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# Development of GIS-based models to predict plant community structure in relation to western juniper establishment

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ABSTRACT

During the past 130 years, western juniper (*Juniperus occidentalis* Hook.) has rapidly expanded into sagebrush communities impacting plant structure and function. Predictions of intercanopy shrub density and cover with woodland development can provide insight into site condition and ecological resiliency in western juniper encroached areas. The purpose of this study is to model shrub density and cover in relation to juniper competition across a heterogeneous landscape in a southeast Oregon watershed. Independent variables included in model development were derived from high-resolution color imagery, a 10 m digital elevation model, and field-based vegetation and soil moisture measurements. Juniper cover and three intercanopy classes, representing different levels of juniper competition, were delineated from 1:5000 scale color (RGB) imagery. A competition index was produced from the classified image representing a gradient of potential competition with juniper. An integrated moisture index was generated representing variability in soil moisture due to hillslope solar radiation, curvature of the landscape and flow path direction and flow accumulation (flow path density). Plant density, plant cover, and percent soil moisture (gravimetric) were measured from 10 m $\times$ 10 m plots located throughout the watershed study area. Multiple stepwise regression produced the best-fit model for predicting plant density or cover for mountain big sagebrush (*Artemesia tridentata* ssp. *vaseyana* Beetle), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh)), and all shrub species combined. The prediction of total shrub density was significantly greater than expected by chance ($p < 0.001$), with a 0.865 coefficient of determination. Total shrub cover also had a high correlation between observed values and environmental gradients ($R^2 = 0.773$). These data can be used by land managers to assess the change in plant structure with increasing juniper canopy cover, a measure important for monitoring impacts from juniper woodland establishment.



## 1. Introduction

Western juniper (*Juniperus occidentalis* Hook.) occupies over nine million acres in the Intermountain West, USA. Since the late 1800s, western juniper expansion has increased within its range at unprecedented rates (Tausch et al., 1981; Miller and Wigand, 1994). In eastern Oregon, for example, western juniper canopy cover (>10%) has increased by 80% from 1939 to 1988 (Gedney et al., 1999; Miller et al., 2005). Associated with its expansion, this species modifies watershed dynamics by altering plant community structure through direct competition with intercanopy and understory shrub and herbaceous plant species (Bates et al., 2000; Miller et al., 2000). Bates et al. (2000) determined that two years after cutting western juniper, understory plant biomass was nearly nine times greater and perennial plant cover was three times greater than uncut juniper understory vegetation. These data suggest that juniper woodlands suppress and fragment understory and intercanopy plant communities, including sites dominated by big sagebrush (Bates et al., 2000; Knick et al., 2003). With declining cover, higher bare ground exposure in intercanopy areas increases raindrop impacts, impairs infiltration rates, increases runoff and sheet flow, and decreases soil moisture availability (Pierson et al., 2007; Petersen and Stringham, 2008). The purpose of this research is to develop a method for predicting sagebrush density and cover in a western juniper encroached watershed that can be used to assess ecological condition and predict potential impacts of woodland expansion.

Shrub cover and density can be effective indicators of ecological condition and resiliency, and can facilitate ecosystem restoration in the sagebrush grassland region (De Soyza et al., 2000; Pyke et al., 2002; Davies et al., 2006). De Soyza et al. (2000) found that increasing sagebrush cover lowered bare patch size, resulting in

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decreased erosion rates and reduced potential for ecosystem deterioration. Shrub structure has also been shown to influence infiltration rates, sediment transport, the tortuosity and connectivity of flow paths, and soil properties (Weltz et al., 1998). Greater plant cover and density reduce hillslope runoff by increasing flow path length and sinuosity and increasing infiltration potential (Ludwig et al., 1997). Sagebrush plants provide hiding cover and forage for a diversity of plant and animal species, including many sagebrush obligate wildlife species such as the greater sage-grouse (*Centrocercus urophasianus*) and pygmy rabbit (*Brachylagus idahoensis*) (Wallestad and Pyrah, 1974; Gregg et al., 1994; Himes and Drohan, 2007).

Explanatory variables important to plant dynamics include soil moisture, soil properties, runoff patterns and regions of water accumulation (Western et al., 1999; Moharana and Kar, 2002). However, these variables can have large degrees of variation across landscapes. For example, soil moisture patterns vary spatially across a landscape at a range of scales (Coronato and Bertiller, 1996; Miller et al., 1983). At the catchment and hillslope scale, the spatial variability in soil moisture creates heterogeneity in plant species distribution patterns. The frequency and distribution of precipitation can influence soil water availability which plays a major role in plant composition and productivity (Comstock and Ehleringer, 1992; Bates et al., 2006). Soil moisture patterns can also be influenced by differences in soil evaporation rates, varying by the position of the hillslope in relation to the direction of incident solar radiation (Moore et al., 1993; Waring and Running, 1999).

Characterizing shrub structure and developing land management practices using landscape-scale information and ecological models can facilitate restoration that may be difficult at the plot-scale (Tueller, 1989). Geographic information systems (GIS) and remote sensing are landscape-scale tools that have been used widely in ecological modeling to describe heterogeneous distributions of ecological resources (Tueller, 1989). In addition to providing a tool for analyzing data and communicating results, ecological models are probably most valuable for making predictions such as plant distribution patterns (Turner et al., 2001). This includes models that predict spatial and temporal changes to plant community structure resulting from woodland encroachment (Turner et al., 1993). Ecological models have been developed using remotely acquired terrain indices to predict soil moisture variability and availability for plant growth and development over time and space (Iverson et al., 1997; Western et al., 1999). Iverson et al. (1997) developed an integrated moisture index from digital elevation data to accurately predict soil moisture and its influence on oak forest productivity in areas with relatively high topographic relief and shallow soils. Studies have shown that the most influential explanatory variables for predicting soil moisture include incoming solar radiation, slope position (slope, aspect, and elevation), and hillslope configuration (Dubayah and Rich, 1995; Mitasova et al., 1996; Iverson et al., 1997).

Research is needed to investigate plant community structure and dynamics at a variety of landscape scales, ranging from ecological sites to regional landscapes (Turner and Gardner, 1991). Disturbance patterns that result from woodland encroachment and subsequent ecological recovery following land treatment will vary both spatially and temporally, therefore, characterizing plant community dynamics and applying land management practices at the watershed-scale can account for variability in plant community response and ecological recovery that would be more difficult to detect at the plot-scale (Turner et al., 1993).

## 2. Study objectives

The objective of this study is to develop predictive models for total shrub, big sagebrush (*Artemesia tridentata* spp. *vaseyana* Beetle), and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh)) density and cover in a western juniper encroached watershed in southeast Oregon. Remote sensing and GIS are used to develop and apply ecological models across a heterogeneous ecosystem at the catchment scale.

## 3. Methods

### 3.1. Study location and description

This study was conducted in a watershed located in the Steens Mountain in southeast Oregon, located in the High Desert Ecological Province, along the northern extent of the Great Basin Desert (Anderson et al., 1998). Elevation ranges from approximately 1707 m to 2073 m and average annual precipitation is 32 cm. Soils of the study site are characterized as loamy-skeletal, mixed frigid lithic Argixerolls, belonging to the Pernty-Rock outcrop complex type (South-Slopes PZ 12-14 ESD) and mixed, superactive frigid pachic Haploxerolls belonging to the Westbutte-Lambring rock outcrop complex type (North-Slopes PZ 12-14 ESD). These soils are formed from colluvium and residuum deposits, weathered from basalt and rhyolite parent material. Soils consist of gravely to cobbly loam or silt loams from the surface to approximately 20–30 cm depths. These soils typically contain between 20% and 70% rock (stones and cobbles) with the highest content usually occurring just above bedrock (NRCS, 2000).

Historic vegetation composition on the South-Slopes PZ 12–14 ecological site was approximately 70% grasses with 30–50% of bluebunch wheatgrass, 10% forbs, and 20% shrubs including 5–10% mountain big sagebrush and 2–10% antelope bitterbrush (*Purshia tridentata* (Pursh)). The North-Slopes PZ 12–14 ecological site occurs on northerly exposures of mountain sideslopes with historic species composition of 10–15% mountain big sagebrush, 2–10% antelope bitterbrush, 2–5% snowberry (*Symphoricarpos rotundifolius* A. Gray) and 40–50% Idaho fescue (*Festuca idahoensis* Elmer). Neither site was reported to have had juniper in the "historic plant community". Current plant communities at this site consist of bluebunch wheatgrass, Idaho fescue, mountain big sagebrush, rubber rabbitbrush (*Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird), antelope bitterbrush, and western juniper.

### 3.2. Study design and plant community assessment

Plots used to collect plant cover, plant density, and soil moisture were arranged in a complete randomized block experimental design with two factors; aspect and juniper competition level. Aspect was divided into four cardinal directions (north, south, east, and west) using a 10 m USGS digital elevation model (DEM) in Erdas Imagine GIS (1991). Within each aspect, three competition levels were identified from high-resolution (1:5000 scale) color imagery, delineated with a supervised classification in GIS (see Section 3.3.1). The "high-competition" level represented intercanopy areas in juniper occupied stands with high percent bare ground and low shrub cover (<5% foliar cover). The "moderate-competition" level represented intercanopy areas with low bare ground and high intercanopy shrub cover (>10% foliar cover). Control sites, representing the matrix plant community, were identified as those areas that lacked direct competition with juniper roots. Juniper canopy cover was also delineated from the supervised classification. Percent juniper cover at each plot was measured from the classified image using a 400 $m^2$ window surrounding the center of the plot.

Within each aspect, four replicate plots of each competition level were randomly selected and ground-truthed. Since "high competition" conditions were not observed on north-facing slopes,