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GIS Ordination Approach to Model Distribution of Shrub Species in Northern Utah

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A GIS Ordination Approach to Model Distribution of Shrub Species in Northern Utah

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ABSTRACT

Anthropogenic and natural disturbances represent a serious threat to natural ecosystems dominated by big sagebrush (Artemisia tridentata). Conservation efforts aim to restore original species composition and prevent the invasion of undesirable species. In order to restore the historic plant communities, we need a clear understanding of how species compositions are distributed along environmental gradients. Species ordination is a process of placing plant species along environmental gradients. This study was conducted in Rich County, Utah, where substantial changes in species composition have been documented in recent years. Field data, literature review, multivariate analyzes, GIS and remote sensing techniques, and expert knowledge were used to define environmental variables and their respective suitability ranges of where shrub species may occur along this area. Ordination and CART-statistical analyzes were used to estimate and predict suitability of shrub species along environmental gradients. GIS procedures were used to spatially predict species distribution. Field data and the Southwest Regional Gap Analysis Project data provided useful information to build the model and 20 percent of field data was withheld to cross-validate the findings. Final results showed that the shrub species distribution in the rangelands of Northern Utah, specifically Rich County, might be driven by precipitation and temperature gradients -influenced greatly by elevation. Slope contributing area, NDVI, and solar radiation were statistically significant factors explaining shrub distribution. To our perception, soil moisture availability might be the most explanatory variable behind these findings. In the model validation, the Kappa coefficient was K = 61.3 percent and the overall model accuracy was 74 percent. The location of species distribution areas, in the final map, can be useful to managers in order to define where resources might be allocated to preserve and restore these native rangeland ecosystems.

In Monaco, T.A. et al. comps. 2011. Proceedings – Threats to Shrubland Ecosystem Integrity; 2010 May 18-20; Logan, UT. Natural Resources and Environmental Issues, Volume XVII. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan Utah, USA.

RESUMEN

Perturbaciones naturales y antropogénicas representan una seria amenaza para los ecosistemas naturales dominados por sagebrush (Artemisia tridentata). Los esfuerzos conservacionistas se enfocan en restaurar la composición original de las especies y prevenir la invasión de especies indeseables. Para poder prevenir o restaurar las comunidades vegetales, necesitamos un claro entendimiento de como la composición de especies esta distribuidas a lo largo de gradientes ambientales. La ordinación de especies es un proceso de colocar las diferentes especies dentro de un rango de variables ambientales. Este estudio fue conducido en el Condado de Rich, estado de Utah, USA, donde cambios sustanciales en la composición de especies han sido reportados en los últimos años. Datos de campo, revisión de literatura, análisis multivariados, técnicas SIG y de teledetcción, así como también el conocimiento de expertos en la materia, fueron utilizados para definir los rangos de variables ambientales sobre los cuales las especies estudiadas de arbustos se localizan. Análisis de regresión usando técnicas de ordinación y árboles de decisiones, fueron utilizados para predecir las variables ambientales y sus respectivos rangos, donde estas especies podrían habitan. Datos de campo y resultados del proyecto Southwest Regional Gap Analysis proveyeron de información útil para construir el modelo y 20 percent de las muestras de campo fueron retenidas para validar los resultados. Los resultados finales muestran que la distribución de especies arbustivas en el norte de Utah, específicamente en el Condado de Rich, pueden estar gobernadas por gradientes de precipitación, temperatura -ambas variables influenciadas por la altitud-. El área de la pendiente tributaria, el Índice Normalizado de Diferenciación de la Vegetación (NDVI, por sus siglas en inglés) y la radiación solar, también resultaron estadísticamente significativos como variables predictoras. De acuerdo a nuestra percepción, la disponibilidad de humedad en el suelo podría ser la variable oculta detrás de las otras variables. En la validación del modelo, el Coeficiente Kappa fue de K = 61.3 percent y la precisión global del modelo resultó =74 porciento. La localización de las especies en el mapa final, puede ser de gran ayuda para las agencias de gobierno para decidir donde los esfuerzos de restauración podrían concentrarse para proteger y preservar estos importantes ecosistemas nativos.

INTRODUCTION

Shrub ecosystems occupy large areas in the western U.S. and have long provided society with grazing opportunities, water, wildlife habitat and recreational values. Nearly 45 million hectares in the western U.S. are dominated by sagebrush ecosystems (*Artemisia* spp.) (West 1999). In recent decades, their abundance and ecological condition has declined in reaction to natural and anthropogenic processes (Wisdom et al. 2005a). Documented examples of such processes include the invasion of non-native, colonizing herbaceous species (i.e. Cheatgrass (*Bromus tectorum*) mainly on the warmer and drier low altitudes, and the encroachment of woodlands, such as Pinyon-Juniper, in the cooler and wetter and higher altitudes (Suring et al. 2005, Wisdom et al. 2005b). Land management concerns include the loss of prime agricultural land, urban growth and encroachment, loss of prime habitat, regrowth of native vegetation following wildland fire events, erosion, rangeland and forest health changes due to management prescriptions, and the distribution and expansion of wide-ranging noxious weeds (Holechek et al. 1989). Both human and natural perturbations have a significant impact on these sagebrush ecosystems.

Species ordination may assist in restoring these natural ecosystems to their original species distribution. Species ordination is the process of placing species along one or more environmental gradients or to abstract axes that may represent such gradients (Austin 1985). The objective of ordination is to locate patterns of species composition along gradients. Intents for species ordination and classification started at the beginning of last century. In 1930, Ramensky began to use informal ordination techniques for vegetation. Such informal and largely subjective methods became widespread in the early 1950's (Austin 1985). Whitaker introduced the unimodal model concept, in which species abundance was a function of a position along a single gradient (Whittaker and Niering 1965). Today, ordination may be seen as an exploratory data-analysis technique that identifies pattern, such as trends, clusters or outliers, using a multivariate set of data.

Decision-tree classifiers are well appropriated for land cover mapping, especially when considering multiple environmental explanatory variables spatially distributed over an area (Vayssieres and Plant 1998). First, as a non-parametric classifier, decision trees require no previous assumptions of normality, which is useful as many land-cover classes and when environmental features do not show a normal distribution. Second, decision trees accept a variety of measurement scales in addition to categorical variables, which may be the case while using ancillary data (De'Ath 2002). Traditional parametric classifiers have difficulty dealing with differences in spatial and ancillary measurement scales. Decision-tree classifiers have demonstrated improved accuracies over the use of traditional classifiers (Dixit and Geevan 2002). Finally, decision tree software is readily available, computationally efficient, and by using a hierarchical approach to define decision rules, is relatively user-friendly to a variety of users. (Lowry et al. 2005, 2007).

To our knowledge, linking multivariate ordination studies and GIS analysis is a relatively novel task. Few studies report the use of spatially explicit ordination data to place areas of species occurrence in maps (Merzenich and Frid 2003). Some other studies mention the use of GIS data to determine the values of environmental variables used in the ordination process. The purpose of this study was to spatially predict the occurrence of seven sagebrush shrub types in the rangelands of Rich County, Utah using a GIS predictive model.

METHODS

Study Area

The study area was located in Rich County, Utah. The rangelands of Rich County in Northern Utah are characterized by having vegetation dominated by sagebrush (*Artemisia* spp.) communities associated with native and introduced grasses (Stoddard 1940). Rich County is predominantly composed of salt desert scrub, big sagebrush-steppe and shrublands, as well as pinion-juniper ecosystems (Washington-Allen et al. 2004, 2006). Rich County is best characterized as a higher elevation big sagebrush-steppe/shrubland environment ranging from the pinion-juniper ecosystems to sub-alpine forests and meadows. Our work focused on the big sagebrush-steppe shrublands and pinion-juniper ecosystems. Both study areas have suffered changes due in historical disturbance regimes ranging from grazing, burning, drought, and flooding events. These areas have been under commercial agriculture and grazing for years.

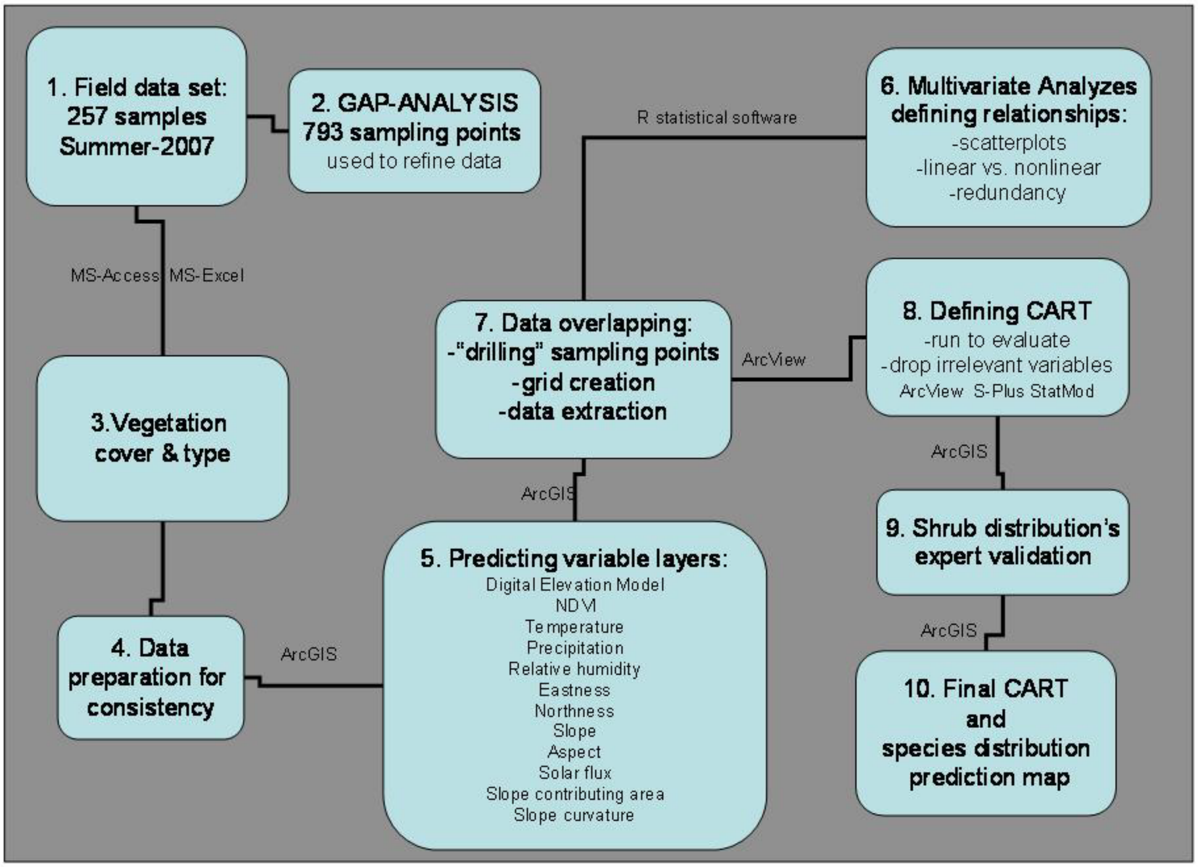

Figure1. Generalized data flow model illustrating creation of CART for shrub species distribution in Rich Co., UT.

Some big sagebrush ecosystems have converted to exotic annual grasslands or to pinion-juniper environments while an equal area has been maintained its natural condition (West 1999).

The area exhibits an ascending elevation gradient (from 1,500 to 2,100 meters above sea level) from East to West. Precipitation may range from 200 to 300 mm per year and temperature will usually range between -40 degrees C to 40 degrees C.

Methodology

The methodology used in this study is described in Figure 1. Field data was acquired in summer of 2007. Field forms were developed in a Microsoft Access database to record GPS coordinates and pictures. Seven shrub species distributed in 257 sites (figure 2) were used as a field-input data in these analyzes (See table 1 for scientific names, common names, and USDA's plant codes). Data was refined and standardized with the SouthWest Gap Analysis data. Data layers were produced by clipping raw data layers to a 1 km buffered Rich County boundary, and then scaling by standard deviation. The standard deviations were multiplied by 100 and rounded to the nearest whole number. Spatial data was manipulated using ArcGIS ver 9.2, and environmental data was extracted (drilling) from each layer and the Software R was used to study potential relationships, linearity, normality and redundancy among variables. Table 2 shows all explanatory variables used in this study. All layers and data points were arranged in ArcView® ver 3.2 GIS software. Spatial analysis extension was used along with StatMod Zone, an extension for ArcView developed by the USU Remote Sensing and GIS laboratories (Garrard 2003). This extension was designed to simplify statistical modeling with spatial data. This tool facilitates the creation of classification and regression tree (CART) and makes it easy to map the results of these models. The StatMode Zone extension works along with ArcView, and S-Plus to provide the most significant variables and dropping the least relevant variables until it displays the final CART and the species distribution map.

It is important to mention that previous to the use of CART analysis, we used the R statistical software to perform other analyzes such as Principal Component Analysis (PCA) and Cluster Dendrogram Analysis. None of them provided useful results. In addition, the GAP Analysis sampling points for Rich Co. were also used (approximately 900 points). Analyses were also performed using the GAP analysis data alone and combined with the 257 points taken in 2007. The resulting species distribution maps did not provide useful results either. Distribution was confused and did not seem to represent past or current or even a logical species distribution.

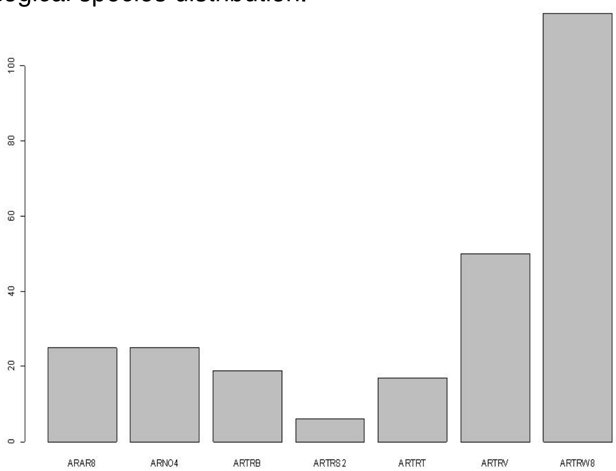

Figure 2. Histogram of number of sampled sites per species. Seven species were sampled in a total of 257 sites - Rich Co., UT.

Model Accuracy

Many methods of accuracy assessment have been discussed in remote sensing literatures (Sardinero 2000, De'Ath 2002). Three measures of accuracy were tested in this study, namely overall accuracy, error matrix and Kappa coefficient. The overall accuracy is evaluated from a predicting model output with respect to geo-referenced data; the term accuracy is used typically to express the degree of 'correctness' of the predicting model (Foody 2002). The matrix error displays the statistics of the image classification accuracy showing the degree of misclassification among classes (Jensen 2005). The Kappa coefficient is a measure of agreement between a model prediction map and reference –field obtained-data (Lowry et al. 2007).

Model accuracy assessment was performed to compute the probability of error for the shrub prediction map. A total of 69 samples (20 percent of all samples) were previously randomly withheld for the accuracy assessment. Samples were "drilled" into the final prediction map to determine which samples fell correctly into the modeled classes. Procedure involved the use of ArcGIS ver 9.2 and the spatial analysis tool: sampling.

RESULTS AND DISCUSSION

Significant Environmental Variables

Final results showed that the shrub species distribution in the rangelands of Northern Utah, specifically in Rich County, might be driven by precipitation and temperature gradients, and influenced greatly by elevation. Slope-contributing area, NDVI, and solar radiation also resulted in statistical significance, explaining most of the shrub occurrence and distribution. Elevation and eastness were sometimes excluded to avoid redundancy from the analyses, because they presented strong relationships with precipitation and temperature. This analysis provided useful information to study potential relationships, linearity, normality and redundancy among variables, and shows the distribution of shrub species along gradients of all studied environmental variables in Rich County, Utah (figure 3).

In the CART analysis (figure 4), the final model was statistically significant for the following environmental variables: precipitation, temperature, slope contributing area, NDVI and solar radiation. All studied variables and their relationships with the shrub species are described below:

Precipitation: The main driver of presence humidity at each site. For this particular study, Figure 5 shows that the snowfield sagebrush (ARTRS2) sites receive larger amounts of precipitation than sites located at higher elevations. The other species did not seem to receive different amounts of rainfall.

Temperature: shrub species behaved inversely proportional to elevation and precipitation. Figure 6 shows also that snowfield sagebrush (ARTRS2) sites have the lowest average temperature, located at the higher elevation sites. The other species did not seem to be affected by this variable; however, it showed statistical significance at the time of mapping the shrub community distribution.

Table 1. Sagebrush Shrub Species: 7 species or subspecies, 257 sites - Rich Co., UT.

USDA's plant Species code	No. sites	Scientific Name (Genus and Species)	Common Name
ARAR8	25	Artemisia arbuscula subsp. arbuscula	Low sagebrush
ARNO4	25	Artemisia nova	Black sagebrush
ARTRB[a]	19	Artemisia tridentata X "bonnevillensis"	Boneville sagebrush
ARTRS2	6	Artemisia tridentata subsp spiciformis	Snowfield sagebrush
ARTRT	17	Artemisia tridentata subsp tridentata	Basin big sagebrush
ARTRV[a]	50	Artemisia tridentata subsp vaseyana	Mountain big sagebrush
ARTRW8	114	Artemisia tridentata subsp wyomingensis	Wyoming big sagebrush

[a] Plant codes and names are not officially assigned.

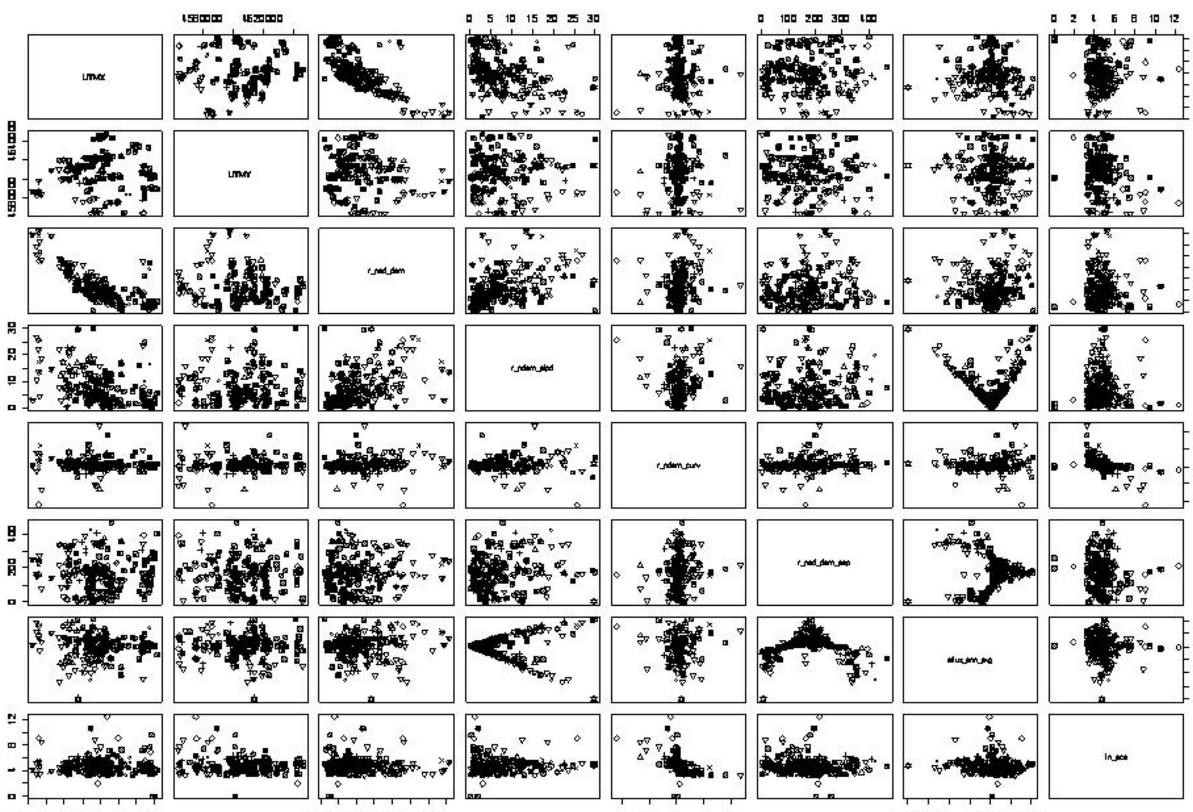

Figure 3. Multivariate assessment of all explanatory variables that explain shrub spatial distribution in Rich County, Utah. Precipitation and temperature are excluded, since they presented strong relationships with elevation and eastness.

Table 2. List of potential explanatory variables used in this study.

Variable	Explanation
Aspect	Aspect, as computed by ArcMap [-1 = flat]
Elevation	Elevation from the USGS National Elevation Data Set (m).
Normalized Difference Vegetation Index (NDVI)	Mean annual NDVI changes over the years for a particular site, a composite of maximum.
Slope curvature	Curvature from r_ned_dem calculated by ArcMap (positive values=convex slope, negative values=concave slope)
Northness	Northing coordinate, NAD83, Zone 12Y UTM coordinates (meters)
Eastness	Easting coordinate, NAD83, Zone 12X UTM coordinates (meters)
Slope	Slope from elevation data set (degrees)
Solar flux index	Annual average solar flux calculated using Zimmerman solar radiation model on r_ned_dem and using Dayment monthly temperature grids (kJ/sq.m/day).
Slope contributing area	log of upslope contributing area calculated using Tarboton "Tau DEM" ArcMap plug-in (ln(m))
Temperature	Average annual temperature calculated from Dayment grids (1/100 C).
Precipitation	Sum of annual precipitation grids calculated from Daymet grids (1/100 cm)

Slope contributing area: this is a measure of moisture availability at each side and it depends on the amount of surface and underground water. Figure 7 shows that there is no apparent change in this variable among the studied shrub species.

NDVI: the Normalized Difference Vegetation Index is an indicator of the amount of greenness reflected by the vegetation. It shows in Figure 8 that there is no apparent difference among species with respect of the greenness values of vegetation.

Solar flux index: is a climatic variable that indicates the amount of heat received by a site (figure 9). The species snowfield sagebrush (ARTRS2) was found in areas where solar heat was higher and mountain big sagebrush (ARTRV) was found in areas were solar flux was lower. Solar flux did not appear to be an explanatory variable of the final model.

Elevation: All species were predicted to be found in a range between 1,950 and 2,300 masl (figure 10), except for snowfield sagebrush (ARTRS2) where it can be found at higher altitude between 2,450 and 2,600 masl. The CART analysis did not find this variable to be statistically significant (figure 4).

Slope: All studied shrub species were found to be located within 3 to 17 degrees of slope (figure 11). No major differences were found among species. The CART model did not take into account this variable as a major explanatory variable of the final model (figure 3).

Slope curvature might be a significant topographic variable explaining shrub distribution along rough terrain (figure 12). However, in this study, the CART model dropped this variable due to either not enough number of samples or little consistency in the field information. All species were located on almost flat surfaces except for black sagebrush (ARNO4), snowfield sagebrush (ARTRS2), and mountain big sagebrush (ARTRV), which were found to occur on slightly concave slopes.

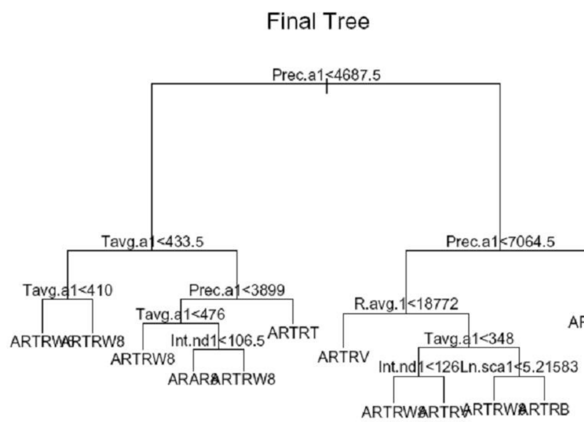

Figure 4. Summary of Classification Regression Tree Analysis – S-Plus output.

Aspect is considered one of the most important environmental variables explaining species distribution, because it greatly affects photosynthetic rate and soil moisture availability (figure 13). Most species were found on north facing slopes (60 to 180 degrees) that are cooler, less exposed to the sun heat, and consequently retain more moisture. Aspect was not an explanatory variable of the final CART model (table 3).

Eastness (figure 14) and Northness (figure 15) were also analyzed, and they are associated to the location with respect to the X and Y coordinates of the sampling sites. In the case of the X location, this was associated with elevation, with increases from East to West, and Northness was also associated with temperature, which has a slight decrease moving north. These two variables were not included in the model because of the obvious correlation to the previously mentioned variables.

Table 3. Summary of Classification Tree Analysis of ArcView-SPlus-StatMod output.

Number of branches	Value	Deviance/N	Prediction	Probability
1	7	26.58	ARTRV	0.63
2	8	53.42	ARTRW8	0.76
3	9	107.3	ARTRW8	0.55
4	11	43.49	ARTRT	0.48
5	12	44.12	ARTRV	0.65
6	20	8.04	ARTRW8	0.95
7	42	9.54	ARAR8	0.78
8	43	11.15	ARTRW8	0.71
9	52	23.48	ARTRW8	0.45
10	53	35.87	ARTRV	0.47
11	54	82.46	ARTRW8	0.50
12	55	44.62	ARTRB	0.39

Shrub Community Description

This study is the first to provide an extensive description of shrub vegetation patterns in the Rich County area. We found that shrub vegetation patterns in these shrublands are highly variable and sometimes indistinct, probably more so than in wetter climates. The main finding would probably center on the fact that vegetation composition is ordered along a complex environmental gradient running from the lower to the higher slope gradient. There was also a clear elevation gradient from the valley (east) to the western highest peaks. Within this main gradient, shrub vegetation patterns are further related to specific landforms, topographic positions, microsites, and plant associations.

The environmental features correlated with these shrub distribution patterns are surrogates for the underlying processes and mechanisms. We suggest there are three major drivers of shrub vegetation patterns in Rich County: (i) hillslope processes associated with elevation, (ii) moisture gradients; and (iii) anthropogenic disturbances such as fire and grazing. The distribution of the three locally prevalent subspecies of *A. tridentata* (mountain, Wyoming, and Bonneville sagebrushes) correlates generally with environmental gradients: mountain sagebrush at high elevations, and Wyoming sagebrush and big sagebrush at low elevations. While soil moisture and temperature generally correspond to elevation and aspect, we found that in Rich County, high elevation sites are often too dry for mountain sagebrush (ARTRV), and it is displaced by Wyoming sagebrush (ARTRW8). A hybrid between these two subspecies, Bonneville sagebrush (ARTRB) represents a fourth community type that occurs in habitats that are intermediate in available moisture. The hybridization zone is clearly delineated at the intermediate elevation, following the contour lines (figure 16). The fifth community type modeled in this study is low sagebrush (ARAR8) a species growing on shallow, fine textured or rocky soils that occur as islands within this region.

Much of the variation in shrub vegetation is a product of hillslope processes and the environmental changes associated with ridge-top to valley bottom gradients. We also suggest that the moisture gradient is one of the main drivers of shrub distribution, and in fact, this is the main driver for most plant community distributions (Parker 1982, Adams and Anderson 1980). It is strongest at the base of the slopes and then decreases as the slope increases. The strength of the gradient may be related to the spatial distribution of precipitation along the elevation axis; that is, there is relatively little precipitation at higher elevations and more precipitation at the valleys. Additionally, shrub distribution is affected by the change in temporal distribution of precipitation, but also to moisture distribution regimes.

Finally, the anthropogenic disturbances have affected the current distribution of shrub vegetation. For instance, species such as black sagebrush (ARNO4) and snowfield sagebrush (ARTRS2) were not mapped because either they do not have enough samples or they did not show a very well defined distribution pattern. For us, the second may be the cause of uneven distribution of these species. Anthropogenic disturbances, such as grazing and fires, are more likely to be the cause of such erratic distribution.

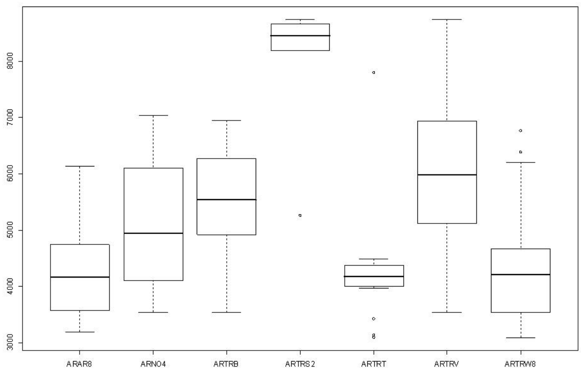

Figure 5. Distribution of shrub species along the Precipitation (1/100cm) gradient, Rich County, Utah.

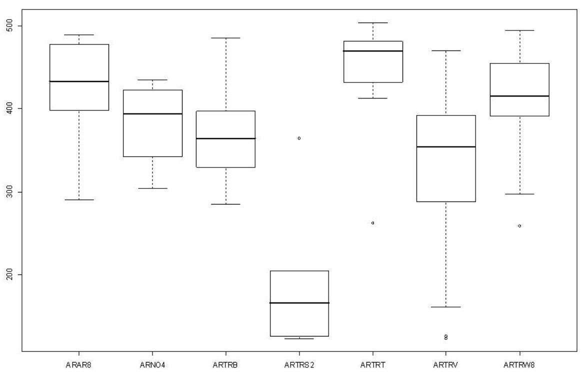

Figure 6. Distribution of shrub species along the Temperature (1/100 degrees C) gradient in Rich County, Utah.

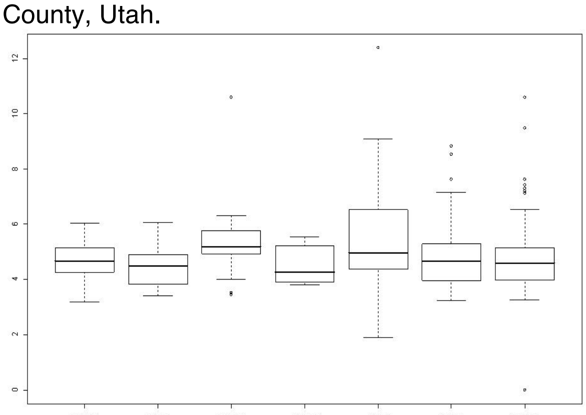

Figure 7. Distribution of shrub species along the Upslope Contributing Area gradient (Log of in meters) in Rich County, Utah.

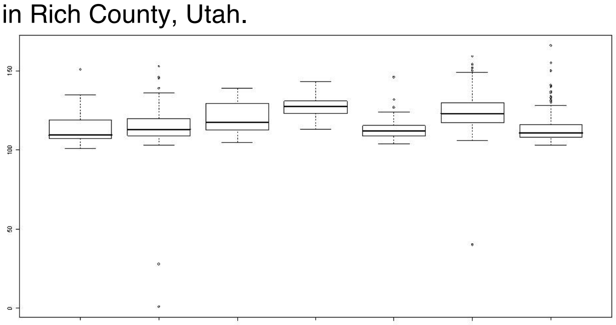

Figure 8. Distribution of shrub species along the NDVI in Rich County, Utah.

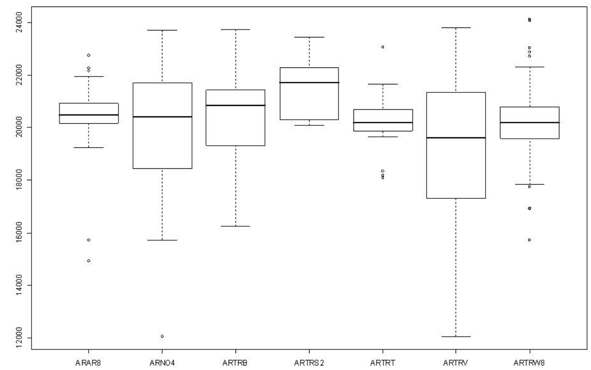

Figure 9. Distribution of shrub species along the solar flux gradient (kJ/sq.m/day) in Rich County, Utah.

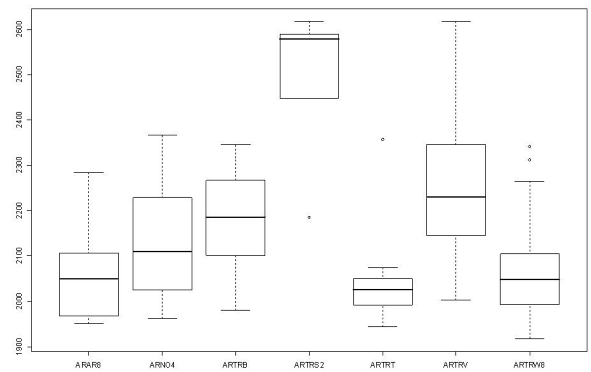

Figure 10. Distribution of shrub species along the elevation (meters) gradient in Rich County, Utah.

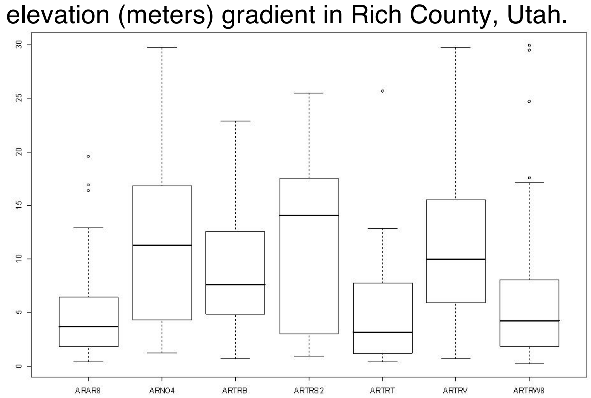

Figure 11. Distribution of shrub species along the slope (degrees) gradient, Rich County, Utah.

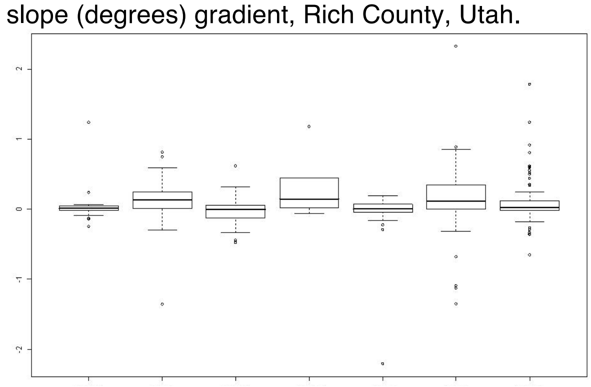

Figure 12. Distribution of shrub species along the slope curvature gradient (Concave (+values) Convex (-values)) in Rich county, Utah.

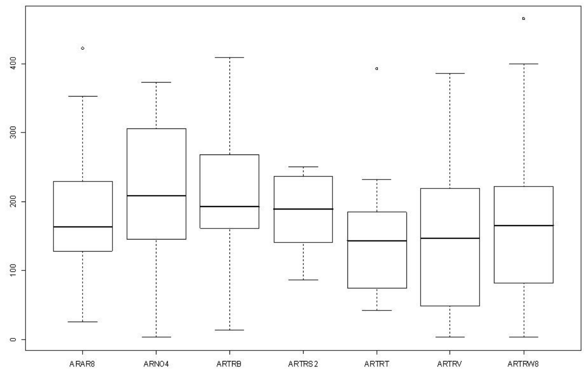

Figure 13. Distribution of shrub species along the aspect gradient (Degrees) in Rich County, Utah.

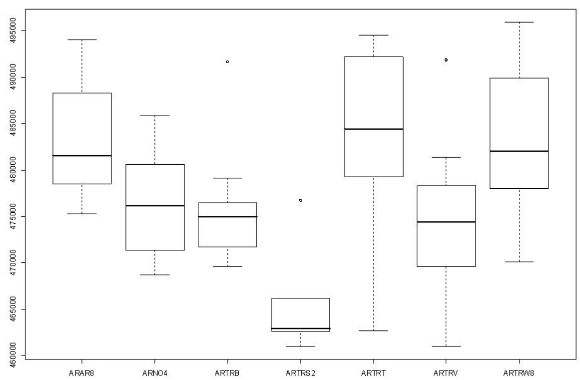

Figure 14. Distribution of shrub species along the X Coordinate (Eastness, in meters) in Rich County, Utah.

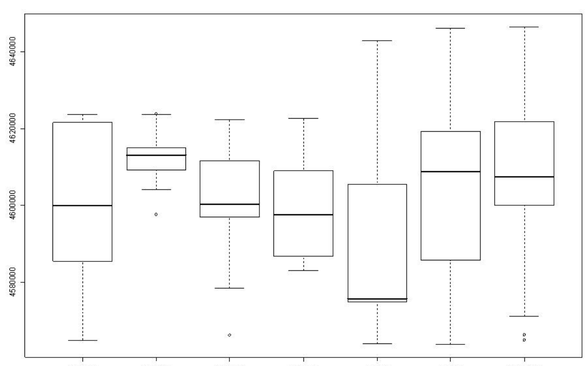

Figure 15. Distribution of shrub species along latitude (Y Coordinates, Northness in meters) in Rich County, Utah.

Shrub Descriptions

Finals results showed that only 5 shrub species (out of seven) were predicted with the final CART model. The spatial distribution of the 5 studied shrub species in a 3-D map of Rich County, Utah can be seen in Figure 16. It shows the distribution of: mountain big sagebrush (ARTRV), Wyoming big sagebrush (ARTRW8), basin big sagebrush (ARTRT), low sagebrush (ARAR8), and Bonneville sagebrush (ARTRB).

Wyoming big sagebrush (ARTRW8) was the best predicted species and can be found following several branches (rules). Its location can be predicted with the highest probability, 95 percent (branch # 6) (table 3). Black sagebrush (ARNO4) and snowfield sagebrush (ARTRS2) were dropped from the model, because the model either needed more field data or could not establish a distinguishable distribution pattern based on these variables.

Mountain big sagebrush (ARTRV) was predicted at the higher elevation while basin big sagebrush (ARTRT), low sagebrush (ARAR8), and Wyoming big sagebrush (ARTRW8) were predicted at the lower elevations. The proposed hybrid involving Wyoming sagebrush and mountain sagebrush (Shultz 2009) is called "*Bonnevillensis*" (ARTRB), and was predicted in the middle elevation areas, a finding which is consistent with other investigations of hybrid zones for these subspecies of big sagebrush (West 1999, Garrison 2006, Shultz 2009) (Figures 10 and 16). Expert knowledge and the Southwest Regional Gap Analysis Project (Lowry et al. 2005) data were used to corroborate the findings.

This description of species distribution is drawn from a review of literature as it is being compiled in a new work on sagebrush taxonomy and ecology (Tart and Shultz, in prep). These descriptions are supported by our findings of habitat preferences for the various kinds of sagebrush species occurring in Rich County.

1. Mountain big sagebrush (ARTRV). Mountain big sagebrush generally occurs in moister sites than Wyoming sagebrush (ARTRW8), and at higher elevations. In arid mountain ranges, however, the two subspecies may be found at the same elevation. In these situations, mountain sagebrush will be growing in snow-accumulation depressions, east or north-facing slopes, or in areas protected by an overstory of aspen. It occurs in a wide range of mountain habitats, but predominantly on well-drained soils that are higher in organic matter than sites where one typically finds Wyoming big sagebrush.

2. Wyoming big sagebrush (ARTRW8). Wyoming big sagebrush occurs in drier sites than Mountain big sagebrush and is often found on soils with slow infiltration rates (Shumar and Anderson 1986). It also occurs on soils with a greater proportion of summer precipitation (Miller and Eddleman 2000, Winward 2004) or where grazing has reduced the competition from native grasses.

3. Basin big sagebrush (ARTRT). It generally occurs at lower elevations than Mountain or Wyoming big sagebrush and is typically found in valleys. In agricultural areas and low elevation rangelands, this is the subspecies that is now restricted primarily to fencerows and roadsides. It grows in deep, fertile soils that have been plowed for agriculture.

4. Low sagebrush (ARAR8). Low sagebrush occurs on shallow, fine-textured or rocky soils at low to high elevations. It is usually found in isolated “island” communities within the Mountain or Wyoming sagebrush zones.

5. Bonneville sagebrush (ARTRB). Considered a hybrid and named informally as “Bonneville sagebrush” by Al Winward (Garrison 2006, Shultz 2009), this type occurs more commonly with mountain big sagebrush (ARTRV) than with Wyoming big sagebrush (ARTRW8). It has a more diverse herbaceous understory (McArthur and Sanderson 1999, Winward 2004) and is considered an important plant association for various species of wildlife (Shultz 2009).

Model Validation

The Kappa coefficient was K = 61.26 percent, and overall accuracy was close to 74 percent (Overall classification = 73.91 percent). The measures of accuracy are shown in Table 4. The overall accuracy is expressed as a percentage of the test-pixels successfully assigned to the correct classes. The results obtained are presented in Table 4, where it contains: the overall confusion matrix, the classification accuracy, and the Kappa coefficient.

From the present analysis, the mountain big sagebrush (ARTRV) achieved 100 percent of classification accuracy with the highest overall accuracy. The 26 sites fell correctly into that class in the predicted model. It was followed by Wyoming big sagebrush (ARTRW8) with 85 percent accuracy, Bonneville sagebrush (ARTRB) (25 percent accuracy) and the low sagebrush (ARAR8) (18 percent accuracy). In general, the model performed better when more field data (reference) was available, but also when the model identified and recognized a clear distribution pattern.

A visual validation was also performed using expert knowledge and field observations. Final distribution of shrub species was corroborated by experts that agreed that final distribution satisfies requirements where the studied shrub species are expected to be found.

Table 4. Error Matrix of the Shrub Prediction Model and the Reference data.

Predicted Data	**Reference Data**					
	ARAR8	**ARTRB**	**ARTRT**	**ARTRV**	**ARTRW8**	**Total**
ARAR8	2	0	0	0	1	3
ARTRB	0	1	0	0	0	1
ARTRT	1	0	0	0	0	1
ARTRV	1	3	0	26	3	33
ARTRW8	7	0	1	0	23	31
Total	11	4	1	26	27	69
% per specie	18.2	25	0	100	85.2	

Overall classification = 73.91%
Kappa Index (K) = 61.26%

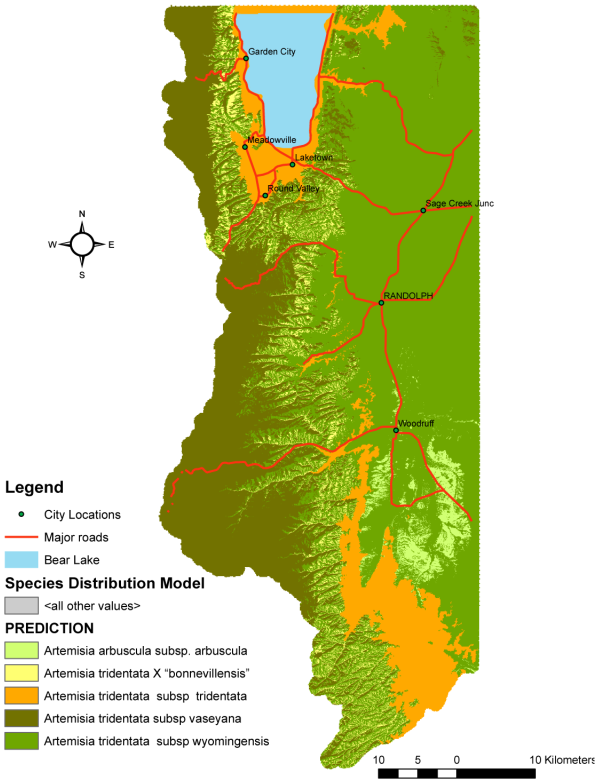

Figure 16. Final map of prediction of shrub species distribution in Rich County, Utah.

CONCLUSIONS

The major findings for this study revealed that environmental features are correlated with patterns associated with mechanisms responsible for shrub distribution in Rich County. The major environmental drivers consisted of processes associated with elevation, temperature, moisture availability and, at small scales by anthropogenic disturbances, such as fire and grazing. This is true, particularly for the most prevalent shrub subspecies of mountain sagebrush (ARTRV), which is usually distributed at higher elevations, and Wyoming sagebrush (ARTRW8) and basin big sagebrush (ARTRT) at low elevations. In Rich County, we also found that higher elevation sites are typically low in moisture availability for mountain sagebrush (ARTRV), and that might be the reason why it is substituted by Wyoming sagebrush (ARTRW8). The Bonneville sagebrush (ARTRB) constitutes a hybrid between these two subspecies and it is the fourth largest shrub community type. Low sagebrush (ARAR8) constitutes the fifth largest shrub community, and its distribution occurs in patches mostly driven by the presence of shallow, fine textured or rocky soils. The actual distribution of black sagebrush (ARNO4) and snowfield sagebrush (ARTRS2) occurred in our sites, but not in sufficient abundance for predicting modeling or their distributions depend upon, mostly, by human disturbances.

This study demonstrates the effective use of GIS ordination techniques for unbiased identification of homogeneous geographic units, based on topographic, edaphic, and climatic parameters. Older ordination techniques provided little spatial information of where species distribution was located in heterogeneous landscapes. GIS and Remote Sensing techniques along with statistical analyzes, especially CART analysis, offer a promising tool to place plant distributions along environmentally dissected gradients. This analysis would provide important knowledge of where management efforts might be directed to restore this area to its pristine condition.

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