989; Thilenius et al 1995) along the Missouri River and associated tributaries, there is a lack of quantitative tools to classify and document seral stages based on succession and to monitor the changes. The plains cottonwood is the dominant tree with understory species of narrowleaf willow (Salix exigua), western snowberry (Symphoricarpos occidentalis), and peachleaf willow (Salix amygdaloides). Additional information for vegetative characteristics on the plains cottonwood ecological type are presented by Girard et al. (1989), Thilenius et al (1995) and Rumble and Gobeille (2004).

The plains cottonwood ecological type and associated seral stages are highly important to wildlife. The importance of the cottonwood type is disproportionate to the total land area occupied. Loss of seral stages (and associated age and structural diversity) needed to maintain the diversity of wildlife and plants within the cottonwood type is a key concern because some wildlife species require specific seral stages for maintaining their populations (Steenhof et al. 1980; Rumble and Gobeille 2001; Rumble and Gobeille 2004). Seral stage classification of plains cottonwood woodlands, especially in key areas, can provide an accurate assessment of tree and habitat conditions within a limited period as related to wildlife species (Uresk, 1990; Uresk et al. 2010). Once procedures for seral classification and monitoring are developed, resource managers can apply the results in the decision-making processes to enhance management and restoration of the plains cottonwood type.

The ecological status of the plains cottonwood type has undergone many changes over time following human induced and natural disturbances (Carter, et al. 2012; Dixon et al. 2012). However, little work has been done to describe relationships between disturbance processes and associated seral stages or to identify and quantify key disturbance transition indicators between seral stages or successional communities. Qualitative state and transition models have received much attention in recent years (Briske et al. 2005) and generally provide a framework to understand natural and human induced disturbances. Nevertheless, these models are conceptual and qualitative, based on expert opinion and personal judgments (Twidwell et al. 2013). State and transitional models attempt to describe community phases and are equivalent to seral or successional stages (USDA-NRCS 2013). State and transitional models (conceptual) can be quantified using multivariate statistical models we have developed based on field data and plant succession as an approach for predicting an ecological process of vegetation change with discrete categories (Uresk 1990; Uresk et al. 2012; Uresk et al. 2013; Uresk and Mergen 2014). This multivariate model approach can be applied and incorporated into the ecological site descriptions for state and transition models (Bestelmeyer et al. 2010; USDA-NRCS 2013). The method and approach described in this paper and previous publications provide a tool for using empirical data to identify vegetation indicators for seral stages and community phase descriptions and transitions.

The objectives of this study were to develop a quantitative multivariate model and tool for identification and classification of seral stages for the plains cottonwood type and to provide a sampling and monitoring protocol for the plains cottonwood type.
STUDY AREA

This study was conducted along Lake Sharpe and Oahe Reservoir, including the river tributaries located in the approximate geographic center of the Dakotas. The project extended from Big Bend Dam at Fort Thompson, South Dakota, to Bismarck, North Dakota. The shoreline is bordered by rugged bluffs, which smooth out into gentle and rolling hills upstream. Tree growth is sparse and tends to occur mostly on tributary ravines except where bottomland riparian forests occur in North Dakota and major stream drainages (Cheyenne, Moreau, Grand, Cannonball Rivers). Major stream drainages may be dominated by shrubs or, in more mesic situations, trees. Common shrubs include silver buffaloberry (*Shepherdia argentea*), western snowberry chokecherry (*Prunus virginiana*), Saskatoon serviceberry (*Amelanchier alnifolia*) and skunkbush sumac (*Rhus trilobata*). Trees include plains cottonwood, and willows (*Salix* spp.). Willow trees are common codominants on floodplains of lower order drainages. Other trees include green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), boxelder (*Acer negundo*), hackberry (*Celtis occidentalis*), and bur oak (*Quercus macrocarpa*). Rocky Mountain juniper (*Juniperus scopulorum*) is found on shallow soils on steep north facing slopes along drainages leading to the major rivers (Severson 1981; Barker and Whitman 1988). Plant nomenclature followed USDA-NRCS (2015).

The climate of the northern Great Plains is semi-arid continental and characterized by wide daily and seasonal fluctuations in temperature and by erratic precipitation within the study area. May and June are the wettest months and 75% of the annual precipitation falls from April through September. Locally severe thunderstorms are common in summer. Mean annual precipitation at Bismark, ND, is 16.4 in (417 mm) with an average maximum temperature of 52.7 F (11.5 C) and minimum temperature of 29.8 F (-1.2 C). Mean annual precipitation at Pierre, SD, is 17.7 in (450 mm); annual maximum and minimum temperatures are 59.2 F (15.1 C) and 35.2 F (1.8 C), respectively. At Chamberlain, SD, mean annual precipitation is 23.6 in (599 mm) with average maximum and minimum temperatures of 59.5 F (15.3 C) and 34.8 (1.6 C), correspondingly (HPRCC, 2015).

METHODS

The data collection and analyses followed procedures described by Uresk (1990) with additions to the experimental design to account for tree measurements in this section. A preliminary survey of the study area was undertaken to assess the range of variability within the plains cottonwood ecological type. Study sites were selected so the full range of variability based on plant succession (early to late) was sampled within this type.

Data were collected on 71 macroplots (sites). Each macroplot was randomly selected within one of three perceived seral stages, early, mid, and late (Cochran 1977; Thompson et al. 1998; Levy and Lemeshow 1999). First, an area was located within the perceived seral stage for site location. Once the area was
located, a random direction and a random number of paces were established,

prior to macroplot location for transects. Within each perceived seral stage,

macroplots 65.6 ft X 131.2 ft (20 m X 40 m) were established. Two adjacent

plots were established for cottonwood stands in narrow riparian systems to stay

within the riparian zone, each 32.8 ft X 131.2 ft (10 m X 40 m). The two plots

were combined and analyzed as one site. Diameter at breast height (DBH) was

measured in inches on all trees that had a DBH greater than 1 in (2.54 cm)

within the macroplot. These data were converted to total basal area (ft²/acre; 1

ft²/acre = 0.23 m²/ha) as a new variable for analyses. Plains cottonwood stems <1

in (2.54 cm) were counted within the macroplot. However, plots established in

eyearly succession with many stems < 1-inch, required sub-sampling to count the

number of stems. All stems were counted along two parallel, 32.8 yds (30 meter)

belt transects, 1.1 yds (1 meter) wide. Subsample measurements collected within

the 71.8 yd² (60 m²) subplot were corrected to the 65.6 ft. x 132.2 ft. (20 x 40

meter) plot 956.8 yd² (800 m²) for analyses.

Two parallel 32.8 yards (30m) transects were established 22 yards (20 m) apart

within the macroplot. Canopy cover (six classes) of plant species was estimated

within 7.9 in X 19.7 in (20 cm X 50 cm) frames (Daubenmire 1959). These

quadrats were located at an 3.3 foot (1m) intervals along each of the two transect

for 60 microplots. All microplot data were averaged by transect. The two transect

means were then averaged for each macrosite to generate a grand mean for data

analyses. Additional details for macroplot establishment and transects may be

obtained from USDA Forest Service website (Uresk et al. 2010): http://www.

fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml

Preliminary examination of all data reduced the number of variables to seven

variables (n = 71 sites) for further analyses. Most understory plant species were

highly variable among all macroplots and present in minimal amounts (<3%

canopy cover). Thus, these plant species were not considered for further analyses

in model development. The seven variables including plant species with a high

consistency within the plains cottonwood ecological type: plains cottonwood tree

diameter at breast height (DBH), tree number for cottonwood trees >1 in DBH,

stems <1 in DBH , basal area (ft²/acre ;1 ft²/acre = 0.23 m²/ha), percent canopy

cover for narrowleaf willow, western snowberry, and peachleaf willow. Stepwise
discriminant analyses were used for initial data reduction of the seven variables

on the three perceived seral stages (early, mid, late) from field observations (Uresk

1990). This initial data reduction resulted in three variables for model develop-

ment: cottonwood tree diameter (DBH), tree number, and number of stems <1

in within a macroplot (0.2 acres or 0.08ha). These three variables were analyzed

with a non-hierarchical clustering procedure, ISODATA (Ball and Hall 1967,
del Moral 1975), which grouped the 71 macroplots (sites) into four distinct

clusters (seral stages). Stepwise discriminant analysis applied to the four clusters

(seral stages) estimated the compactness of the clusters and provided Fisher clas-

sification coefficients for seral stage classification and monitoring within the cot-

ttonwood ecological type (Uresk 1990; SPSS 2003 ). Misclassification error rates

were estimated with SAS (1988, 2012) and SPSS (2003) using a cross validation

procedure or “leave one site out”. The cross validation procedure was repeated

for each of the sites for a true error rate. By collecting data from additional sites
(approximately, 20-30 sites), including sites outside the original study area in western North Dakota and South Dakota, I subjected the developed model to field-testing.

RESULTS

Cluster analysis (ISODATA), a non-hierarchical analysis, grouped the 71 sites into 4 distinct seral stages (P < 0.001) based on three variables (Table 1). Basal area (69 ft²/a (16 m²/ha)) and canopy cover of understory plants for narrowleaf willow (4%), western snowberry (3%) and peachleaf willow (3%) did not enter into the final analyses. Stepwise discriminate analysis for model development was built on cottonwood tree diameter at breast height and tree number >1in, and stem number <1 in, as predictive variables for seral stage classification and monitoring transitions within the plains cottonwood ecological type. The distributions of the three variables throughout the seral stages show the dynamics occurring within the plains cottonwood ecological type (Figure 1). Tree diameter dominated the late seral stage with a mean of 25 in (63.5 cm). Tree number, with an average of 240 trees, was low in the late seral stage but was greater in the early intermediate seral stage. Stem number, at a mean of 1938 stems, clearly dominated the early seral stage.

Tree and non-tree plant species by life form varied among seral stages (Figure 2). Forbs dominated the late intermediate and early seral stages with 43 and 38 species, respectively. Graminoids remained relatively constant among the seral stages ranging from 14 to 19 species. Shrubs varied from 3 to 10 species throughout the 4 seral stages, while trees ranged from 3 to 7 species.

Key plant variables by seral stage

![Figure 1. Key variables with tree diameter, stem number and tree number throughout four seral stages in the Plains Cottonwood ecological type. Graph provides an approximate mixture of variables at each seral stage.](image-url)
Fisher’s discriminant function coefficients (SPSS 2003) for ecological seral stage classification and monitoring with 3 key variables for plains cottonwood are presented in Table 2. Variables with the greatest coefficients by seral stage express the importance of the key variable within a stage for this ecological type. These key variables with corresponding coefficients interrelate together within the model to classify seral stages and do not function as independent variables. An example of calculating seral stage assignment by Fisher coefficients from key variables is presented in Table 3. In this example seral stage assignments are calculated using the following data for key variables: mean tree diameter (DBH) = 8 in (20.3 cm)), stems = 74 and cottonwood tree number = 63. These key variables are multiplied by the coefficients for each seral stage (row) and the products, including the constant, are summed (+ and -) for a score. The greatest positive score or least negative score, when all scores are negative, is the assigned seral stage. In this example, the assigned seral stage is late intermediate with a score of 5.4. Overall accuracy of the model based on cross validation was 95% (SAS 1988). Additional information on plot establishment, data collection, seral stage classification, monitoring and trend monitoring, including programs for personal data assistants (PDAs) and personal computers, can be obtained at USDA Forest Service website (Uresk 2010): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

![Number of plant species by life form](image)

*Figure 2. Number of plant species by category throughout the four seral stages in the Plains Cottonwood ecological type.*
Table 1. Key variables used in model development for Plains Cottonwood ecological type by seral stages with standard errors (in parentheses).

<table>
<thead>
<tr>
<th>Seral stage</th>
<th>n</th>
<th>Diameter$^1$</th>
<th>Stem number$^2$</th>
<th>Tree number$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>9</td>
<td>25 (2)</td>
<td>24 (22)</td>
<td>9 (1)</td>
</tr>
<tr>
<td>Late intermediate</td>
<td>30</td>
<td>7 (1)</td>
<td>38 (19)</td>
<td>76 (7)</td>
</tr>
<tr>
<td>Early intermediate</td>
<td>14</td>
<td>4 (1)</td>
<td>104 (45)</td>
<td>240 (19)</td>
</tr>
<tr>
<td>Early</td>
<td>18</td>
<td>1 (1)</td>
<td>1938 (293)</td>
<td>2 (1)</td>
</tr>
</tbody>
</table>

$n =$ number of sites, 0.08ha (0.2 acres) each.

$^1$ Diameter = inches. Convert inches to centimeters by multiplying by 2.54.

$^2$ Stems <1-inch

$^3$ Trees >1-inch

Table 2. Fisher’s discriminant function coefficients (SPSS 2003) for ecological classification model based on tree diameter, stem number, and tree number for Plains Cottonwood ecological type by seral stage.

<table>
<thead>
<tr>
<th>Species</th>
<th>Late</th>
<th>Late intermediate</th>
<th>Early intermediate</th>
<th>Early</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (inches)$^1$</td>
<td>2.496</td>
<td>0.882</td>
<td>1.107</td>
<td>0.123</td>
</tr>
<tr>
<td>Stem number &lt;1 inch$^2$</td>
<td>0.001</td>
<td>0.072</td>
<td>0.001</td>
<td>0.005</td>
</tr>
<tr>
<td>Tree number &gt;1 inch$^2$</td>
<td>0.084</td>
<td>0.001</td>
<td>0.175</td>
<td>0.003</td>
</tr>
<tr>
<td>Constant</td>
<td>-33.051</td>
<td>-7.034</td>
<td>-24.385</td>
<td>-6.135</td>
</tr>
</tbody>
</table>

$^1$ Diameter breast height (DBH)

$^2$ Convert inches to centimeters by multiplying inches by 2.54

Table 3. An example of assigning seral stages by using Plains Cottonwood Fisher’s discriminant coefficients with diameter (DBH) 8-inches, stem number 74, and tree number 63 from new data collected from the field.

<table>
<thead>
<tr>
<th>Seral</th>
<th>Diameter (inches)</th>
<th>Stem number &lt;1”</th>
<th>Tree number &gt;1”</th>
<th>Constant</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>(2.496 * 8) + 0.001 * 74 + 0.084 * 63 - 33.051 = -7.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Int.</td>
<td>(0.882 * 8) + 0.072 * 74 + 0.001 * 63 - 7.034 = 5.41$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Int.</td>
<td>(1.107 * 8) + 0.001 * 74 + 0.175 * 63 - 24.385 = -4.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>(0.123 * 8) + 0.005 * 74 + 0.003 * 63 - 6.135 = -4.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$ Coeff = Fisher’s discriminant classification coefficient. Diameter = diameter at breast height (DBH)

$^2$ Assigned seral stage
DISCUSSION

The plains cottonwood ecological type has undergone major changes, mainly by human caused disturbances along the Missouri River, most recently with the building of large dams for water storage, flood control, electrical production, and irrigation for farming. These large dams have altered natural fluvial processes and periodic flooding needed for floodplain development and the associated long-term sustainability of the cottonwood type. Substantial losses of cottonwood woodlands are found behind the dams along the Missouri River. However, regulated water flows below the dams are limited to provide adequate regeneration of cottonwoods, and long-term sustainability (Dixon et al. 2012; Carter et al. 2012).

Inventory, monitoring and assessment of the cottonwood woodlands will provide valuable information about the ecological condition and successional status of these cottonwood woodlands related to environmental or human induced stresses. The developed model is quantitative and can be used to describe the dynamics occurring among cottonwood seral stages throughout the riparian system based on three key variables for plains cottonwood (DBH, stem number <1 in DBH, tree number >1 in DBH). This model requires collecting only the three key variables on permanent sites, yearly or every few years and can determine trends within a seral stage or among seral stages, allowing resource professionals to meet objectives. Data collected for these three variables by the Forest Service Inventory and Analyses (FIA) would provide seral stage assignment and trends over time. The variables are not linear and show variations throughout the four stages (Figure 1). All developed model coefficients can be incorporated into the conceptual state and transition models used by the Natural Resource Conservation Service (NRCS), Bureau of Land Management (BLM), and USDA Forest Service that are qualitative (Bestelmyer et al. 2003; Briske et al. 2005; Twidwell et al. 2013; USDA-NRCS 2013). Once the model coefficients are incorporated into state and transition models, these models will then become a powerful tool for sustaining our natural resources.

Management for all four ecological seral stages as a mosaic within the plains cottonwood type enhances plant and animal diversity across the landscape. Plant species diversity among the seral stages was approximately the same for total numbers, but proportions of life forms varied among the stages (Figure 2). Some bird and mammal species require single seral stage and others multiple stages (Rumble and Gobeille 2004; Rumble and Gobeille 2001). Most bird species were observed to be in the late and late intermediate stages, while the early seral stages had more small mammals than the late seral stages.

Cottonwood trees in the late seral stage were not abundant and many were becoming decadent with no understory cottonwood regeneration or recruitment due to lack of flooding and scouring within the flood plain. Planting cottonwood cuttings has been proposed to increase regeneration, but with limited success. Possible reasons are related to lower water depth, competing vegetation and livestock grazing (Dreesen, et al. 2002; Hoag 2007). Heavy livestock grazing (late seral stage) with substantial hoof action during the spring for 3-4 days on a small
area resulted in regeneration of cottonwood seedlings (personal observations). I recommend further scientific research using livestock for regeneration of cottonwood in old decadent stands. In this current study, cottonwood regeneration was primarily in narrow channels for river tributaries flowing into the Missouri River. Other trees in the cottonwood ecological type were green ash, boxelder, peachleaf willow, American elm, and Russian olive. Green ash and Russian olive were abundant in many areas within cottonwood stands. Cottonwood regeneration is limited with the invasion of these trees because space and the opportunity for water to scour the soil for establishment of new seedlings.

The number of cottonwood saplings (stem number) showed a steady decrease from early to late seral stage as expected within the cottonwood type (Table 1). The late seral stage, primarily old cottonwood stands, had variable understories that were highly diverse, ranging from grass to grass/forb to grass/forbs/shrubs. Green ash was the dominant tree in some cottonwood stands, especially in areas where flooding and scouring was not evident for many years. Russian olive, a nonnative invasive species was dominant within some cottonwoods stands in areas of moist saline soils. To monitor changes or trends for the plains cottonwood ecological type with co-dominant trees, I recommend establishing permanent plots within the co-dominant woodlands and collecting data for the 3 key variables for only the plains cottonwood. Monitoring the plains cottonwood with key variables over time will provide information on seral stage status and trends within a co-dominant tree complex.

The developed ecological seral stage classification and monitoring model based on multivariate statistical methods defined three key variables related to plains cottonwood succession in riparian systems. Four seral stages representing early to late succession were identified quantitatively with a classification accuracy of 95%. Information required to define the seral stages using the model include DBH of cottonwood trees >1 inch, cottonwood stem number <1 inch and cottonwood tree number. These are the only measurements required for seral stage classification and monitoring. Data collection may be conducted yearly or every few years on two plots per section (square mile). Sites selected should be at a minimum of one-quarter mile apart. See USDA-Forest Service website for additional information at Uresk et al. (2010): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml. Using this model to classify seral stages and monitor changes within and among seral stages, resource managers will be able to develop and evaluate their management plans.

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LITERATURE CITED


