AN ABSTRACT OF THE THESIS OF

Ya-Chian Chen for the degree of Master of Science in Forest Resources presented on December 2, 1996. Title: Spatial and Temporal Distributions of Western Juniper in John Day Fossil Beds National Monument, Oregon.

Abstract approved:______________________________

Edward E. Starkey

Post-settlement juniper expansion in the western states has been reported for decades, including western juniper (*Juniperus occidentalis* Hook ssp. *occidentalis*) woodlands in the northwestern states. A 15 km^2 study area in the Sheep Rock Unit of John Day Fossil Beds National Monument in eastern Oregon was selected to study spatial and temporal distribution patterns of western junipers, and build statistical models for the patterns. Environmental characteristic data are from soil, vegetation and contour maps. Western juniper data are from aerial photos. Image processing techniques and geographical information system (GIS) were used to process data. Nonparametric statistical methods, including Kruskal-Wallis one-way analysis of variance by ranks, Spearman rank correlation coefficient, chi-square test and chi-square partitioning, and classification and regression tree (CART) were used for data analysis and building statistical models. The results show a clustering spatial distribution pattern. Western juniper is more abundant above elevations of about 900 to 1,000 meters MSL, on sites with soil type 15f- Gwin-Rock outcrop complex or 43f- Simas-Badland association, and on medium slopes, but probabilities of juniper occurrence on less steep slopes are higher at lower elevations. Northeastern aspects have significantly lower juniper abundances than other aspects. Junipers prefer sites with higher surface flow accumulation, except extremely high flow accumulation supporting only low juniper abundances. The CART spatial model shows three density classes classified by four out of five environmental characteristics with a misclassification rate of 0.27. Temporally, juniper density in the study area has increased from 37 junipers/ km^2 to 1,404 junipers/ km^2 during the last century. However,

relationships of this expanding pattern to environmental characteristics are obscure. There is no conspicuous difference between habitats of young and old junipers, except perhaps soil types. The likelihood for finding mature or old junipers is higher in sites with soil type 41e- Simas very stony clay loam, 43f- Simas-Badland association or 46f- Snell-Anatone complex. The spatiotemporal distribution pattern of western juniper in the study area could be described as a clustering pattern with chronologically increased abundances. Juniper may continue to increase its abundance and expand from high density areas to low density or non-juniper areas. Unless juniper density is controlled, it seems likely that junipers will dominate most of the monument's landscape in the future.

Spatial and Temporal Distributions of Western Juniper in John Day Fossil Beds National Monument, Oregon

by

Ya-Chian Chen

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Ya-Chian Chen, Author

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SPATIAL AND TEMPORAL DISTRIBUTIONS OF WESTERN JUNIPER IN JOHN DAY FOSSIL BEDS NATIONAL MONUMENT, OREGON

1. INTRODUCTION

Pinyon-juniper woodlands are common in semi-arid areas in the western states. Within those areas, the western juniper (*Juniperus occidentalis* Hook ssp. *occidentalis*) (Vasek 1966) woodland is the northwestern representation (Franklin and Dyrness 1988).

Post-settlement juniper expansion has been reported for decades (Adams 1975, Eddleman 1984, Eddleman 1987, Bedell et al. 1993, Miller and Wigand 1994, Miller and Rose 1995). As the dominant overstory species, increased western juniper density has affected the ecosystem in many respects. As junipers increased in size and density, understory production was reduced and composition changed (Vaitkus 1986), resulting in the decline of available forage for livestock and wildlife (Burkhardt and Tisdale 1969). Increased dominance of western junipers resulted in watershed degradation, and decreased productivity, biodiversity, water quantity and quality, and resource values with significant economic and ecological consequences (Bedell et al. 1993).

Juniper has been classified as non-commercial because of its low productivity and lack of demand for use as lumber. Historically, only small amounts of juniper have been harvested for fence posts and firewood. During the past decades, different techniques, such as burning, chaining, cutting, plowing and poisoning, have been used to remove junipers for restoration of various ecosystem and rangeland values (Miller and Wigand 1994, Belsky 1996). However, the demand for wood products is increasing, and the commercial market value of juniper is rising, and will likely continue to grow. In the future. conflict could be over management of juniper for wood production and control and reduction of density to preserve ecosystem values.

Many efforts have been made to study western junipers and to develop management strategies. However, in many respects western junipers are still unknown.

Studies of the spatial and temporal distribution patterns of western junipers on a large scale are needed to provide the basic information of western juniper on a landscape level. Geographic Information Systems (GIS) are convenient tools for spatial and temporal studies. Also, they provide an efficient method of dealing with a huge database on a landscape level. Using GIS to study juniper distribution pattern can help to understand the chronology of western juniper historic expansion, the relationship between western junipers and the physical environment, and how the relationship changed temporally. This information is important to national park managers for deciding the quantity and location of juniper removal. Also, description of spatiotemporal patterns helps to examine the causes of juniper expansion, to understand fluctuations of vegetation communities and wildlife populations, and helps the model building for such a woodland ecosystem.

The objectives of this study are to:

1. Describe the spatial distribution pattern of western junipers within and adjacent to the Sheep Rock Unit of John Day Fossil Beds National Monument.
2. Determine the temporal distribution pattern of western junipers within the study area during historic time.
3. Build statistical models for the spatial and the temporal distribution patterns of western junipers.

2. LITERATURE REVIEW

2.1 ECOLOGY OF WESTERN JUNIPER

2.1.1 Distribution

Juniperus occidentalis Hook. has been separated into two subspecies by Vesek (1996). *J. o.* ssp. *australis* is usually referred to as Sierra juniper and occupies the range from Susanville, Lassen County California southward. The northern subspecies, *J. o.* ssp. *occidentallis*, is usually referred to as western juniper and is the subject of this study.

Western juniper is widely distributed in the Intermountain Northwest. It occurs from northern California to southern Washington and extends to northern Nevada and southwestern Idaho (Figure 2.1; Dealy et al. 1978b). The greatest concentration of western juniper is in central and eastern Oregon.

2.1.2 Environmental characteristics

The *Juniperus occidentalis* Zone is the most xeric of the tree-dominated zones in the Pacific Northwest (Franklin and Dyrness 1988). The moisture regime is drier than *Pinus ponderosa* forest and wetter than steppe or shrub-steppe (Driscoll 1964). Hot-dry summer and cold-wet winter characterizes the climate of western juniper woodlands. Summer temperatures may reach as high as 46°C (114°F) and winter temperatures of -47°C (-53°F) have been recorded (Vaitdus 1986). Calculated from the climatic data of the representative stations within the western juniper zone in Oregon (Bend, Redmond and Prineville), the average temperature is about -0.5°C in January and 18.3°C in July. The average precipitation is about 257 mm (US Weather Bureau 1965). Most precipitation falls during the winter, and the hot summer months are often completely dry (Franklin and Dyrness 1988).

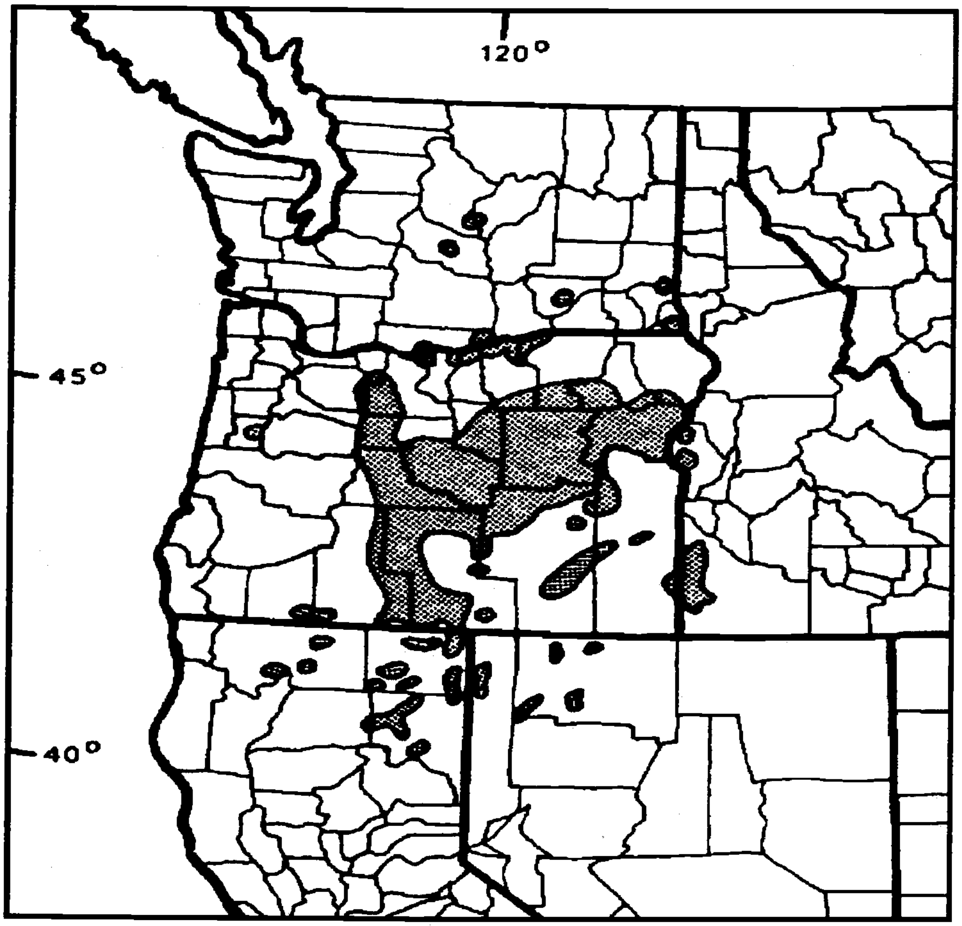


Figure 2.1 General distribution of western juniper. (form Dealy et al. 1978b)

Western juniper woodlands are found in various environmental conditions. The elevation ranges for western juniper depend on locations. Along the Columbia River drainage of eastern Washington, western juniper is found in scattered locations at 600 to 1,800 feet elevation (183 to 549 meter MSL). In central Oregon, it occurs most abundantly on high plateaus at 3,000 to 4,000 feet (914 to 1,219 meter MSL) and at 4,000 to 5,000 feet (1,219 to 1,524 meter MSL) in northeastern California (Sowder and Mowat 1958). Western juniper is present on all exposures and slopes. This species is common on level and undulating topography, moderately sloping alluvial fans, low terraces, canyon sideslopes and steep escarpments, and scattered on rocklands and rocky scarps.

Western juniper occurs on soils derived from various parent materials - igneous, sedimentary, and metamorphic in origin. These soils include basalt, andesite, rhyolite, pumice, volcanic ash, tuff, welded tuff, and colluvial, alluvial or eolian mixtures of the proceeding (Dealy et al 1978a, 1978b). Camborthids (Sierozems), Haplarigids (Sierozem and Brown soils) and Haploxerolls (Chestnut) soil great groups are common within this woodland zone (Franklin and Dyrness 1988). Dense western juniper woodlands are usually found on Mollisols, Argixerolls, Haploxerolls, and Haplaquolls. Scattered western junipers are common on Aridisols including Camborthieds, Durargids, and Haplargids, and also on Argixerolls of Mollisols.

Profile development differs among soils but is often weak. Where the soil is shallow, the depth is between 25 to 30 cm and broken indurated subsoil layers or fractured bedrock occur. The depth of deep soil can reach over 122 cm and often have stony, cobbly or gravely layers somewhere in the profile. Soil textures vary broadly from sandy to clay. Surface horizons are medium to coarse textured, low in organic matter, and slightly acid (pH 6.0) to neutral (Franklin and Dyrness 1988). Soil temperatures within western juniper zone are usually mesic (mean annual soil temperature between 8 to 15 °C), but some are frigid (5 to 8 °C) (Dealy et al 1978a, 1978b).

2.1.3 Plant communities and succession

Western juniper is found between *Pinus ponderosa* and grassland vegetation zones. It is the primary species of the overstory in this savanna-like woodland; however, occasional ponderosa pine occurs in canyon bottoms, on north slopes, or ridges extending out from the edge of the pine forest (Dealy et al. 1978a, 1978b). Big sagebrush (*Artemisia tridentata*) is the dominant understory shrub in most plant communities; however, rabbitbrush (*Chrysothamnus* spp.) or bitterbrush (*Purshia tridentata*) take its place on some sites. The grass layer is dominated by bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*) or mixes of the two.

Its extensive root system and leaf morphology allow western juniper to compete for soil nutrients and moisture. Also, because western juniper is physiologically active much of the year, it takes up readily available nutrients from the soil and uses water very early in the spring before other plants begin to grow. Because of its high competitive ability, western juniper easily dominates many sites and is able to live as long as 800 to 1,000 years or more. However, western juniper is vulnerable to fire. Small junipers less than 50-years-old are easily killed by fire (Burkhardt and Tisdale 1976), but larger trees are more resistant unless the crown is heavily scorched. Lightning fires have been common in the western juniper woodland (Shinn 1980), and thus play an important role in the succession. Immediately after a fire, annual grasses may dominate, followed by perennial forbs and grasses. If the area does not reburn, shrubs reestablish and become dominant, and the area is gradually reinvaded by trees. About 60 to 70 years after a fire, juniper becomes dominant again (Barney and Frischknecht 1974).

2.2 WESTERN JUNIPER EXPANSIONS

Juniper expansion can be discussed on both prehistoric and historic time scales. The expansion patterns and causes have been studied and considered as different (Mehringer and Wigand 1986, Neilson 1986, Miller and Wigand 1994).

2.2.1 Prehistoric expansion

Past juniper distribution has been reconstructed based on paleobotanical records provided from pollen and macrofossils from lake sediments and ancient packrat middens. Studies in the northwestern Great Basin, eastern Oregon and northeastern California, indicate that western juniper has been in most of its present range since about 6,000 years ago (Bedell 1973, Mehringer and Wigand 1987, Miller and Wigand 1994). About 4,500 years ago, juniper pollen values began to rise and remained high, with intermittent decreases, until approximately 1,900 years ago. About 1,000 years ago, juniper pollen values increased again and fluctuated with several peaks and drops (Figure 2.2; Wigand 1987, Mehringer and Wigand 1987, 1990). During the prehistoric juniper woodland maximum, both the lower and the upper juniper tree lines lay below those of today (Mehringer and Wigand 1987, 1990). The rate and degree of the fluctuating change of western juniper woodland were equal to or greater than those seen over the past hundred years (Mehringer and Wigand 1987).

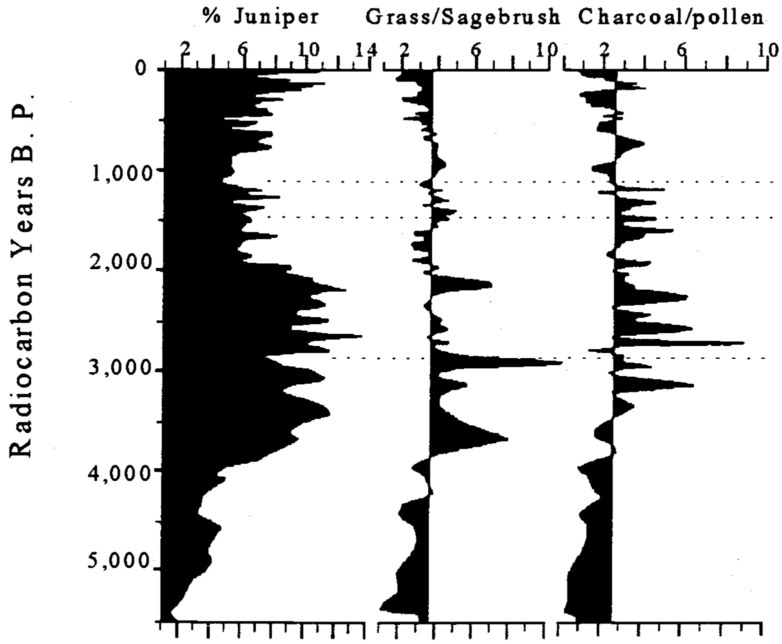


Figure 2.2 Relative abundance of juniper pollen during the last 5500 radiocarbon years at Diamond Pond in southeastern Oregon, and the ratios of grass pollen to sagebrush pollen and of charcoal to pollen plotted about their means (from Mehringer and Wigand 1987)

Prehistoric juniper distribution and abundance apparently fluctuated with climatic patterns. About 5,400 years ago, the weather was warmer and drier than present. Afterward, temperature remained warm, but winter and summer precipitation increased gradually (Miller and Wigand 1994). From 4,000 to 2,000 years ago, conditions were significantly wetter than present. Then, aridity increased, particularly between 1,900 and 1,000 years ago (Wigand 1987). The periodic wetness and drought coincided with the fluctuation of juniper pollen values. Also, severe drought and fire occurring between 700 and 500 years ago were coincident with a drop in juniper pollen values. A pattern of greater winter precipitation developed from 400 to 500 years ago, initiating a gradual re-expansion of juniper woodland in the northern Great Basin (Mehringer and Wigand 1990). Re-expansion of Great Basin woodlands was just getting underway when Europeans first entered the area (Miller and Wigand 1994).

2.2.2 Historic expansion

During the last century, there has been a significant change in the density, distribution and age structure of all juniper woodlands in the western United States. Historical reports described central Oregon as an open rolling landscape with abundant bunchgrasses and a wide scattering of juniper trees during the 1800s (Rich et al 1950, Caraher 1977). Today, many sites in central Oregon are covered by dense juniper woodlands. In southeastern Oregon bogs, the abundance of juniper pollen has gradually increased since A.D. 1,500 and sharply increased in the mid-1900s (Mehringer 1987). The chronology of juniper establishment indicated that juniper began increasing during the 1880s, and progressing sharply in 1960s (Figure 2.3; Miller and Rose 1995). Western juniper has expanded its range to twice its former extent (Eddleman 1984), and is still expanding into adjacent shrub steppe communities, open meadows, grasslands, aspen groves, and riparian communities (Eddleman 1987, Young and Evans 1981, Miller and Wigand 1994, Miller and Wigand 1995).

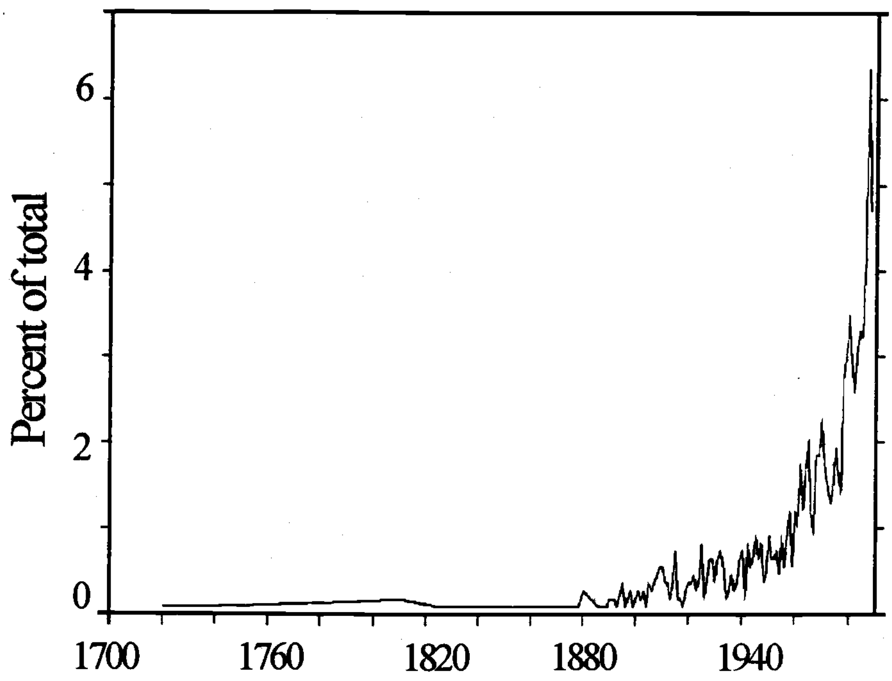


Figure 2.3 Years of establishment for *Juniperus occidentalis* trees on Steens Mountain, Oregon (n=1200). (from Miller and Rose 1995)

The causes of the historic juniper expansion are undoubtedly complex, with climate change, reduced fire frequencies and overgrazing by livestock the most likely responsible factors (Burkhardt and Tisdale 1976, Young and Evans 1981, Quinsey 1984, Bedell et al. 1993, Miller and Wigand 1994). Miller and Wigand (1994) indicated that mild winter condition and increased precipitation in the northern half of Great Basin during the late 1800s and early 1900s probably contributed to the vigorous growth of juniper. But they also indicated that the conditions would have increased the potential for fire due to the increased production of light fuels: grasses and forbs. However, in a study in Owyhee Plateau, Burkhardt and Tisdale (1976) suggested that a climate trend toward more xeric conditions might have reduced the annual production of fuel. Also, the correlation between climate and juniper establishment was found not significant (Burkhardt and

Tisdale 1976, Quinsey 1984). Hence, the effect of climate on the historic expansion is unclear.

Fire frequency is an important factor in woodland succession. Frequent fire occurrence keeps shrubs and trees from dominance, and restricts trees to local areas where factors such as topography or low site productivity limit fire frequencies. In juniper woodlands in southwestern Idaho, fire occurred every four years between 1860 and 1910, but since 1910, only two fires have occurred (Burkhardt and Tisdale 1976). Prior to the early 1900s, short fire intervals, approximately 10-year to 20-years, also occurred in other similar juniper woodlands in northern California and southern Arizona (Quinsey 1984).

Domestic livestock brought in by Euro-American settlers during late 1800s and early 1900s contributed to the juniper expansion in several ways. The greatest influence was the reduction of fine fuels resulting in a decrease of fire frequency. It may also have encouraged the expansion through seed dissemination, reducing competition and increasing safe sites for juniper seedling establishment through shrub increase (Miller and Wigand 1994).

As the result of expansion, western juniper stands have generally been placed into two groups based on tree maturity. The old stands, also called climax or ancient stands, are dominated by mature junipers older than 150 years, and contain large dead junipers and rotted stumps. Juniper seedlings and young junipers also occur in the old stands. The young stands, as well as seral or invading stands, only contain trees younger than 100 years old. The old trees are large, with heavy lower limbs, are associated with the lichen, *Letharia vulpina*, and usually have round-topped crowns. The young trees have conical shaped crowns with prominent terminal leaders and lack lichen colonies (Burkhardt and Tisdale 1969).

The differences between the topographic characteristics and the vegetation conditions of the old and the young juniper stands are striking. The old stands grow on mesa edges, ridges or knolls where fractured bedrock comes near the surface. The soil depth of these sites varies from zero to several feet, and sometimes rock outcrops can occupy up to 50 percents of the ground surface. Juniper density and cover are positively related to the amount of bedrock fracturing. The understory vegetation is generally sparse because of poor soil conditions. Young stands occur on valley slopes and bottoms adjacent to old stands. The soil is more uniform, much deeper and has few or no rock outcrops. The number of trees in the young stands is various depending on how far expansion has progressed and on stand age. However, the very high density occurring in the young stands, as great as 420 adult junipers/ half acre (about 210,000 adult junipers/ km^2), hasn't been found in the old stands (Burkhardt and Tisdale 1969). The understory cover of the young stand sites is higher, and more species are found as well.

Although the extend of juniper woodlands between 4,000 to 2,000 years ago might have been greater than that of today, and there were several re-expansions during the past 1,000 years, several factors appear to be different between the prehistoric and the historic expansions. Climate cycle coincided with the fluctuation of juniper abundance during the prehistoric period; however, the correlation between climate and the historic expansion is unclear. Grasses during the prehistoric time were more abundant and fires were more frequent than those during the historic expansion. Without efficient controls, the reduced fire frequency may allow further expansion.

3. STUDY AREA

3.1 LOCATION AND BRIEF HISTORY

The study area is located in the Sheep Rock Unit of John Day Fossil Beds National Monument in eastern Oregon. The area is about 15 km^2, occupying about half of the total area of this unit (Figure 3.1). John Day Fossil Beds National Monument was established in 1975, and besides Sheep Rock, there are Painted Hills and Clarno Units. Before 1975, parts of the monument were protected as an Oregon State Park to preserve the paleontological and unique geological resources within the area. However, grazing has been allowed on some sections of the study area. A large portion of the Sheep Rock unit was purchased from Cant and Mascall families, who farmed the lowlands along the John Day River and grazed cows and sheep on the hills above for over 60 years.

3.2 CLIMATE

The climate in eastern Oregon is semi-arid, with hot-dry summers and cold-wet winters. According to climate data recorded at the nearest weather station, in Dayville, from 1961 to 1990, the lowest mean monthly temperature occurred in December and the highest in July (Figure 3.2). Summer temperatures over 100°F were not unusual, and winters with temperatures colder than 0°F have been recorded. Most precipitation, including rainfall and snowfall, occurs during winter (Figure 3.3). Summer rainfall was relatively low, but occasionally severe thunderstorms could cause flashfloods.

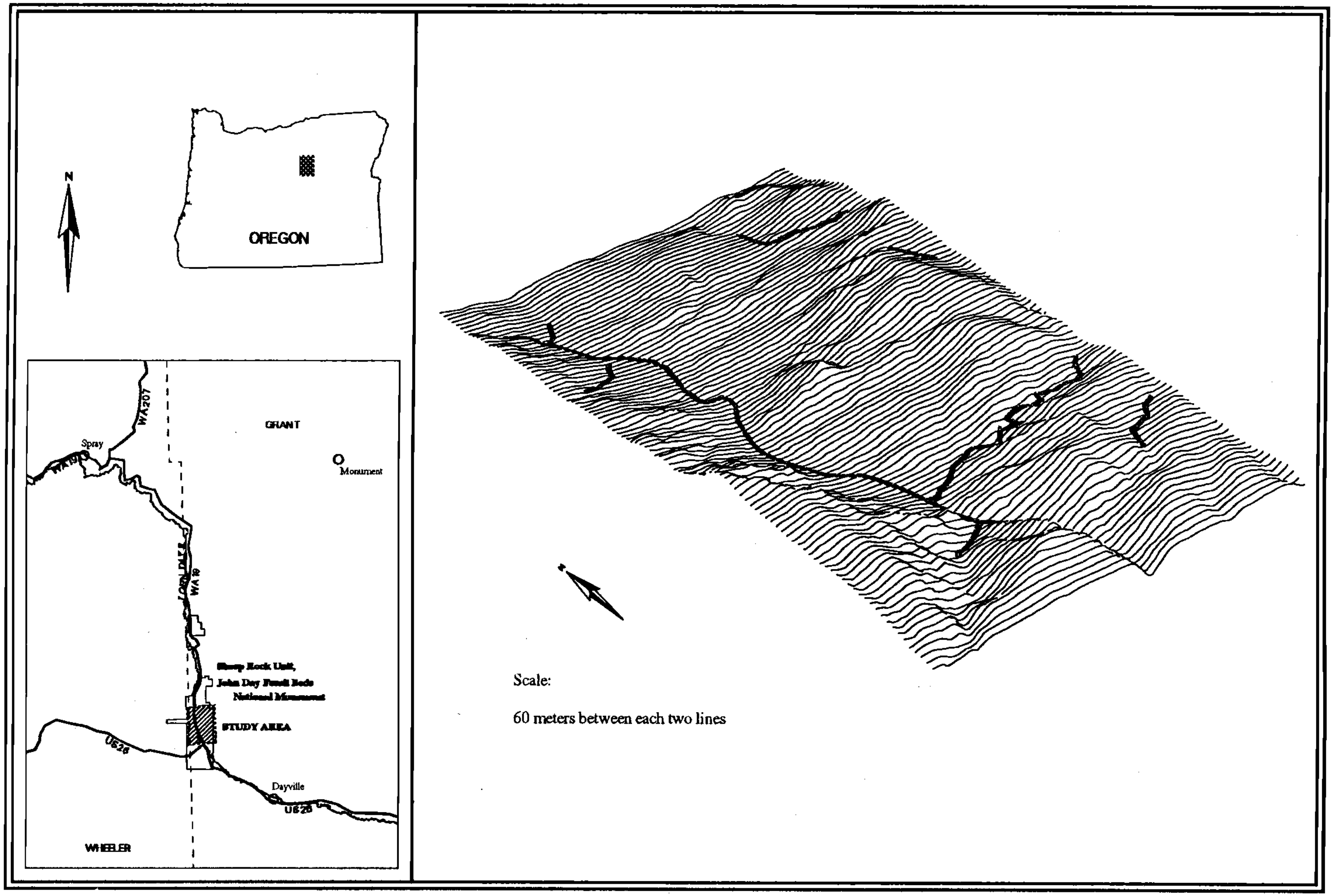


Figure 3.1 Location and perspective view of the study area.

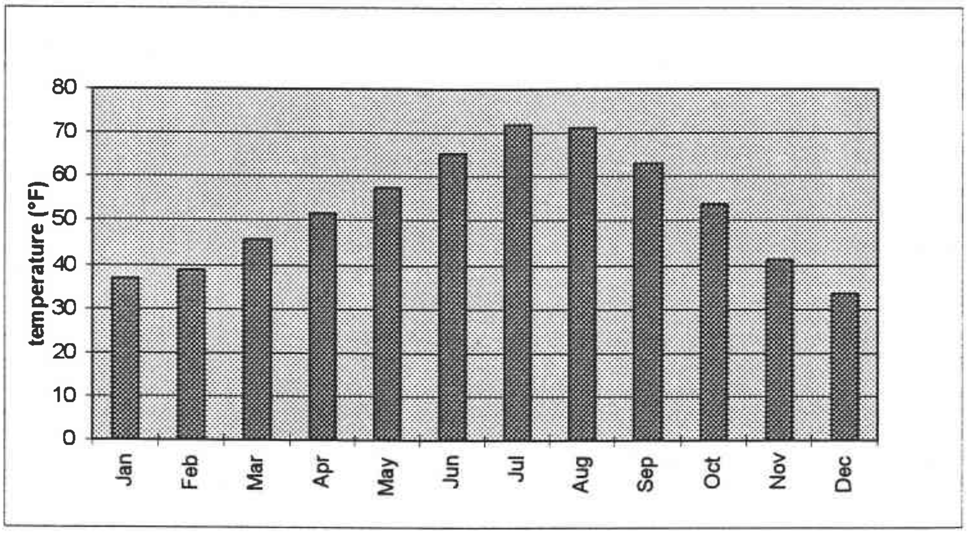


Figure 3.2 Mean monthly temperature in Dayville from 1961 to 1990 (Data source: Oregon Climate Service).

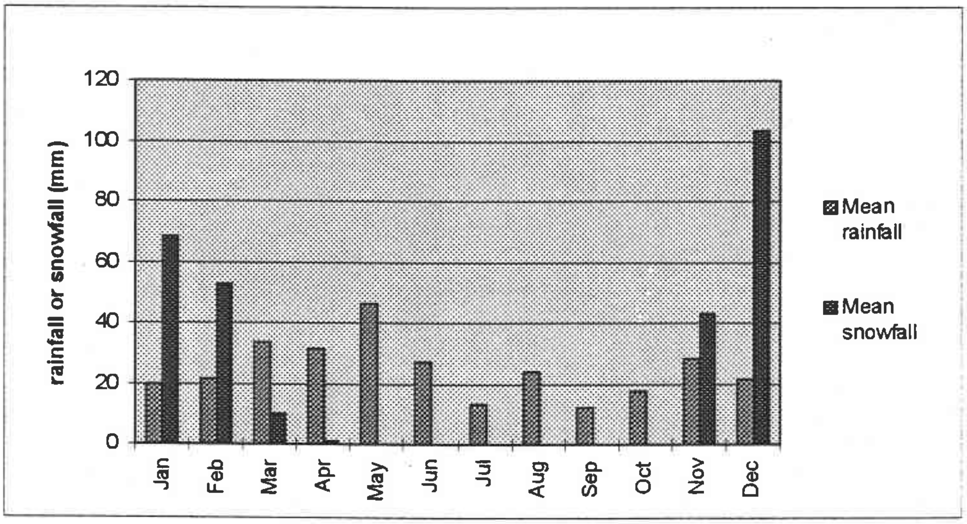


Figure 3.3 Mean monthly precipitation in Dayville from 1961 to 1990 (Data source: Oregon Climate Service).

3.3 TOPOGRAPHY AND SOILS

The landscape of the Sheep Rock Unit is undulating, from the lowest John Day River valley bottom extending to the rolling hills. Elevations range approximately from 650 to 1,250 meter MSL. The slope varies from level to about 50°, with various aspects.

Except for a narrow band along the John Day River, most of the soil in the study area is well drained, stony, and has low available water capacity (0.5 to 10 inches, or 1.3 to 25.4 cm). The hazard of runoff and erosion is medium to high, and particularly severe on steep slopes and badlands. More than two thirds of the soil belongs to Simas or Gwin series. The area near the river has well drained soils that formed in mixed alluvium on alluvial fans. The water capacity is higher and the risk of runoff and erosion is lower (Figure A.1; USDA, SCS 1981).

3.4 VEGETATION

Grazing and agricultural use have disturbed the area since the late 1800s. Since many species have been reduced or replaced by increaser or exotic species, the original vegetation is difficult to determine.

The John Day River provides habitats for the species associated with riparian communities and cultivated fields. Otherwise, these plant species would unlikely exist in the semi-arid area. Adjacent to those sites, a greasewood/ cheatgrass (*Sarcobatus vermiculatus/ Bromus tectorum*) community occurs on the lowland. Cheatgrass is an exotic species indicating disturbance. Big sagebrush (*Artemisia tridentata*), Sandberg's bluegrass (*Poa sandbergii*) and shadscale (*Atriplex confertifolia*) are also common on disturbed lowlands. The more pristine vegetation exists at higher elevation, or on the rocky, steep slopes and areas away from water resources. Bluebunch wheatgrass (*Agropyron spicatum*) is the understory indicator for the area where livestock grazing was limited. It's likely the decreaser species were replaced by Sandberg's bluegrass in the more disturbed area. The main community of the more pristine vegetation is the Big sagebrush/

bluebunch wheatgrass. Other understory species, such as Thurber's needlegrass (*Stipa thurberiana*), Idaho fescue (*Festuca idahoensis*), and slenderbush buckwheat (*Eriogonum microthecum*) also occur. Western juniper is the sole overstory species in the community. However, western juniper has extended its distribution into the disturbed lowlands, and an increase of its density has been observed as well (Figure A.2; Youtie and Winward 1977).

4. METHODS

Geographic information systems (GIS) are computerized mapping systems for capture, storage, management, analysis, and display of spatial and descriptive data (Coulson and et al. 1990). Combined with other techniques, such as remote sensing, photogrammetry, and statistical design, GIS provides an environment for spatial studies. In this study, the GIS software ARC/INFO, Version 7.0 for UNIX system was used, along with the image processor, PHOTOSHOP Version 2.5.1 for MS Windows, and UNIX S-plus Version 3.3 for statistical analysis.

4.1 DATA

Soil and vegetation maps, a digital elevation model (DEM) and western juniper information from photos were the data resources. The soil map was derived from the soil survey of Grant County in Oregon, and digitized into ARC/INFO and registered to the real world coordinates. Digital vegetation (Youtie and Winward 1977) and contour maps were obtained from the Cooperative Park Studies Unit of the University of Idaho.

All the western juniper information was obtained from aerial photos purchased from the WAC corporation (520 Conger Street, Eugene, Oregon 97402-2795). The aerial photos were taken in 1986 with a camera of 12 inch focal length at approximately 6,000 feet MSL of flying height. For each nine by nine inch photo, only the central five by five inch quadrat was used to prevent photo distortion. All the central quadrats were divided into four equal quarter quadrats to reduce memory requirements while processing images, and all the quarter quadrats were numbered for later sampling. 59 out of 288 quarter quadrats were randomly sampled and scanned at a high resolution of 500 pixels per inch. In PHOTOSHOP, every juniper crown was selected manually with the help of photo interpretation, and then the background deleted. As a result, a black and white image was created for each quarter quadrat and transferred to UNIX ARC/INFO. After converting the black and white raster image to vector coverage, each juniper crown became a polygon. The polygon area was saved, and then the polygon coverage converted to a point coverage. Hence, each point in the resulting coverage has the original juniper crown area on the photograph. The orthophotos of the study area were digitized and registered in advance to provide coordinates for the control points. Based on these control points, the point coverage for each quarter quadrat was transformed to the real world coordinates and then combined into a final point coverage containing all the sampled areas with juniper location coordinates and original crown areas on the photos.

The DEM was created from the digital contour map by ARC/INFO at a 30 meter grid. In GRID, the raster system in ARC/INFO, the DEM was processed to derive aspects, slopes and surface flow accumulation values. For each 900 m^2 unit, the surface flow accumulation value is the number of other units from where surface flows flow into that unit. Units with high flow accumulation values are where surface flows accumulate, rivers or streams form, or water courses occur. Zero flow accumulations indicate locations of ridges (Jenson and Domingue 1988). Aspect, slope and surface flow accumulation were combined with rasterized soil and vegetation data, and converted to vector again. The resulting coverage consisted of 30 by 30 meter units, each with environmental characteristics, including elevation, aspect, slope, surface flow accumulation, soil and vegetation type. Only the area included in the sampled photos was used and the heavily disturbed sites near the roads and the cultivated fields were excluded.

The coverage carrying the environmental characteristics was then overlaid with the final point coverage of western juniper. As a result, the environmental characteristics were attached to each individual western juniper. The real juniper crown area was calculated by the following equation:

$$A = \frac{a}{s^2} = \frac{a}{\left[f/(H-h)\right]^2}$$ -- Equation 4.1

A: Real crown area
a: Original photo crown area
s: Local scale
f: Camera focal length
H: Flying height
h: Local elevation

For each 30 by 30 meter unit, the juniper density and the juniper canopy coverage were derived for further analysis (Figure 4.1).

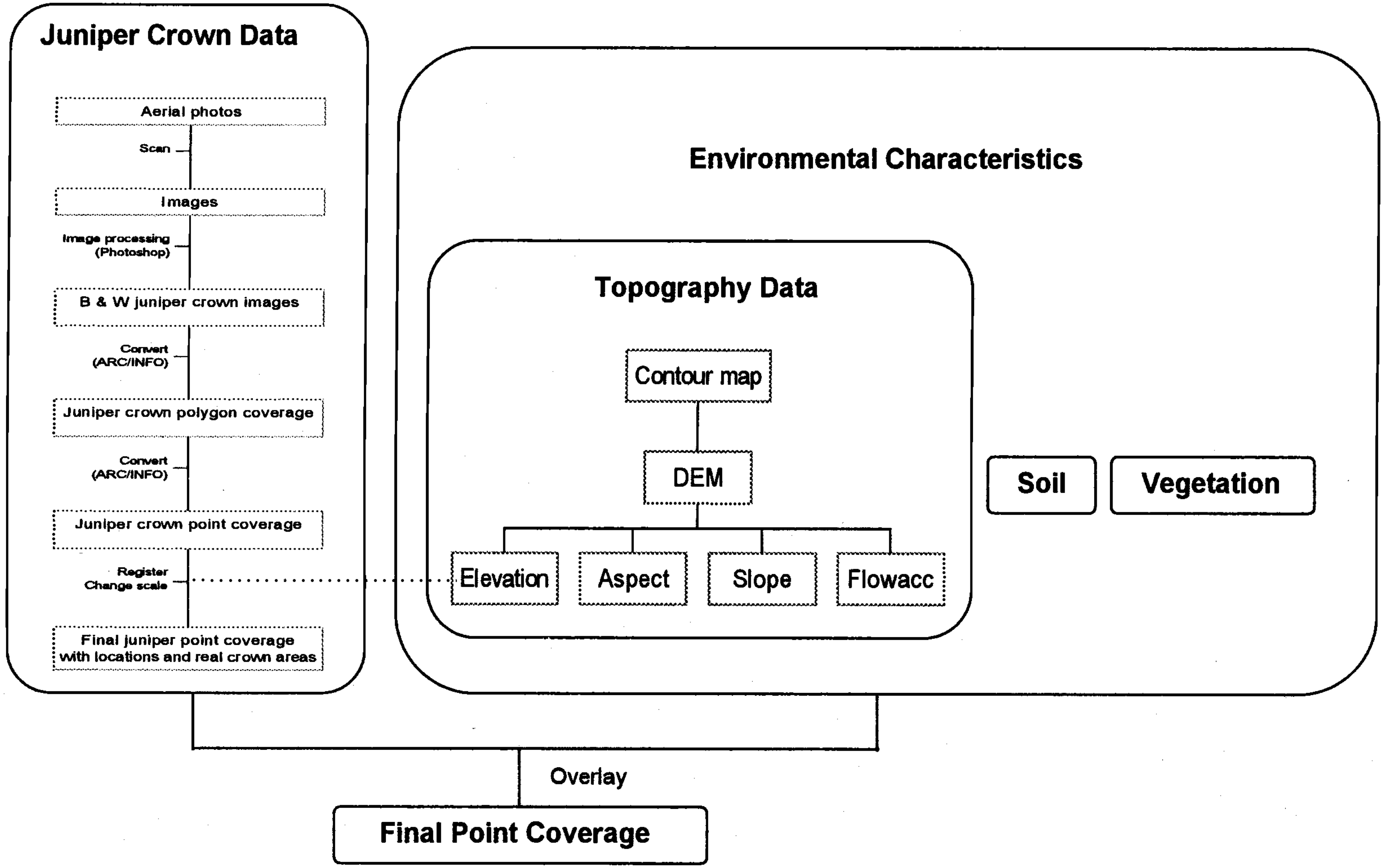


Figure 4.1 Flow chart of analytical process

4.2 STATISTICS

Parametric statistical methods were avoided because of the extreme skewness of the data distribution. Nonparametric methods, including chi-square test, the Kruskal-Wallis one-way analysis of variance by ranks, and the Spearman rank correlation coefficient, were used for testing the relationship between western juniper distribution and environmental characteristics. A tree-based modeling technique was applied to build statistical models.

4.2.1 Spatial distribution pattern

4.2.1.1 Randomness

Under complete spatial randomness (csr), tree density has a Poisson distribution. The randomness of juniper density is determined by the Pearson's chi-square goodness-of-fit test. The departure from csr is measured by Fisher's relative variance index (I). Values of I greater than one suggest a pattern of clustering, and values less than one suggest a pattern of regularity (Cressie 1993).

$$I = \frac{s^2}{\bar{x}} \qquad \text{-- Equation 4.2}$$

s^2 : sample variance
$\bar{x}$: sample mean of the quadrat counts.

4.2.1.2 Relationship with environmental characteristics

The selection of testing methods is based on the nature of the variables. The Kruskal-Wallis test is capable of testing the relationship between a numeric and a categorized variable. Assuming the categorized variable has k classes, the Kruskal-Wallis test is able to test if the k random samples of the numeric variable are all identical by comparing the k rank distributions. When the hypothesis of identicalness is rejected, a multi-comparison procedure is taken to test the difference of the numeric variables between each two classes. The Spearman rank correlation coefficient (rh_0) measures the degree of correspondence between the ranks of two numeric variables. When the ranks of each pair of observations are exactly the same, the two variables have a perfect direct relationship and the rh_0 equals to +1. When the rank of one variable within each pair of observations is the reverse of the other, the two variables have a perfect inverse relationship and the rh_0 equals to -1. A rh_0 not significantly different from zero indicates independence between the variables (Daniel 1978).

Both of the juniper parameters, density and canopy coverage, are numeric measurements. The relationships between the juniper parameters and the categorized environmental characteristics: aspect and soil type, were tested by the Kruskal-Wallis test, followed by the multi-comparison procedure when the hypothesis of identicalness among different classes was rejected. The Spearman rank correlation coefficients were calculated to test the independence between the juniper parameters and the numeric environmental characteristics: elevation, slope and surface flow accumulation.

4.2.1.3 Modeling

The main interest of this study was to understand the distribution of western junipers in the study area. Therefore, samples were randomly selected from the whole study area (the population) without particular experimental designs for testing specific hypotheses. The sampling results in a complex and large data set characterized by lack of control over key variables. Hence, the orientation is not towards the testing of specific hypotheses but towards discovering regularities or irregularities in the collected data. Traditional descriptive statistics are able to provide some understanding of the data, but more sophisticated analysis is generally desirable. The data set was difficult to fit to a parametric statistical model, such as regression, because of its features of high dimensionality, a mixture of data types and a nonstandard data structure. As a result, tree-based modeling, a nonparametric tool, was used to explore the data structure and predict the distribution of junipers.

Tree-based modeling, also known as binary tree, binary segmentation or recursive partitioning (Fielding 1978, Ciampi et al. 1994, Mola & Siciliano 1994), was originated by social scientists and also widely applied to medical science (Breiman et al. 1984). It is a classification method for predicting the response of an object by predictor variables. The models are fitted by binary recursive partitioning whereby a data set is successively split into increasingly homogeneous subsets until it is infeasible to continue (Clark and Pregibon 1992). The result is a binary hierarchical tree with classified groups of response variables as the leaves and predictor variables to split the branches.

Although statistical inference for tree-based modeling is still in its infancy, it is gaining widespread popularity. This method provides easier interpretation, especially when the set of predictor variables contains a mix of numeric variables and factors. It handles interaction between variables automatically and is invariant to monotone transformations of predictor variables. It is robust to outliers and capable of dealing with missing data. It satisfies not only numeric response variables, but also categorized response variables at more than two levels (Breiman et al. 1984, Clark and Pregibon 1992, Venables and Ripley 1994).

Several procedures have been proposed for constructing a tree (Sonquist et al 1974, Fielding 1978, Breiman et al. 1984, Mola and Siciliano 1994). Breiman et al. (1984) have provided important results in this field with the introduction of the well-known CART (Classification And Regression Tree) methodology. This methodology was adapted in S-plus (Clark and Pregibon 1992) and used in this study.

The construction of a tree is based on four parts, 1) the selection of splitting rules, 2) the termination of partitioning, 3) the class assignment, and 4) the determination of tree size (Breiman et al 1984). Regression tree is called specifically for numeric response variables, and classification tree for categorized response variables.

The splitting rules are composed of all the possible partitioning of the predictor variables (x). If x is a categorized variable with k levels, there are $2^{k-1}-1$ splitting possibilities. If x is an ordered factor or numeric variable with k ordered levels or distinct values, there are k-1 ways to divide x (Breiman et al 1984). For each possible splitting, the data set is divided into two subsets and the homogeneity of the response variable (y) in either subset is calculated. The splitting rule creating highest homogeneous subsets is selected to construct the tree. The subsets are termed as nodes and divided again until the nodes are homogeneous or the numbers of observers in the nodes are too small. The class assignment is determined by the distribution of the response variable (y) within the node. If y is categorized, the class with highest probability is assigned to the node. If y is numeric, the node is assigned the average value of y's within the node.

Since tree size is not intentionally limited in the growing process, the resulting tree could become very large with many small nodes and an inaccurate misclassification rate. The tree can be simplified without sacrificing the goodness-of-fit. An independent sample from the same population is fitted for the tree to find the size with the smallest deviance. Another method called cross-validation is used for smaller sample sizes. The method divides the data set into N subsets, S_n, n = 1, 2..., N. S_1 is retained as the test sample for testing the goodness-of-fit of the tree constructed by the other N-1 subsets. Then, S_2 is retained as the test samples with other N-1 subsets constructing the tree, and so on. After repeating the procedure N times, the N test results are integrated to determine the simplified tree size and the misclassification rate. Residual analysis is the standard diagnosis for regression trees. The misclassification rate for classification tree and the standard deviance for regression tree evaluate the goodness-of-fit of the model.

The regression trees were constructed for both the juniper density and the total crown cover; however, the residual analyses for both models indicated the interpretation was likely misleading. Hence, juniper density was categorized into six classes based on the density (y) range: $y = 0/900\ m^2$, $0/900\ m^2 < y \leq 5/900\ m^2$, $5/900\ m^2 < y \leq 10/900\ m^2$, $10/900\ m^2 < y \leq 15/900\ m^2$, $15/900\ m^2 < y \leq 20/900\ m^2$, and $y > 20/900\ m^2$, and used to construct the classification tree with five environmental predictor variables: elevation, aspect, slope, surface flow accumulation and soil type.

4.2.2 Temporal distribution pattern

4.2.2.1 Categorize juniper crown area

Simple linear regression was applied to measurements of juniper age and crown area from Larsen (1994). And then, the juniper real crown area was categorized into several classes to reflect tree ages. The resulting juniper crown area class was used to test the relationship with environmental characteristics, and to construct the classification tree.

4.2.2.2 Relationship with environmental characteristics

The characteristics of environments where different juniper crown area classes exist were compared by the Kruskal-Wallis test and the chi-squared test. The identicalness of the numeric characteristics: elevation, slope and flow accumulation, was tested by the Kruskal-Wallis test, followed by the multi-comparison procedure. The chi-squared test was used for testing the independence between juniper crown area class and the categorized characteristics: aspect, soil type and vegetation type, by comparing the expected and the observed frequencies in each category (Daniel 1978).

The overall computed chi-squared value tests the hypothesis of independence between two categorized variables; however, the relationships of independence or dependence among some categories may be masked or diluted by a single chi-squared value. Therefore, a technique known as partitioning of chi-square or decomposing chi-square was used to gain some insight into this problem (Bresnahan & Shapiro 1966, Maxwell 1961, Daniel 1978, Iversen 1979, Freeman 1987). Assuming the variables have r and c categories respectively, a r x c contingency table with (r-1)(c-1) degrees of freedom is created for the chi-squared test. The contingency table can be partitioned into as many components as permitted by the following rules: (1) The number of subtables cannot be greater than the number of degrees of freedom in the original table. (2) Each cell frequency of the original table must appear as a cell frequency in one and only one subtable. (3) Each marginal total of the original table must appear as a marginal total of one and only one subtable. (4) Subtable cell frequencies not appearing in the original table must appear as marginal totals in a different subtable. Marginal totals not appearing in the original must appear as either cells or grand totals (Bresnahan & Shapiro 1966, Iversen 1979, Freeman 1987). The sum of the chi-squares for the subtables is equal to the chi-square for the original table by using the maximum likelihood chi-square (Iversen 1979). The formula is :

$$x^2 = 2\sum n_{ij}\log(n_{ij}n/n_{i+}n_{j+})$$
$$= 2[\sum n_{ij}\log(n_{ij}) - \sum n_{i+}\ln(n_{i+}) - \sum n_{+j}\ln(n_{+j}) + \sum n\ln(n)] \text{ --- Equation 4.3}$$

n_{ij} : frequency shown in the cell on ith row and jth column
n_{i+} : marginal frequency of ith row
n_{+j} : marginal frequency of jth column
n : total frequency

For a contingency table, there may be many different ways for partitioning. In this study, the partitioning of juniper crown area is mainly for comparing the two smaller crown area classes, the two larger crown area classes, and comparing the classes with smaller crown area and the classes with larger ones. Aspect was partitioned for comparing north with south, and east with west. Soil types within the same soil series were compared: type 14e (Gwin-Rockly complex) and 15f (Gwin-Rock outcrop complex) of series Gwin, and type 41e (Simas very stony clay loam) and 43f (Simas-Badland association) of series Simas. According to the similarity of crown size distributions within different soil types, soil types were divided into three groups for comparison: Gwin series with type 26f (Lickskillet rock outcrop complex) for group1, type 18d (Hack extremely stony loam) with 4f (Balder very stony loam) for group2, and Simas series with type 46f

(Snell-Anatone complex) for group3 (Figure 5.9f). Comparison between group1 and group2 was conducted, since both have fewer or no old junipers. Then, group1 and group2 together was compared with group3. Vegetation types were partitioned into three groups: group1 mainly with brush and grass communities, group2 with mountain mahogany, and group3 with western juniper communities. Different vegetation communities within each group were compared, as were the three groups. Detailed partitioning tables are provided in appendix (Table A.1, Table A.2, Table A.3).

4.2.2.3 Modeling

A classification tree was used for modeling again. Response variables were the crown area categories. The predictor variables were the same as those in the spatial modeling, with the addition of one more factor, vegetation type.

5. RESULTS AND DISCUSSION

5.1 SPATIAL DISTRIBUTION PATTERN

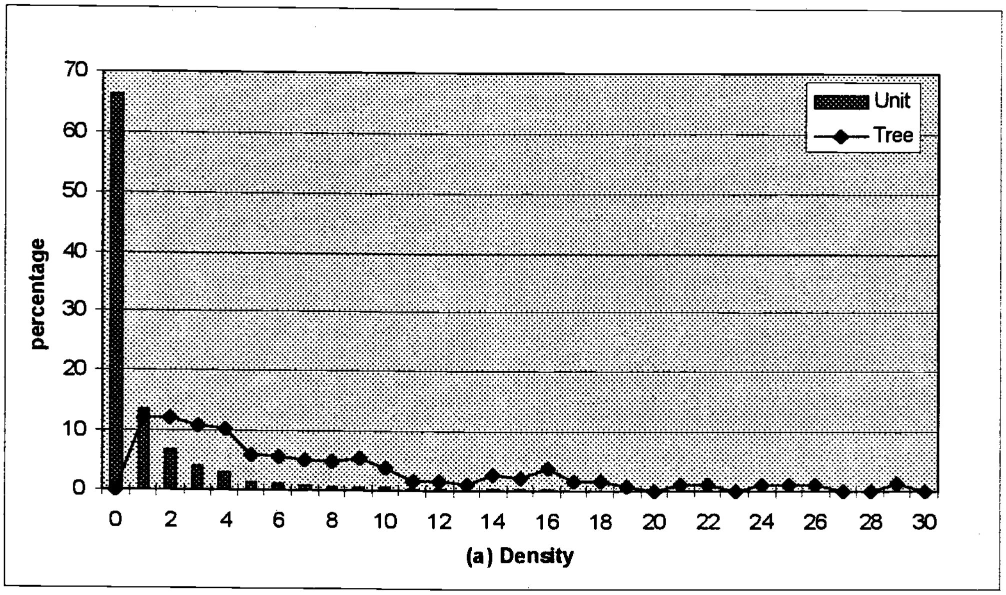
5.1.1 Randomness and point pattern

Western junipers are not distributed randomly in the study area (Pearson's chi-square goodness-of-fit test p-value = 0.0000). Fisher's relative variance index (I) suggests a clustered pattern of distribution (I = 7.37).

The density of junipers in the study area is from 0/ 900 m^2 to 29/ 900 m^2. Over 60 percent of the sampled units have no juniper, and almost 30 percent have densities below 5/ 900 m^2. Only 102 out of 1,957 units (5.2%) have densities higher than 5/ 900 m^2. Among these units, 71 units have densities from 6/ 900 m^2 to 10/ 900 m^2, 15 units from 11/ 900 m^2 to 15/ 900 m^2, and only 16 units higher than 15/ 900 m^2. Although the units with densities greater than 5/ 900 m^2 occupy less than 10 percent of the sampled area, they have almost half of the total number of junipers within the sampled area (Figure 5.1a).

The juniper canopy coverage ranges from 0 m^2/ 900 m^2 to 215.2 m^2/ 900 m^2 and has a similar distribution pattern as the density. Over 90 percent of the units have canopy coverages less than 40 m^2/ 900 m^2, and less than 10 percent have canopy coverages greater than 40 m^2/ 900 m^2 (Figure 5.1b). The total canopy coverage in the latter is almost twice that found in the former units.

Although western junipers exist in various environmental conditions, the distributions of juniper density and canopy coverage suggest that western junipers are clustered spatially. Most junipers are distributed on east to northeast part of the study area, scattering southward and westward, and tending to have lower densities in areas near to the John Day River (Figure 5.2).



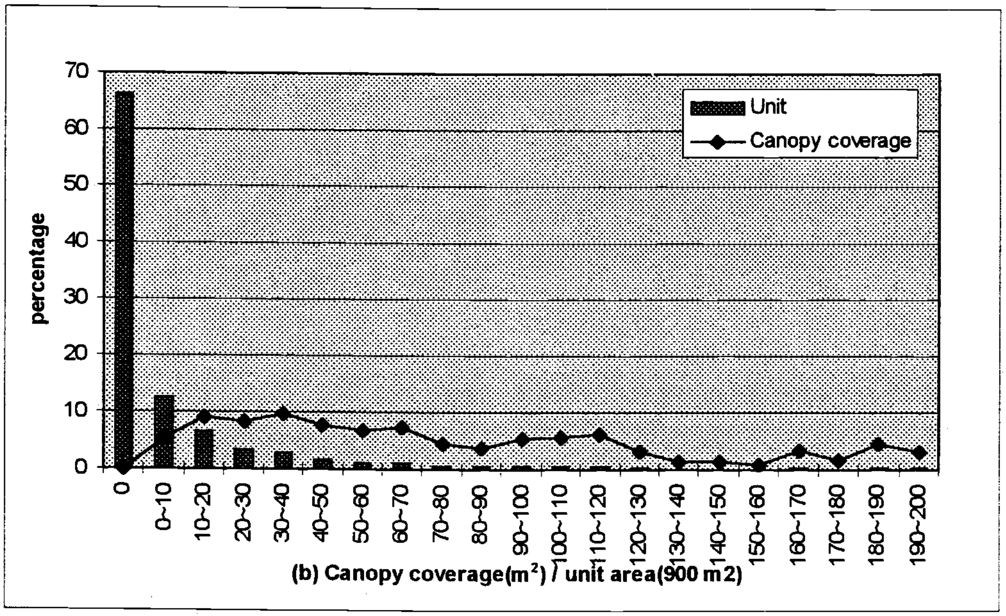


Figure 5.1 Juniper density and canopy coverage distributions. (a) Unit: percentage of units at certain density; Tree: percentage of juniper number at certain density. (b) Unit: percentage of units at certain canopy coverage range. Canopy coverage: percentage of total canopy coverage at certain canopy coverage range.

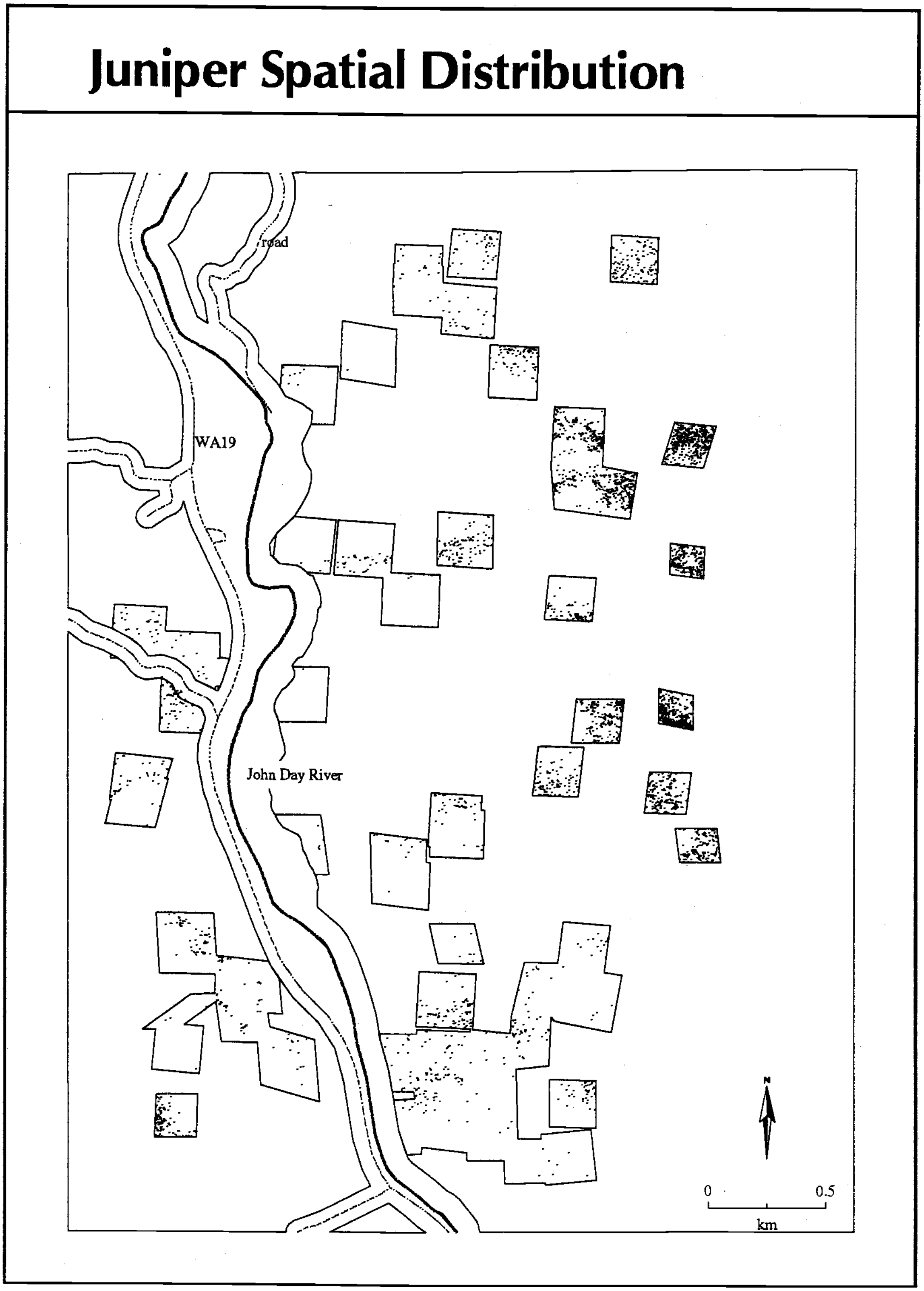


Figure 5.2 Western juniper spatial distribution in the study area.

5.1.2 Relationship with environmental characteristics

5.1.2.1 Elevation

The sampled elevations range from 674 to 1,157 meters MSL. Both juniper density and canopy coverage are not significantly independent from elevation (Table 5.1). The Spearman rank correlation coefficient(rh_0) indicates a direct association between juniper density and elevation (rh_0 = 0.28), as well as between canopy coverage and elevation (rh_0 = 0.27). Direct associations are also suggested by the trend shown in the scatter diagrams (Figure 5.3a, Figure 5.4a). Low elevations only support low densities and low canopy coverages. As the elevation rises, greater densities and canopy coverages occur besides low densities and canopy coverages.

Juniper density was also categorized into several classes and plotted against elevation to show elevation ranges for different density classes (Figure 5.3f). The 900 m^2 units without juniper or with low densities (class 'none', '0<y<=5', and '5<y<=10') exist at a wide elevation gradient ranging from about 700 to 1,200 meters MSL; however, densities higher than 10/900 m^2 occur only when the elevation is above approximately 900 meters MSL.

Western juniper is more abundant above elevations of approximately 900 to 1,000 meters MSL. Sowder and Mowat (1958) found the elevation range of abundant western junipers in central Oregon was between 914 to 1,220 meter MSL. Results of this study show a similar lower boundary, but the elevations of the study area do not reach the higher boundary.

Juniper density and canopy coverage appear to increase more rapidly at high elevation than at low elevation, but decrease slightly above approximately 1,100 meters MSL (Figure 5.3a). However, the possible nonlinear relationship is undetectable by the simple correlation coefficients.

Table 5.1 P-values of the relationship tests for juniper density and canopy coverage. The '-' mark indicates lack of significant relationship, and '+' indicates significant relationship.

Juniper parameter	*Environmental factor*	*Test method*	*relationship*	**p-value*
Density	Elevation	Spearman	+	.0000
	Slope	Spearman	+	.0002
	Flow accumulation	Spearman	+	.0000
	Aspect	Kruskal-Wallis	+	.0012
	Soil type	Kruskal-Wallis	+	.0000
Canopy coverage	Elevation	Spearman	+	.0000
	Slope	Spearman	+	.0001
	Flow accumulation	Spearman	+	.0000
	Aspect	Kruskal-Wallis	+	.001
	Soil type	Kruskal-Wallis	+	.0000

* significant level is based on a p-value <= 0.05

5.1.2.2 Slope

Sampled slopes vary between 0° to 50°. Neither juniper density nor canopy coverage are significantly independent from slope (Table 5.1). The overall association between density and slope is inverse (rh_0 = -0.08), as is the association between canopy coverage and slope (rh_0 = -0.09). However, a nonlinear relationship is strongly suggested from the scatter diagrams (Figure 5.3b, Figure 5.4b). Low densities and canopy coverages exist on various slopes ranging from 0° to 50°, but high densities and canopy coverages have narrower slope ranges. Densities between 5/ 900 m^2 to 15/ 900 m^2 exist on the slopes ranging from 5° to 40°. Densities higher than 15/ 900 m^2 were only found on medium slopes, about 10° to 30° (Figure 5.3g). Western junipers tend to be denser at medium slopes.

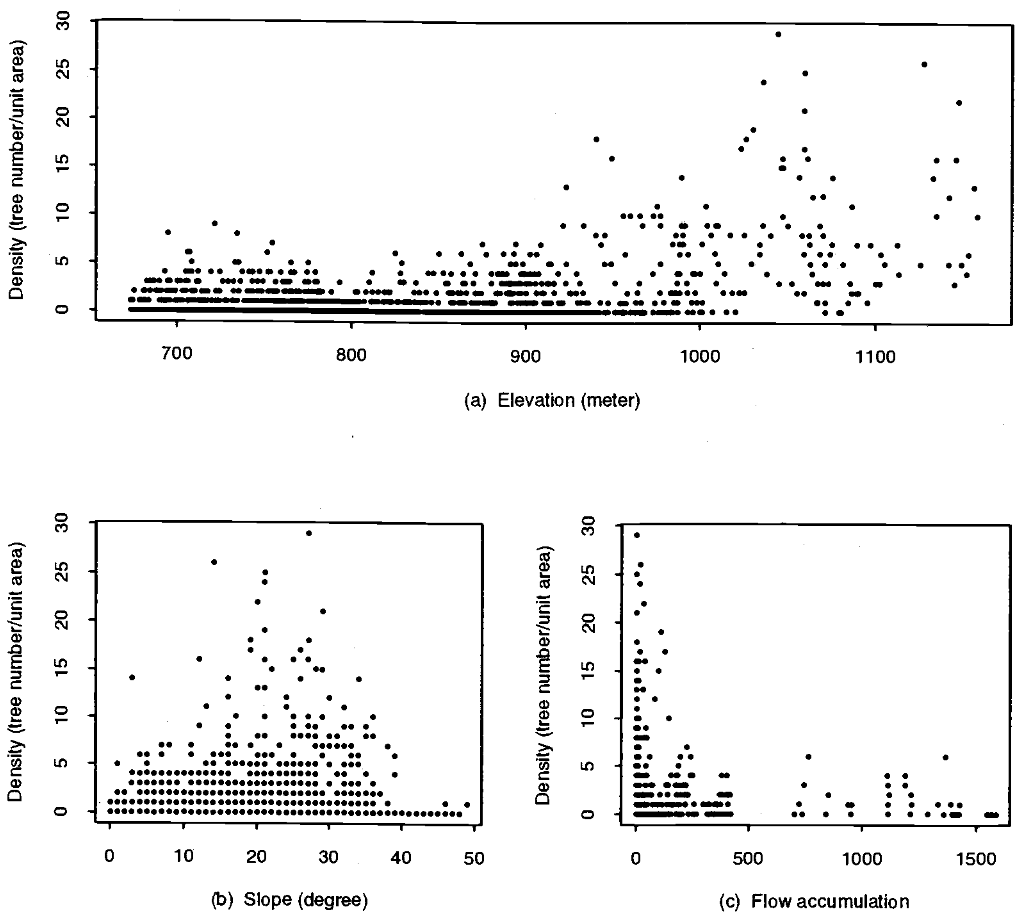


Figure 5.3 Scatter diagrams (a to c) and boxplots (d to i) showing relationships between juniper density and environmental characteristics. In boxplots (d) to (i), boxes represent the middle half of data, with values between upper and lower quartiles. White bars indicate medians and 'x' marks means. Whiskers are drawn to the nearest value not beyond a standard span of 1.5 times the inter-quartile range. '*' marks are values beyond the range.

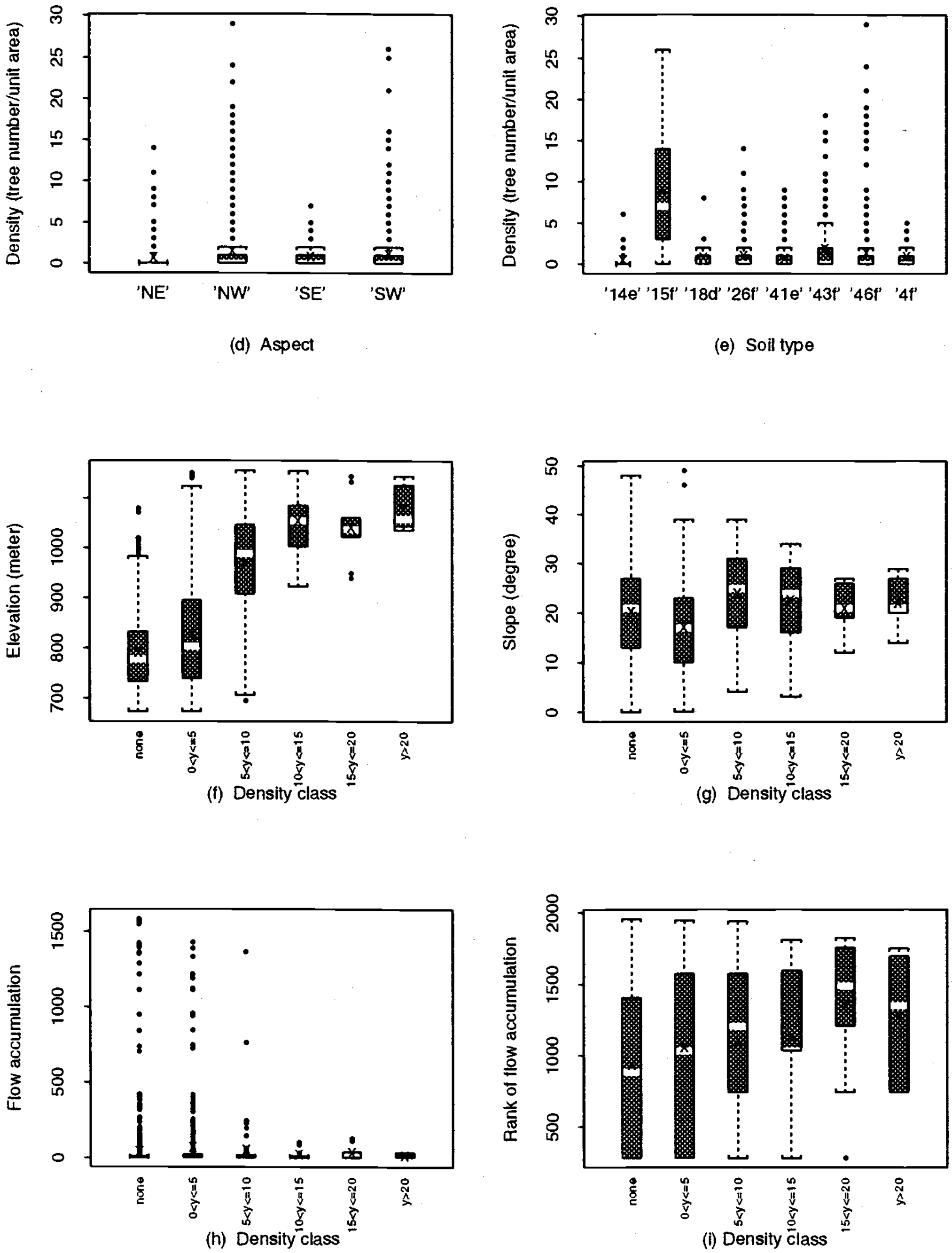


Figure 5.3. Continued

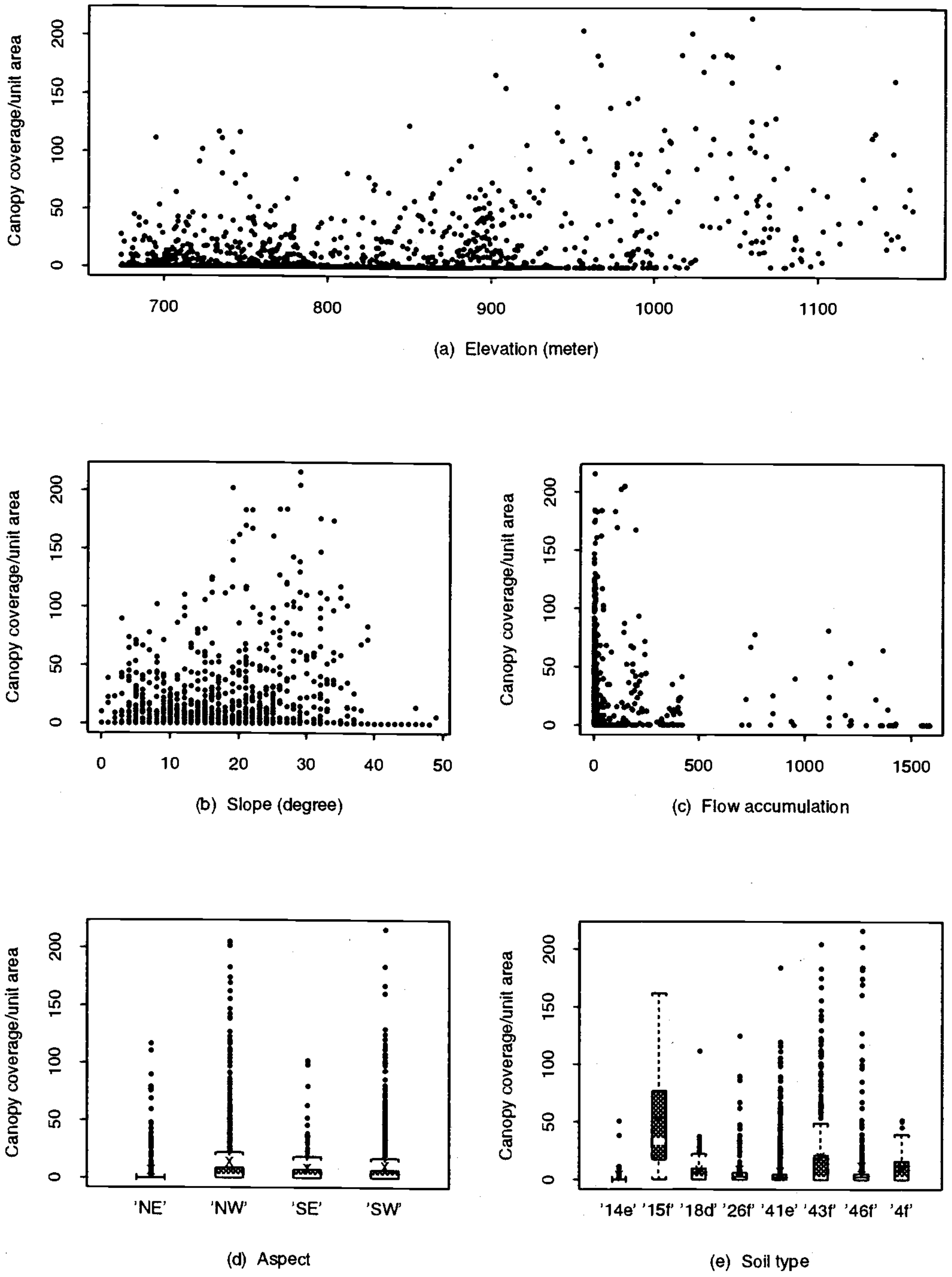


Figure 5.4 Scatter diagrams and boxplots showing relationships between juniper canopy coverage per unit area and environmental characteristics.

5.1.2.3 Flow accumulation

The sampled surface flow accumulation values from 0 to 1,584. The diagrams of juniper density, canopy coverage and juniper density class against surface flow accumulation value (Figure 5.3c, 5.4c and 5.3h respectively) all indicate an inverse association- high densities and canopy coverages only occur in areas with low surface flow accumulation values, but low densities and canopy coverages distribute widely along the surface flow accumulation gradient. However, Spearman rank correlation coefficients oppositely suggest an overall direct association of surface flow accumulation with juniper density, and with canopy coverage (rh_0 for juniper density = .133, rh_0 for canopy cover = .140). Although the direct association is detected by plotting the ranks of surface flow accumulation values instead of plotting the original measurements (Figure 5.3i), the relationship between surface flow accumulation and junipers may be inconclusive.

5.1.2.4 Aspect

Various aspects are found in the study area. The differences among the juniper densities and the canopy coverages on the four aspects are significant (Table 5.1). Northeastern aspects have the lowest juniper density and canopy coverage ranks. Juniper density on northeastern aspect is significantly different from those on northwestern and southwestern aspects (p-values: NE vs. NW = 0.012, NE vs. SW = 0.034), and suggestively different from that on southeastern aspect (p-value = 0.076). Juniper canopy coverage on northeastern aspect is significantly different from those on the other three aspects (p-values: NE vs. NW =0.013, NE vs. SE = 0.041, NE vs. SW = 0.041). Densities and canopy coverages on aspects other than northeast are not statistically different (p-values > 0.05).

Low densities and canopy coverages are observed on all aspects, However, densities higher than 15/ 900 m^2 and canopy coverages larger than 150 m^2/ 900 m^2 only occur on western aspects. (Figure 5.3d, Figure 5.4d, Table 5.2).

Table 5.2 Juniper density and canopy coverage on different aspects.

Statistic \ Aspect	*NE*	*NW*	*SE*	*SW*
Density range	0 -14	0 - 29	0 - 7	0 - 26
Density mean	0.64	1.44	0.77	1.09
Density median	0	0	0	0
Canopy coverage range	0 - 116.6	0 - 204.7	0 - 101.6	0 - 215.7
Canopy coverage mean	5.9	13.6	7.9	9.6
Canopy coverage median	0	0	0	0

Assuming other factors are constant, southern aspects are drier than northern aspects, and western aspects are drier than eastern aspects. Northeastern aspect is the most mesic, and southwestern is the most xeric (Whittaker 1960). Western junipers appear on all exposures, but are less abundant in the most mesic sites. Also, higher abundances occur on the more xeric western aspects.

5.1.2.5 Soil type

Juniper densities and canopy coverages differ significantly among the eight sampled soil types (Table 5.1). Type 15f (Gwin-Rock outcrop complex) supports significantly higher density and canopy coverage than the other soil types (all p-values for type 15f vs. other types are less than 0.05). Type 43f (Simas-Badland association) supports significantly higher density and canopy coverage than type 26f (Lickskillet rock outcrop complex), 41e (Simas very stony clay loam) and 46f (Snell-Anatone complex) (p-values < 0.05). Differences between the other paired comparisons are not significant.

Again, low densities and coverages exist on all eight soil types; however, higher densities (> 15/ 900 m2) only occur on type 46f (Snell-Anatone complex), type 43f (Simas-Badland association) and type 15f (Gwin-Rock outcrop complex). Type 14e (Gwin-Rockly complex) supports the lowest juniper density and canopy coverage ranks

(Figure 5.3e, Figure 5.4e, Table 5.3). Juniper density and canopy coverage means in soil type 15f (Gwin-Rock outcrop complex) are prominently higher than those in other soil types. This high juniper abundance may associate with the high elevations of these sites (Table 5.3), since elevation has a direct relationship with juniper abundance. The relationship between juniper and soil types is difficult to interpret, because each soil type has complex features which correlate with other factors (Table 5.3).

Table 5.3 Statistics of juniper density and canopy coverage, and soil features in different soil types. Note: soil composition, runoff and erosion hazard are from USDA, SCS(1981). Other features, density and canopy coverage are from the sampled sites in the study area.(unit for density: / 900 m^2, for canopy coverage: m^2 /900 m^2)

Statistics or features\ Soil types	*14e (Gwin-Rockly complex)*	*15f (Gwin-Rock outcrop complex)*	*41e (Simas very stony clay loam)*	*43f (Simas-Badland association)*
Soil composition	50% Gwin very stony silt loam 30% Rockly extremely stony loam	45% Gwin extremely stony silt loam 35% Rock outcrop	Simas very stony clay loam	55% Simas very stony clay loam 25% Badland
Runoff	Medium to rapid	Rapid	Medium to rapid	Rapid
Erosion hazard	Moderate to high	High	Moderate to severe	High
Slope(°) range and mean	3 - 30 (20)	12 - 36 (23)	0 - 48 (18)	0 - 39 (22)
Elevation (m) range and mean	760 - 930 (840)	980 - 1170 (1100)	680 - 1080 (770)	730 - 1080 (880)
Aspect	NW, SW	NW, SW	NW, SW, NE, SE	NW, SW, NE, SE
Density range	0-6	0-26	0-9	0-19
Density mean	0.44	9.07	0.64	1.79
Density median	0	7	0	0
Canopy coverage range	0 - 50.4	0 - 162.1	0 - 184.0	0 - 204.7
Canopy coverage mean	3.0	49.8	6.2	19.1
Canopy coverage medium	0	33.2	0	0

Table 5.3 continued

Statistics or features\ Soil types	*4f (Balder very stony loam)*	*18d (Hack extremely stony loam)*	*26f (Lickskillet rock outcrop complex)*	*46f (Snell-Anatone complex)*
Soil composition	Balder very stony loam	Hack extremely stony loam	45% Lickskillet extremely stony loam 35% Rock outcrop	40% Snell very stony loam 40% Anatone extremely stony loam
Runoff	Medium to rapid	Medium	Rapid	Rapid
Erosion hazard	Moderate to high	Moderate	High	High
Slope(°)	1 - 24 (10)	4 - 16 (8)	3 - 49 (26)	1 - 41 (24)
Elevation (m)	810 - 900 (850)	670 - 710 (690)	740 - 1110 (920)	680 - 1100 (810)
Aspect	NW, SW, SE	NW, SW	NW, SW, NE, SE	NW, SW, NE
Density range	0-5	0-8	0-14	0-29
Density mean	0.84	0.75	0.97	1.32
Density median	0	0	0	0
Canopy coverage range	0 - 51.3	0 - 111.3	0 - 125.0	0 - 215.7
Canopy coverage mean	9.0	7.7	7.6	11.0
Canopy coverage medium	0	0	0	0

5.1.3 Classification tree

The classification tree was constructed from the whole data set, and cross-validation methodology was used to assess its misclassification rate (R). Four of the five environmental characteristics except aspect, and three of the five density classes- class 'none', class '0<y<=5' and class '15<y<=20' are shown in the final classification tree (Figure 5.5). The overall misclassification rate is 0.27. Based on the probability distributions of the classified classes (Table 5.4), classified class 'none' represents the sites without western juniper ($p_{'none'} = 0.75$), '0<y<=5' represents the ones with lower densities ($p_{'0<y<=5'} = 0.61$), and '15<y<=20' represents those with higher densities ($p_{'15<y<=20' + 'y>20'} = 0.625$).

Table 5.4 The performance of the classification tree for juniper density class. The value inside the parenthesis is the probabilities of the true classes within each classified class.

True \ Classified	*'none'*	*'0<y<=5'*	*'15<y<=20'*	*Total*
'none'	1251 (.75)	47 (.17)	0 (.0)	1298 (0.663)
'0<y<=5'	391 (.23)	166 (.61)	0 (.0)	557 (0.285)
'5<y<=10'	23 (.014)	45 (.16)	3 (.1875)	71 (0.0363)
'10<y<=15'	1 (.0006)	11 (.04)	3 (.1875)	15 (0.00767)
'15<y<=20'	1 (.0006)	3 (.011)	6 (.375)	10 (0.00511)
'y>20'	0 (.0)	2 (.011)	4 (.25)	6 (0.00307)
Total	1667 (1.00)	274 (1.00)	16 (1.00)	1957 (1.00)

Juniper density correlated to most of the environmental characteristics, except aspect. Elevation is the most important predictor variable. Four out of ten splits are based on elevation. According to the probability distributions of density classes for different elevation ranges, it is found that juniper density has a direct relationship with elevation, but the relationship inverse as the elevation is higher than 1061.5 meters MSL (Figure 5.5 and Table 5.5: node 2, 4, 5; node 3, 14, 15, 30, 31).

At elevations higher than 984.5 meters MSL, soil type is the only other factor significantly relating to density class distribution. More junipers were expected on sites with soil type 15f and 46f than with type 26f, 41e, and 43f (Figure 5.5 and Table 5.5: node 6 and 7). Below 984.5 meters MSL, juniper occurrence significantly relates to slope and flow accumulation value. For both elevation ranges: from 874.5 to 984.5 meters MSL and below 874.5 meters MSL, probabilities of juniper occurrence are higher on slopes less than about 20° (Figure 5.5 and Table 5.5: node 8 to 11). On less steep slopes, junipers appear to prefer areas with higher flow accumulation values (Figure 5.5 and Table 5.5: node 16, 17, 20, 21). However, the probability of juniper occurrence is reduced at sites with really high flow accumulation values (Figure 5.5 and Table 5.5: node 34, 35).

Although the relationship between juniper and aspect is not uncovered by the classification tree, the result of this modeling is similar to the results of the individual tests for relationships between juniper and environmental characteristics. The relationships with slope detected by both method are inverse: less junipers are expected on steep slopes. Both agree that 15f is the soil type with highest juniper densities. Both found juniper density has a direct association with elevation, except the inverse one detected at very high elevations. The result also shows a direct relationship between density and flow accumulation, except at sites with very high flow accumulation. This relationship agrees with the inconclusive direct association detected by Spearman rank correlation coefficients (Section 5.1.2.3). The explanation for this relationship may be seed dispersal. Juniper seeds appear to spread via water. It may be that the majority of seeds disperses along water courses after being carried down slope by overland flow over frozen soil (Eddleman 1984). The denser juniper distributions along water courses were also observed as interpreting the aerial photos.

Interactions among environmental characteristics were found by the classification tree. For example, soil type is important at elevations higher than 984.5 meter MSL, but not at lower elevations. Also, the relationships of juniper with slope and flow accumulation vary at different elevations. The classification tree appears to be more sensitive than the Spearman rank correlation coefficient for detecting nonlinear relationships with elevation and flow accumulation. It also deals with interactions automatically and determines the relationships between juniper and environmental characteristics in a more precise manner.

This modeling is only based on the data in the study area. Its application on other areas needs further studies. An example for using this classification tree is shown as follows. Assuming a homogeneous site with a elevation of 1000 meters MSL, slope of 30°, flow accumulation value of 500, soil type 41e and NW aspect, the probability for its juniper density being between 0/ 900 m^2 and 5/ 900 m^2 is 73 percent. Be aware that only soil type and elevation were used for classifying the site.

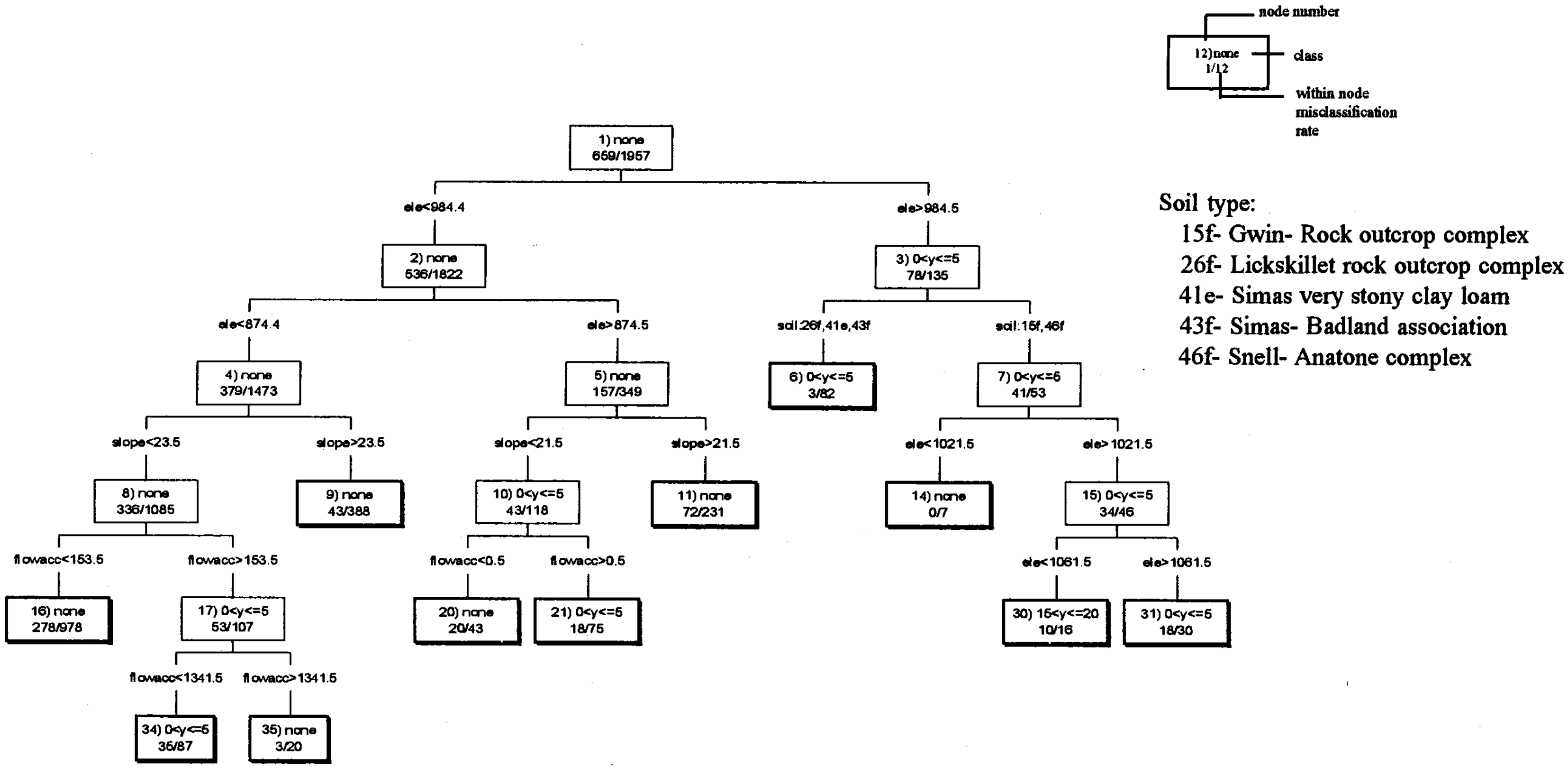


Figure 5.5 Classification tree for juniper density class. Note: class 'none' indicates the juniper density equals zero, class '0<y<=5' indicates the juniper density is larger than zero and less or equal to five, and so on. Shaded boxes are terminal nodes.

Table 5.5 Classification table of juniper density class.

node), split, number, density class, *(class prob.: 'none', '0<x<=5', '5<x<=10', '10<x<=15', '15<x<=20', 'x>20')*
1) root, 1957, 'none', *(0.6633, 0.2846, 0.03628, 0.007665, 0.00511, 0.003066)*
2)ele<984.5, 1822, 'none', *(0.7058, 0.2744, 0.01756, 0.001098, 0.001098, 0.0000)*
4) ele<874.5, 1473, 'none', *(0.7427, 0.2505, 0.006789, 0.0000, 0.0000, 0.0000,)*
8) slope<23.5, 1085, 'none', *(0.6903, 0.3023, 0.007373, 0.0000, 0.0000, 0.0000)*
16) flowacc<153.5, 978, 'none', *(0.7157, 0.2802, 0.00409, 0.0000, 0.0000, 0.0000)* *
17) flowacc>153.5, 107, ' 0<y<=5', *(0.4579, 0.5047, 0.03738, 0.0000, 0.0000, 0.0000,)*
34) flowacc<1341.5, 87, '0<y<=5', *(0.3678, 0.5977, 0.03448, 0.0000, 0.0000, 0.0000)* *
35) flowacc>1341.5, 20, 'none', *(0.8500, 0.1000, 0.0500, 0.0000, 0.0000, 0.0000)* *
9) slope>23.5, 388, 'none', *(0.8892, 0.1057, 0.005155, 0.0000, 0.0000, 0.0000)* *
5) ele>874.5, 349, 'none', *(0.5501,0.3754, 0.06304, 0.005731, 0.005731, 0.0000)*
10) slope<21.5, 118, '0<y<=5', *(0.2797, 0.6356, 0.05932, 0.008475, 0.01695, 0.0000,)*
20) flowacc<0.5, 43, 'none', *(0.5349, 0.4186, 0.02326, 0.0000, 0.02326, 0.0000)* *
21) flowacc>0.5, 75, '0<y<=5', *(0.1333, 0.7600, 0.0800, 0.01333, 0.01333, 0.0000)* *
11) slope>21.5, 231, 'none', *(0.6883, 0.2424, 0.06494, 0.004329, 0.0000, 0.0000)*
3) ele>984.5, 135, '0<y<=5', *(0.08889, 0.4222, 0.2889, 0.0963, 0.05926, 0.04444,)*
6) soil:'26f','41e','43f', 82, '0<y<=5', *(0.06098, 0.5488, 0.3415, 0.04878, 0.0000, 0.0000)* *
7) soil:'15f','46f', 53, '0<y<=5', *(0.1321, 0.2264, 0.2075, 0.1698, 0.1509, 0.1132,)*
14) ele<1021.5, 7, 'none', *(1.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000)* *
15) ele>1021.5, 46, '0<y<=5', *(0.0000, 0.2609, 0.2391, 0.1957, 0.1739, 0.1304)*
30) ele<1061.5, 16, '15<y<=20', *(0.0000, 0.0000, 0.1875, 0.1875, 0.3750, 0.2500,)* *
31) ele>1061.5, 30, '0<y<=5', *(0.0000, 0.4000, 0.2667, 0.2000, 0.06667, 0.06667,)* *

*terminal node

5.2 TEMPORAL DISTRIBUTION PATTERN

5.2.1 Crown area and age

The strong correlation between juniper age and crown area is suggested by fitting Larsen's (1994) data into the simple linear regression model (p-value = 0.0000; Figure 5.6). Approximately 66 percent variation of the crown area is explained by the variation of age ($R^2 = 0.6584$). The model also suggests there is an almost 5 m^2 increase of the crown area for each 10-year growth. The result is used to estimate the time of juniper establishment. The western junipers with crown area larger than 40 m^2 are categorized as old trees established more than 90 to 100 years before the date when the aerial photos were taken, and so on (Table 5.6, Figure 5.6).

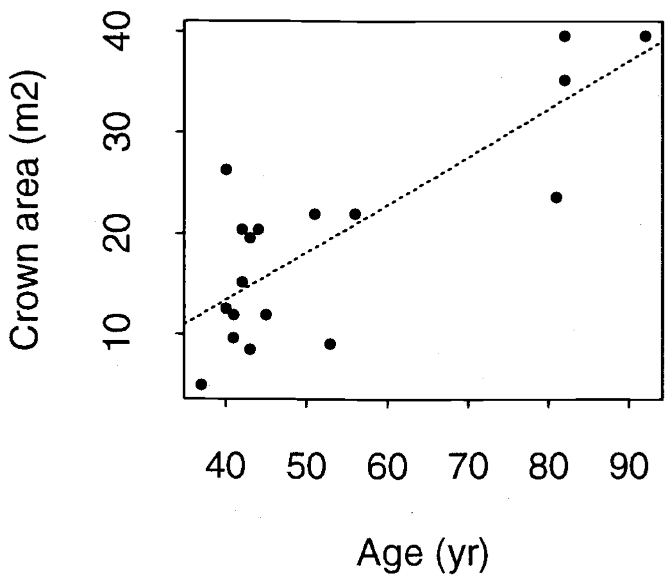


Figure 5.6 Relationship between juniper crown area and age. The dash line was calculated by the simple linear regression model. (Data source: Larsen 1994)

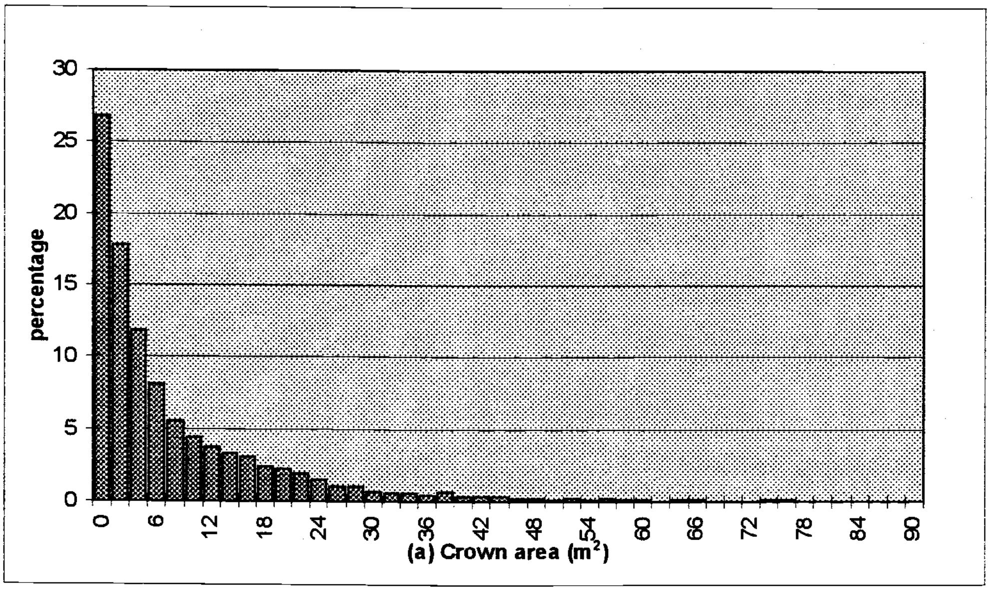
Table 5.6 Western juniper classes categorized by the crown area

Class	*Crown area range, y (m^2)*	*Approximate establishing year before 1986**
Sapling	y<= 10	less than 30 to 40 years
Young	10 <y<= 25	30 to 70 years
Mature	25 <y<= 40	60 to 100 years
Old	y> 40	more than 90 to 100 years

* the aerial photos were taken in 1986.

5.2.2 Crown area distribution

The sampled juniper crown area ranges from 0.12 m^2 to 86 m^2. The frequency of the crown area decreases exponentially as the crown area increases (Figure 5.7a). According to the assumption that older trees have larger crown area, this distribution would be similar to the temporal distribution of juniper establishment. Hence, western juniper amount has exponentially increased chronologically. The old junipers established before about 1890 (1891±5) occupy only 2.6% of the population. The mature junipers established between about 1890 to 1920 (1921±5) occupy 5.5%, the young ones established between about 1920 to 1950 (1951±5) occupy 22.9%, and most of the population, 70.0%, has been established after about 1950 (Figure 5.7b). The distribution of the crown area suggests a landscape with scattered western junipers in the study area before the late nineteenth century, and with a remarkable increase in juniper density during the last 100 years (Figure 5.8). Miller and Rose (1995) found that western junipers have been established steadily from 1880s to 1950s, and began to progress at a geometric rate in 1960s. The result found in this study is similar to theirs. The overall density of western juniper in the study area has increased from 37 junipers/ km^2 to 1,404 junipers/ km^2 during the last century.



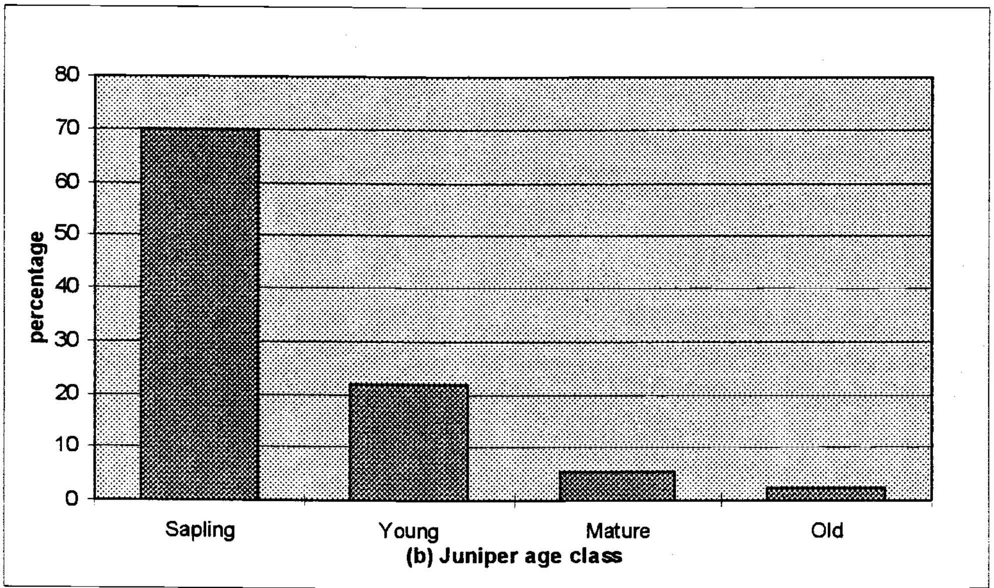
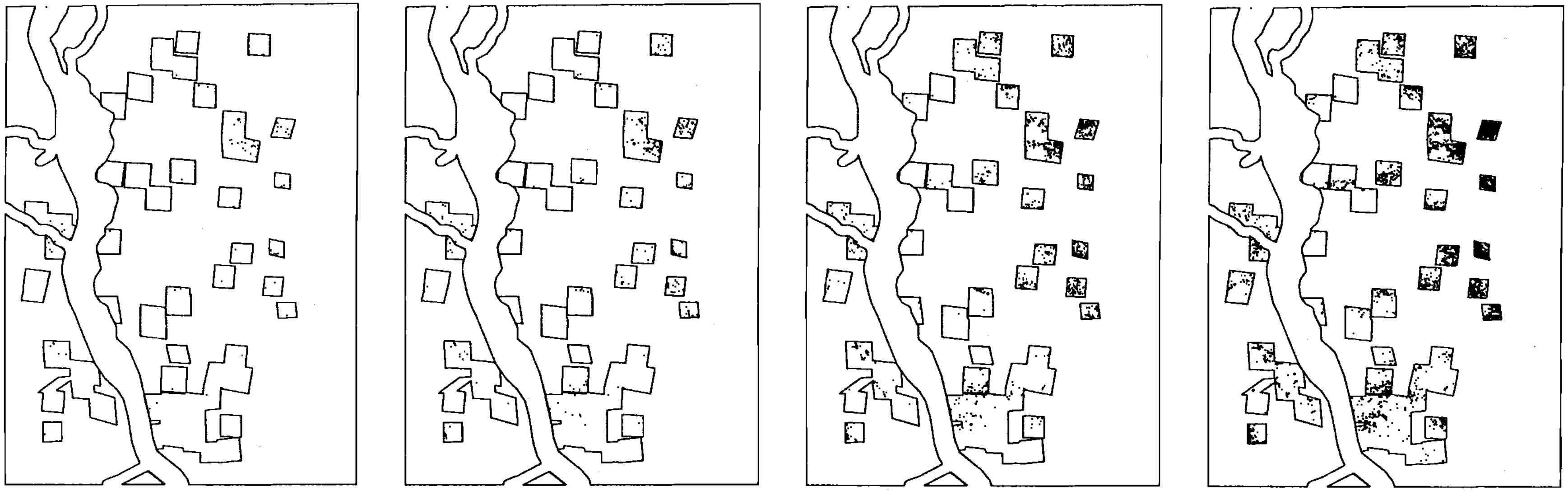


Figure 5.7 Juniper crown area and age class distributions. (a) Percentage of junipers at certain crown area range. (b) Percentage of junipers at certain age class.

Juniper Temporal Distribution



Juniper distribution in ~1890 | Juniper distribution in ~1920 | Juniper distribution in ~1950 | Juniper distribution in 1986

Figure 5.8 Temporal distribution of western junipers. Junipers in about 1890 are the old trees in 1986 (when photos were taken), with crown areas larger than 40 m^2; those in about 1920 include old and mature trees with crown areas larger than 25 m^2; those in about 1950 include old, mature and young trees with crown areas larger than 10 m^2; junipers in 1986 include all the sampled trees.

5.2.3 Relationships with environmental characteristics

5.2.3.1 Elevation

The sampled junipers exist from 674 to 1,173 meters MSL. All of the four crown area classes exist along a wide range of elevation gradients, but the range of old junipers is slightly narrower (Figure 5.9a). Difference among the four crown area classes is significant (p-value = 0.0000); however, the association tendency is not identifiable from the diagram. The multi-comparison procedure shows that the young age class exists at a significantly lower elevation range than the sapling age class (p-value = 0.0000). The comparisons between other paired age classes do not show significant differences.

5.2.3.2 Slope

The sampled junipers exist on the slopes ranging from 0° to about 40°. The Kruskal-Wallis test suggests a difference among the slopes for the four age classes (p-value = 0.0482). However, difference between any two age classes is not found (all p-values > 0.1). The slope ranges, means, and medians for the four age classes are similar as well (Figure 5.9b). Thus, the relationship between slope and juniper age class is obscure.

5.2.3.3 Flow Accumulation

Both the mature and the old age classes do not exist in sites with very high flow accumulation (Figure 5.9c). The flow accumulation rank ranges for different age classes are similar (Figure 5.9d), and the Kruskal-Wallis test did not find significant differences (p-value = 0.1042).

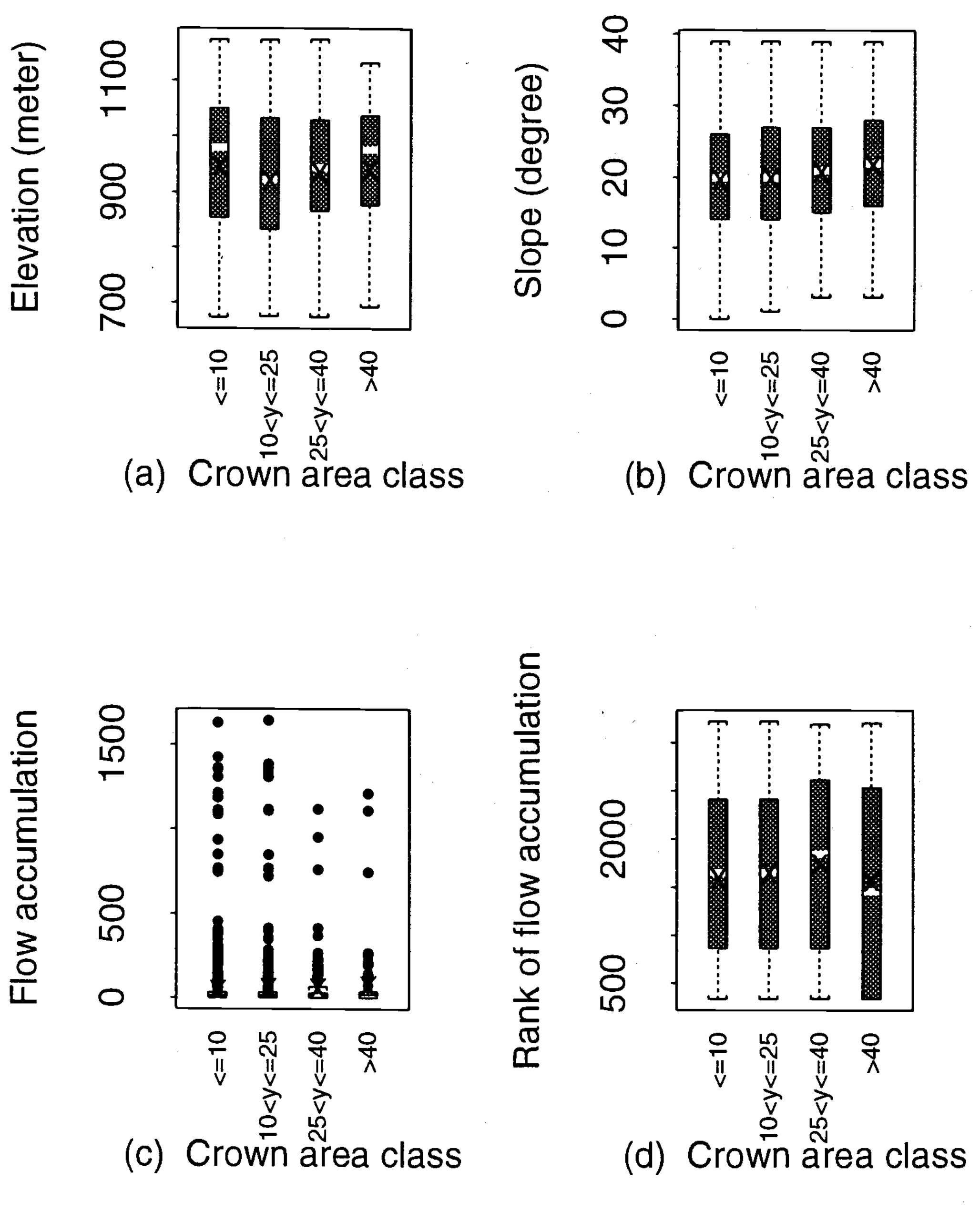
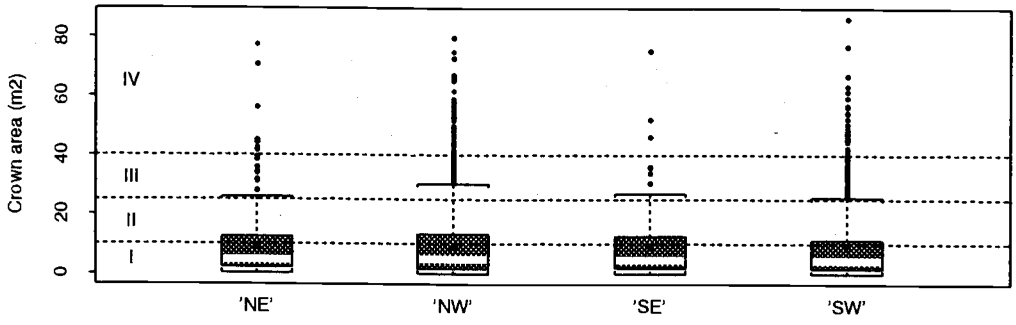
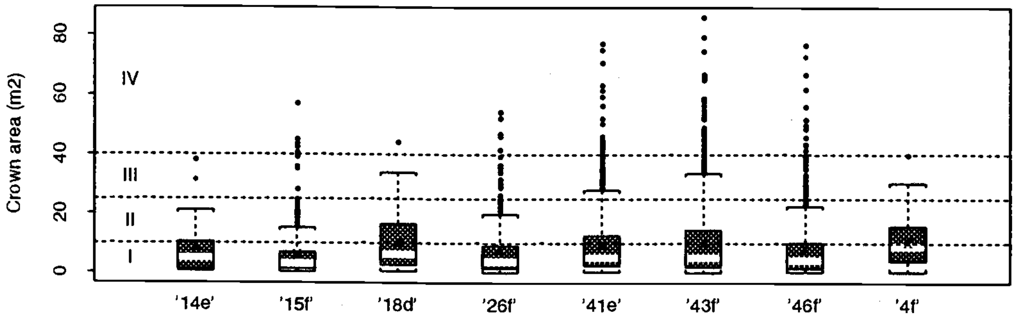


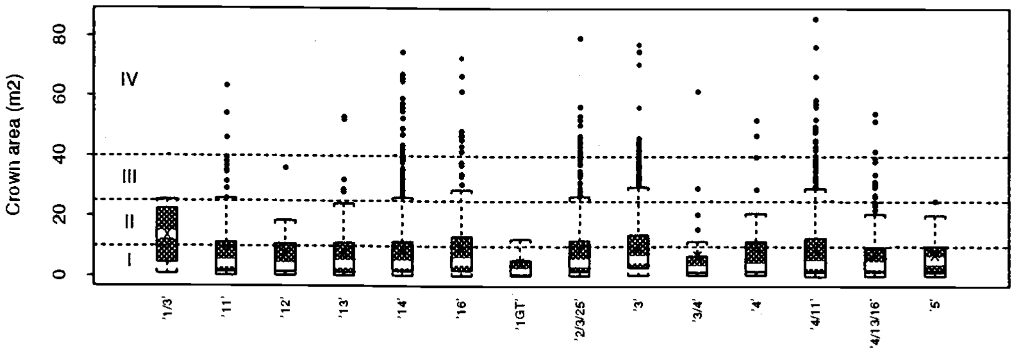
Figure 5.9 Boxplots showing relationships between juniper crown area and environmental characteristics. Note: in boxplots (e) to (g), I: crown area class ‘<=10’, II: ‘10<y<=25’, III: ‘25<y<=40’, IV: ‘>40 m^2’.



(e) Aspect



(f) Soil type



(g) Vegetation type

Figure 5.9 continued

5.2.3.4 Aspect

Overall, juniper age class is independent from aspect (p-value = 0.75; Figure 5.9e). For detail relationships, the frequencies of different age classes on west and on east are not significantly different from the expected frequencies (all p-values > 0.05), and neither for the frequencies on north and on south (all p-values > 0.05).

5.2.3.5 Soil type

The overall relationship between juniper age class and soil type is significant (p-value = 0.0000; Figure 5.9f). After partitioning the overall contingency table into smaller subtables, no significantly difference was found between soil type 14e (Gwin-Rockly complex) and 15f (Gwin-Rock outcrop complex) within series Gwin, and neither between 41e (Simas very stony clay loam) and 43f (Simas-Badland association) within series Simas. Association between juniper age class and soil type occurs mainly in the following comparisons: (1) For the comparisons in group1, the likelihood for finding a mature or old juniper in series Simas is greater than in type 26f. (2) For the comparison between sapling and young age classes within group1 and group2, the likelihood for finding a juniper sapling in group1 is greater than in group2. (3) After combining group1 and group2, the likelihood for finding a juniper sapling in group3 is less than in the combined group for the comparison between sapling and young age classes within the combined group and group3. (4) The likelihood for finding a mature or old juniper in group3 is higher than in the combined group. The detailed results are summarized in Table 5.7.

To sum up, no significant association between soil type and larger junipers, mature and old age classes, was found from chi-square partitioning. Associations between some soil types and smaller junipers, sapling and young age classes were observed. Group3-type 41e (Simas very stony clay loam), 43f (Simas-Badland association) and 46f (Snell-Anatone complex), has a greater likelihood of finding mature or old junipers and a smaller likelihood of finding juniper saplings or young junipers than group1 and group2 combined. It may indicate that the number of offspring produced by individual mature tree or the survival rate of offspring was less on soil type 41e, 43f and 46f. Expansion rate during last century for individual juniper might be less on these soil types.

Table 5.7 The result of chi-square partitioning for soil type

Source			*Chi-square*	*d.f.*	*Significant*
Group1					
	Within series Gwin: 14e vs. 15f				
		sapling vs. young	0.057	1	no
		mature vs. old	3.460	1	no
		sapling + young vs. mature + old	3.493	1	no
	subtotal		7.010	3	no
	Series Gwin vs. 26f				
		sapling vs. young	0.423	1	no
		mature vs. old	0.086	1	no
		sapling + young vs. mature + old	5.983	1	yes
	subtotal		6.492	3	no
Total			*13.502*	*6*	*yes*
Group2					
	18d vs. 4f				
		sapling vs. young	0.832	1	no
		mature vs. old	1.923	1	no
		sapling + young vs. mature + old	0.138	1	no
Total			*2.893*	*3*	*no*
Group3					
	Within series Simas: 41e vs. 43f				
		sapling vs. young	0.021	1	no
		mature vs. old	0.338	1	no
		sapling + young vs. mature + old	2.684	1	no
	subtotal		3.043	3	no
	Series Simas vs. 46f				
		sapling vs. young	9.668	1	yes
		mature vs. old	0.013	1	no
		sapling + young vs. mature + old	2.264	1	no
	subtotal		11.945	3	yes
Total			*14.988*	*6*	*yes*
Group1 vs. Group2					
		sapling vs. young	49.510	1	yes
		mature vs. old	1.332	1	no
		sapling + young vs. mature + old	0.120	1	no
Total			*50.962*	*3*	*yes*
Group1 + Group2 vs. Group3					
		sapling vs. young	5.499	1	yes
		mature vs. old	0.015	1	no
		sapling + young vs. mature + old	17.090	1	yes
Total			*22.604*	*3*	*yes*
Grant Total			*104.95*	*21*	*yes*

*significant level is based on an one-side p-value <= 0.05

5.2.3.6 Vegetation

The overall association between juniper age class and vegetation type is not significant (p-value = 0.21). Also, no significant associations between age class and vegetation type were found within all of the three groups. Group1 is not significantly different from group2. However, group3 is significantly different from the combined group of group1 and group2. The difference is between sapling and young age classes, and no significant differences were found between mature and old age classes, neither between small junipers- sapling and young trees, and large junipers- mature and old trees (Table 5.8, **Table A.1**, **Table A.4**).

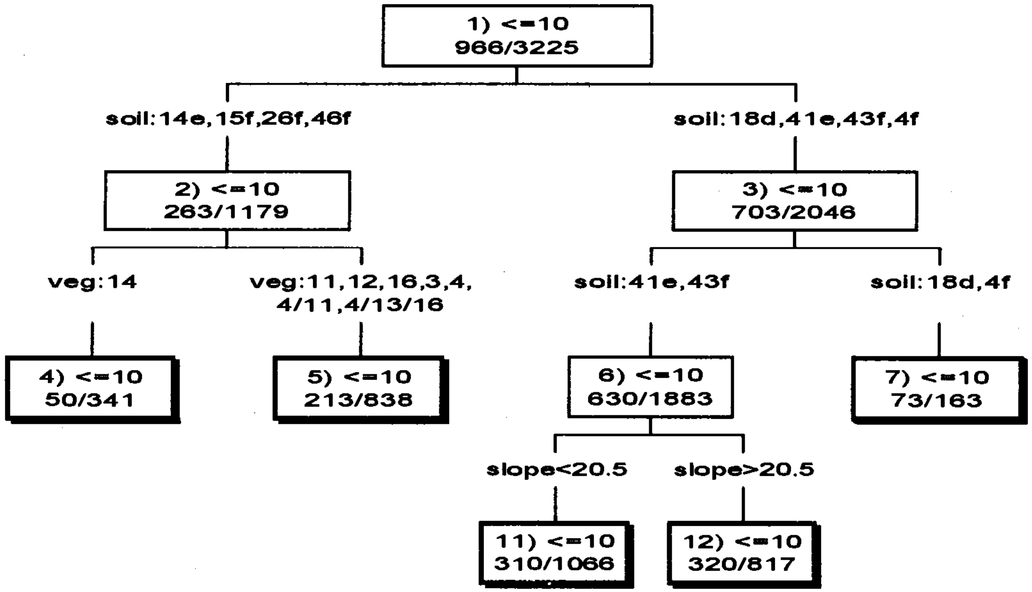
Table 5.8 The result of chi-square partitioning for vegetation type

Source	*Chi-square*	*d.f.*	*Significant*
Group1 (mainly with brush and grass communities)	*15.10*	*15*	*no*
Group2 (with mountain mahogany communities)	*3.94*	*3*	*no*
Group3 (with juniper communities)	*6.32*	*12*	*no*
Group1 vs. Group2	*4.69*	*3*	*no*
Group1 + Group2 vs. Group3			
sapling vs. young	8.034	1	yes
mature vs. old	0.407	1	no
sapling + young vs. mature + old	0.559	1	no
Total	*8.999*	*3*	*yes*
Grant Total	*39.140*	*33*	*no*

*significant level is based on an one-side p-value <= 0.05

5.2.4 Classification tree

The classification tree classifies all the data as sapling age class (Figure 5.10). There is no significant association between juniper age class with any environmental characteristic. This result reflects the obscure relationships detected by the Kruskal-Wallis and the chi-square test.



Soil type:

- 4f- Balder very stony loam
- 14e- Gwin- Rockly complex
- 15f- Gwin- Rock outcrop complex
- 18d- Hack extremely stony loam
- 26f- Lickskillet rock outcrop complex
- 41e- Simas very stony clay loam
- 43f- Simas- Badland association
- 46f- Snell- Anatone complex

Vegetation type:

- 3- Big sagebrush/ Sandberg's bluegrass
- 4- Big sagebrush/ Bluebunch wheatgrass
- 11- Western juniper/ Bluebunch sheatgrass- Thurber's needlegrass
- 12- Big sagebrush/ Bluebunch wheatgrass- Thurber's needlegrass
- 13- Big sagebrush/ Idaho fescue/ Bluebunch wheatgrass
- 14- Western juniper/ Idaho fescue
- 16- Mountain mahogany

Figure 5.10 Classification tree for juniper crown area class.

5.3 EVALUATION

Purposes of this discussion are to assess accuracy, limitations and possible improvements. It will be discussed as two parts: the data processing technique and the statistical analysis.

The crown area was derived from aerial photos to estimate the real crown projection area, and the estimation may be affected by the factors in equation 4.1 (p. 19). Among those factors, focal length is a provided constant value. It is precise and not controlled by the data processing procedure. Original photo crown area, local elevation and flying height are less precise and influence the study more.

Original photo crown areas were derived from only central parts of photos to represent desired projection crown areas; however, photo distortion still existed and may have caused either higher or lower estimations of projection crown areas. This problem becomes more apparent in areas farther from photo centers. Another problem in determining photo crown areas is misinterpreting junipers. In dense juniper stands, trees may be too crowded to be distinguished. Two or more junipers may be digitized as one. This problem was diminished by deleting trees with a crown area larger than 100 m^2. On the other hand, small junipers may be unrecognizable. Those younger than 30 years old are possibly obscured by sagebrushes. Hence, the proportion of sapling junipers in the population may have been even larger than the estimated value. Other tree species were possibly misinterpreted as junipers as well, although a magnifier was used to increase the accuracy of interpretation.

Since the photo set purchased from WAC was not rectified, each photo may have various scales at different locations depending on the local elevations. This problem was diminished by transforming coordinates of juniper GIS coverages based on orthophotos. However, control points are not always available, especially in shaded areas and areas with extremely scattered junipers. Thus, the coordinates of these coverages can only be estimated, resulting in less accurate elevations. The other problem is that shapes of some GIS coverages are twisted after transformation. This problem can be controlled better in area with numerous junipers to provide control points, but in areas without determinative control points, the GIS coverages may not well represent the sampled areas in aerial photos.

The flying height is provided as 6,000 feet MSL; however, variations during flying are inevitable. Moreover, those photos are assumed to be taken vertically, but tilts more than 3° are possible. Both factors cause inaccuracy in estimating real crown projection areas.

Data availability is limited in this study. Fire frequency and regime, and grazing intensity are important factors influencing juniper distribution, but they are not available. Environmental characteristics are based at a landscape level, which provides coarse scale data. For example, soil information is from the soil survey of Grant county, which is at a coarse scale compared with the photo scale, as are vegetation and DEM derived data. Fine scale information, such as proportions of rockiness, bedrock fracturing and detailed understory species distribution, has been considered as relative to old juniper distribution, but not available. Data relating ages with crown areas of western junipers within the study area is also unavailable.

Most of the problems of crown area accuracy could be resolved by photogrammetry techniques with special facilities. The availability of data could be improved by field surveys. However, both are time consuming and expensive. Thus, the analysis is based on available data and the inaccuracy caused by the above factors is assumed not affecting the analysis.

Statistical analysis in this study is challenging because of the multidimension of the data set, interactions between the variables, and the extreme skewness and complexity of the data structure. Multidimension and interaction may be resolved by dividing data sets into homogenous subsets and comparing these subsets. However, this method requires much effort and a huge data set, which is not affordable by manually digitizing juniper crowns. Some statistical methods which are capable of interaction could resolve this problem as well. Multiple regression in parametric statistics is considered mostly, but the extremely skewed distribution of the data doesn't satisfy its assumption of normal distribution. As a result, nonparametric statistical methods and classification tree were used to explore the data set.

Distribution of ranks instead of original measurements are analyzed by Kruskal-Wallis test and used to calculate Spearman rank correlation coefficients. Large variations of original measurements could be reduced when converted to ranks, and thus not detected. Also, non-linear relationships between continuous original measurements could be masked by rank distributions. Even rank distributions preserve the non-linear relationships, Spearman rank correlation coefficients are not capable of detecting such relationships. Furthermore, all the methods used, except classification trees, do not deal with interactions between variables.

Classification trees appear to be a better method in dealing with multidimension and interaction, and this method has many advantages as discussed in chapter 4. However, tree structures could sometimes be instable. At any given node, there may be a number of splits on different variables giving almost the same increase of homogeneity in subsets. Since data are noisy, the choice between those splits is almost random, and results in different evolution of the tree from that node downward. In other words, two similar data sets could develop different tree structures, especially at lower nodes. So, classification trees should be interpreted carefully (Breiman et al. 1984). The classification trees in this study were compared with the tests for relationships of junipers with environmental characteristics, and have similar results.

6. CONCLUSIONS

The spatial distribution of western junipers in the study area shows a clustering point pattern. The clustering nature is shown most prominently over the elevation gradient. Western juniper is more abundant above elevations of approximately 900 to 1,000 meters MSL. This clustering pattern also shows on other environmental characteristics. Soil type 15f- Gwin-Rock outcrop complex and 43f- Simas-Badland association support higher densities and canopy coverages. Denser stands exist on medium slopes, but probabilities of juniper occurrence on less steep slopes are higher at lower elevations. Western juniper abundance is significantly lower on the most mesic northeastern aspect than on others. Extremely high flow accumulation values only support lower juniper abundances, but at lower flow accumulation areas, junipers prefer sites with more surface flow accumulation, which could be water courses.

Temporally, western juniper has expanded remarkably during last century. However, the relationship of this expanding pattern to environmental characteristics is obscure. Age class distributions of western junipers in different environments were similar. It appears that younger junipers exist in various environments, and as do older junipers. There is no conspicuous difference between the habitats of young and old junipers, except perhaps soil types. The likelihood for finding mature or old junipers is higher in sites with soil type 41e- Simas very stony clay loam, 43f- Simas-Badland association or 46f- Snell-Anatone complex. Generally speaking, juniper expansion directions along environmental gradients are not conspicuously detected at the landscape level. It seems reasonable that juniper seeds are dispersed to areas nearest parent trees, and thus environmental characteristics for new established junipers are similar to that of old junipers. The temporal distribution of western juniper at a finer scale and relating to other important factors, such as fire and grazing history, needs further studies.

To sum up, the spatial distribution of western juniper relates to environmental characteristics at the coarse landscape level. Junipers are able to grow in a variety of environments, but their preference for some characteristics is shown by higher probabilities of greater densities or canopy coverages in those areas. This spatial distribution pattern was shown similarly at different time periods, but with chronologically increased densities and canopy coverages. Thus, the temporal distribution of western junipers is mainly from low to high densities and canopy coverages without specific expansion direction along the included environmental characteristics. The spatiotemporal distribution pattern of western juniper in the study area could be described as a clustering pattern with chronologically increased abundances. Although a large portion of the monument currently has an open landscape, juniper may continue to increase in abundance and expand from high density areas to low density or non-juniper areas. The expansion direction could be from areas at high elevations or with medium slopes, soil type 15f-Gwin-Rock outcrop complex and 43f- Simas Badland association, water courses, or western and SE aspects to other areas. Unless juniper density is controlled, it seems likely that junipers will dominate most of the monument's landscape in the future.

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APPENDIX

Table A.1 Chi-square partitioning tables for aspect

(a)

	NE	NW	SE	SW	Marginal total
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{1+}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{2+}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{3+}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{4+}
Marginal total	n_{+1}	n_{+2}	n_{+3}	n_{+4}	Grand total n

=

	NE	NW
Sapling	n_{11}	n_{12}
Young	n_{21}	n_{22}

+

	SE	SW
Sapling	n_{13}	n_{14}
Young	n_{23}	n_{24}

+

	NE	NW
Mature	n_{31}	n_{32}
Old	n_{41}	n_{42}

+

	SE	SW
Mature	n_{33}	n_{34}
Old	n_{43}	n_{44}

	NE	NW
Sapling Young	n_{11} n_{21}	n_{12} n_{22}
Mature Old	n_{31} n_{41}	n_{32} n_{42}

+

	SE	SW
Sapling Young	n_{13} n_{23}	n_{14} n_{24}
Mature Old	n_{33} n_{43}	n_{34} n_{44}

+

	NE	NW	SE	SW
Sapling	n_{11}	n_{12}	n_{13}	n_{14}
Young	n_{21}	n_{22}	n_{23}	n_{24}

+

	NE	NW	SE	SW
Mature	n_{31}	n_{32}	n_{33}	n_{34}
Old	n_{41}	n_{42}	n_{43}	n_{44}

+

	NE	NW	SE	SW
Sapling Young	n_{11} n_{21}	n_{12} n_{22}	n_{13} n_{23}	n_{14} n_{24}
Mature Old	n_{31} n_{41}	n_{32} n_{42}	n_{33} n_{43}	n_{34} n_{44}

Table A.1 Continued

(b)

	NE	SE	NW	SW	Marginal total
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{1+}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{2+}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{3+}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{4+}
Marginal total	n_{+1}	n_{+2}	n_{+3}	n_{+4}	Grand total n

=

	NE	SE
Sapling	n_{11}	n_{12}
Young	n_{21}	n_{22}

+

	NW	SW
Sapling	n_{13}	n_{14}
Young	n_{23}	n_{24}

+

	NE	SE
Mature	n_{31}	n_{32}
Old	n_{41}	n_{42}

+

	NW	SW
Mature	n_{33}	n_{34}
Old	n_{43}	n_{44}

	NE	SE
Sapling	n_{11}	n_{12}
Young	n_{21}	n_{22}
Mature	n_{31}	n_{32}
Old	n_{41}	n_{42}

+

	NW	SW
Sapling	n_{13}	n_{14}
Young	n_{23}	n_{24}
Mature	n_{33}	n_{34}
Old	n_{43}	n_{44}

+

	NE	SE	NW	SW
Sapling	n_{11}	n_{12}	n_{13}	n_{14}
Young	n_{21}	n_{22}	n_{23}	n_{24}

+

	NE	SE	NW	SW
Mature	n_{31}	n_{32}	n_{33}	n_{34}
Old	n_{41}	n_{42}	n_{43}	n_{44}

+

	NE	SE	NW	SW
Sapling	n_{11}	n_{12}	n_{13}	n_{14}
Young	n_{21}	n_{22}	n_{23}	n_{24}
Mature	n_{31}	n_{32}	n_{33}	n_{34}
Old	n_{41}	n_{42}	n_{43}	n_{44}

Table A.2 Chi-square partitioning table for soil type

	14e	15f	26f	18d	4f	41e	43f	46f	Marginal total
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}	n_{1+}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}	n_{2+}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}	n_{3+}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}	n_{4+}
Marginal total	n_{+1}	n_{+2}	n_{+3}	n_{+4}	n_{+5}	n_{+6}	n_{+7}	n_{+8}	Grand total n

=

	14e	15f
Sapling	n_{11}	n_{12}
Young	n_{21}	n_{22}

+

	14e	15f
Mature	n_{31}	n_{32}
Old	n_{41}	n_{42}

+

	14e	15f
Sapling	n_{11}	n_{12}
Young	n_{21}	n_{22}
Mature	n_{31}	n_{32}
Old	n_{41}	n_{42}

+

	14e	15f	26f
Sapling	n_{11}	n_{12}	n_{13}
Young	n_{21}	n_{22}	n_{23}

+

	14e	15f	26f
Mature	n_{31}	n_{32}	n_{33}
Old	n_{41}	n_{42}	n_{43}

+

	14e	15f	26f
Sapling	n_{11}	n_{12}	n_{13}
Young	n_{21}	n_{22}	n_{23}
Mature	n_{31}	n_{32}	n_{33}
Old	n_{41}	n_{42}	n_{43}

+

	18d	4f
Sapling	n_{17}	n_{18}
Young	n_{27}	n_{28}

+

	18d	4f
Mature	n_{37}	n_{38}
Old	n_{47}	n_{48}

+

	18d	4f
Sapling	n_{17}	n_{18}
Young	n_{27}	n_{28}
Mature	n_{37}	n_{38}
Old	n_{47}	n_{48}

+

	14e	15f	26f	18d	4f
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}

+

	14e	15f	26f	18d	4f
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}

+

Table A.2 Continued

	14e	15f	26f	18d	4f
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}

+

	41e	43f
Sapling	n_{14}	n_{15}
Young	n_{24}	n_{25}

+

	41e	43f
Mature	n_{34}	n_{35}
Old	n_{44}	n_{45}

+

	41e	43f
Sapling	n_{14}	n_{15}
Young	n_{24}	n_{25}
Mature	n_{34}	n_{35}
Old	n_{44}	n_{45}

+

	41e	43f	46f
Sapling	n_{14}	n_{15}	n_{16}
Young	n_{24}	n_{25}	n_{26}

+

	41e	43f	46f
Mature	n_{34}	n_{35}	n_{36}
Old	n_{44}	n_{45}	n_{46}

+

	41e	43f	46f
Sapling	n_{14}	n_{15}	n_{16}
Young	n_{24}	n_{25}	n_{26}
Mature	n_{34}	n_{35}	n_{36}
Old	n_{44}	n_{45}	n_{46}

+

	14e	15f	26f	18d	4f	41e	43f	46f
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}

+

	14e	15f	26f	18d	4f	41e	43f	46f
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}

+

	14e	15f	26f	18d	4f	41e	43f	46f
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}

Table A.3 Chi-square partitioning table for vegetation type

	2/3/25	3	3/4	4	12	13	4/13/16	16	4/11	11	5	14	Marginal total
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}	n_{19}	n_{110}	n_{111}	n_{112}	n_{1+}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}	n_{29}	n_{210}	n_{211}	n_{212}	n_{2+}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}	n_{39}	n_{310}	n_{311}	n_{312}	n_{3+}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}	n_{49}	n_{410}	n_{411}	n_{412}	n_{4+}
Marginal total	n_{+1}	n_{+2}	n_{+3}	n_{+4}	n_{+5}	n_{+6}	n_{+7}	n_{+8}	n_{+9}	n_{+10}	n_{+11}	n_{+12}	Grand total n

=

	2/3/25	3
Sapling	n_{11}	n_{12}
Young	n_{21}	n_{22}

\+

	2/3/25	3
Mature	n_{31}	n_{32}
Old	n_{41}	n_{42}

\+

	2/3/25	3
Sapling	n_{11}	n_{12}
Young	n_{21}	n_{22}
Mature	n_{31}	n_{32}
Old	n_{41}	n_{42}

\+

	2/3/25	3	3/4
Sapling	n_{11}	n_{12}	n_{13}
Young	n_{21}	n_{22}	n_{23}

\+

	2/3/25	3	3/4
Mature	n_{31}	n_{32}	n_{13}
Old	n_{41}	n_{42}	n_{23}

\+

	2/3/25	3	3/4
Sapling	n_{11}	n_{12}	n_{13}
Young	n_{21}	n_{22}	n_{23}
Mature	n_{31}	n_{32}	n_{33}
Old	n_{41}	n_{42}	n_{43}

\+

	2/3/25	3	3/4	4
Sapling	n_{11}	n_{12}	n_{13}	n_{14}
Young	n_{21}	n_{22}	n_{23}	n_{24}

\+

	2/3/25	3	3/4	4
Mature	n_{31}	n_{32}	n_{13}	n_{34}
Old	n_{41}	n_{42}	n_{23}	n_{44}

\+

	2/3/25	3	3/4	4
Sapling	n_{11}	n_{12}	n_{13}	n_{14}
Young	n_{21}	n_{22}	n_{23}	n_{24}
Mature	n_{31}	n_{32}	n_{33}	n_{34}
Old	n_{41}	n_{42}	n_{43}	n_{44}

\+

	2/3/25	3	3/4	4	12
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}

\+

	2/3/25	3	3/4	4	12
Mature	n_{31}	n_{32}	n_{13}	n_{34}	n_{35}
Old	n_{41}	n_{42}	n_{23}	n_{44}	n_{45}

\+

	2/3/25	3	3/4	4	12
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}

\+

Table A.3 Continued

	2/3/25	3	3/4	4	12	13
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}

+

	2/3/25	3	3/4	4	12	13
Mature	n_{31}	n_{32}	n_{13}	n_{34}	n_{35}	n_{36}
Old	n_{41}	n_{42}	n_{23}	n_{44}	n_{45}	n_{46}

+

	2/3/25	3	3/4	4	12	13
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}

+

	4/13/16	16
Sapling	n_{17}	n_{18}
Young	n_{27}	n_{28}

+

	4/13/16	16
Mature	n_{37}	n_{38}
Old	n_{47}	n_{48}

+

	4/13/16	16
Sapling	n_{17}	n_{18}
Young	n_{27}	n_{28}
Mature	n_{37}	n_{38}
Old	n_{47}	n_{48}

+

	2/3/25	3	3/4	4	12	13	4/13/16	16
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}

+

	2/3/25	3	3/4	4	12	13	4/13/16	16
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}

+

	2/3/25	3	3/4	4	12	13	4/13/16	16
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}

+

	4/11	11
Sapling	n_{19}	n_{110}
Young	n_{29}	n_{210}

+

	4/11	11
Mature	n_{39}	n_{310}
Old	n_{49}	n_{410}

+

	4/11	11
Sapling	n_{19}	n_{110}
Young	n_{29}	n_{210}
Mature	n_{39}	n_{310}
Old	n_{49}	n_{410}

+

Table A.3 Continued

	4/11	11	5
Sapling	n_{19}	n_{110}	n_{111}
Young	n_{29}	n_{210}	n_{211}

+

	4/11	11	5
Mature	n_{39}	n_{310}	n_{311}
Old	n_{49}	n_{410}	n_{411}

+

	4/11	11	5
Sapling	n_{19}	n_{110}	n_{111}
Young	n_{29}	n_{210}	n_{211}
Mature	n_{39}	n_{310}	n_{311}
Old	n_{49}	n_{410}	n_{411}

+

	4/11	11	5	14
Sapling	n_{19}	n_{110}	n_{111}	n_{112}
Young	n_{29}	n_{210}	n_{211}	n_{212}

+

	4/11	11	5	14
Mature	n_{39}	n_{310}	n_{311}	n_{312}
Old	n_{49}	n_{410}	n_{411}	n_{412}

+

	4/11	11	5	14
Sapling	n_{19}	n_{110}	n_{111}	n_{112}
Young	n_{29}	n_{210}	n_{211}	n_{212}
Mature	n_{39}	n_{310}	n_{311}	n_{312}
Old	n_{49}	n_{410}	n_{411}	n_{412}

+

	2/3/25	3	3/4	4	12	13	4/13/16	16	4/11	11	5	14
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}	n_{19}	n_{110}	n_{111}	n_{112}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}	n_{29}	n_{210}	n_{211}	n_{212}

+

	2/3/25	3	3/4	4	12	13	4/13/16	16	4/11	11	5	14
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}	n_{39}	n_{310}	n_{311}	n_{312}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}	n_{49}	n_{410}	n_{411}	n_{412}

+

	2/3/25	3	3/4	4	12	13	4/13/16	16	4/11	11	5	14
Sapling	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}	n_{17}	n_{18}	n_{19}	n_{110}	n_{111}	n_{112}
Young	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}	n_{27}	n_{28}	n_{29}	n_{210}	n_{211}	n_{212}
Mature	n_{31}	n_{32}	n_{33}	n_{34}	n_{35}	n_{36}	n_{37}	n_{38}	n_{39}	n_{310}	n_{311}	n_{312}
Old	n_{41}	n_{42}	n_{43}	n_{44}	n_{45}	n_{46}	n_{47}	n_{48}	n_{49}	n_{410}	n_{411}	n_{412}

Table A.4 Result of chi-square partitioning for vegetation types.

Source	*Chi-square*	*d.f.*	*Significant*
Group1 (mainly with brush and grass communities)			
2/3/25 vs. 3			
sapling vs. young	3.066	1	no
mature vs. old	1.360	1	no
sapling + young vs. mature + old	0.082	1	no
subtotal	4.508	3	no
2/3/25 + 3 vs. 3/4			
sapling vs. young	4.359	1	yes
mature vs. old	0.276	1	no
sapling + young vs. mature + old	0.398	1	no
subtotal	5.033	3	no
2/3/25 + 3 + 3/4 vs. 4			
sapling vs. young	2.139	1	no
mature vs. old	0.515	1	no
sapling + young vs. mature + old	1.122	1	no
subtotal	3.776	3	no
2/3/25 +3 +3/4 + 4 vs. 12			
sapling vs. young	0.003	1	no
mature vs. old	0.796	1	no
sapling + young vs. mature + old	0.054	1	no
subtotal	0.853	3	no
2/3/25 +3 +3/4 + 4 + 12 vs. 13			
sapling vs. young	0.686	1	no
mature vs. old	0.113	1	no
sapling + young vs. mature + old	0.221	1	no
subtotal	1.020	3	no
Total	*15.10*	*15*	*no*
Group2 (with mountain mahogany communities)			
4/13/16 vs. 16			
sapling vs. young	1.674	1	no
mature vs. old	0.432	1	no
sapling + young vs. mature + old	1.839	1	no
Total	*3.94*	*3*	*no*

Table A.4 continued

Source	*Chi-square*	*d.f.*	*Significant*
Group3 (with juniper communities)			
4/11 vs. 11			
sapling vs. young	0.009	1	no
mature vs. old	1.217	1	no
sapling + young vs. mature + old	1.318	1	no
subtotal	2.546	3	no
4/11 + 11 vs. 5			
sapling vs. young	0.001	1	no
mature vs. old	0.646	1	no
sapling + young vs. mature + old	0.623	1	no
subtotal	1.270	3	no
4/11 + 11 + 5 vs. 14			
sapling vs. young	1.632	1	no
mature vs. old	0.871	1	no
sapling + young vs. mature + old	0.003	1	no
subtotal	2.506	3	no
Total	*6.32*	*12*	*no*
Group1 vs. Group2			
sapling vs. young	4.274	1	yes
mature vs. old	0.279	1	no
sapling + young vs. mature + old	0.139	1	no
Total	*4.692*	*3*	*no*
Group1 + Group2 vs. Group3			
sapling vs. young	8.034	1	yes
mature vs. old	0.407	1	no
sapling + young vs. mature + old	0.559	1	no
Total	*8.999*	*3*	*yes*
Grant Total	*39.140*	*33*	*no*

*significant level is based on one-tail p-value <= 0.05

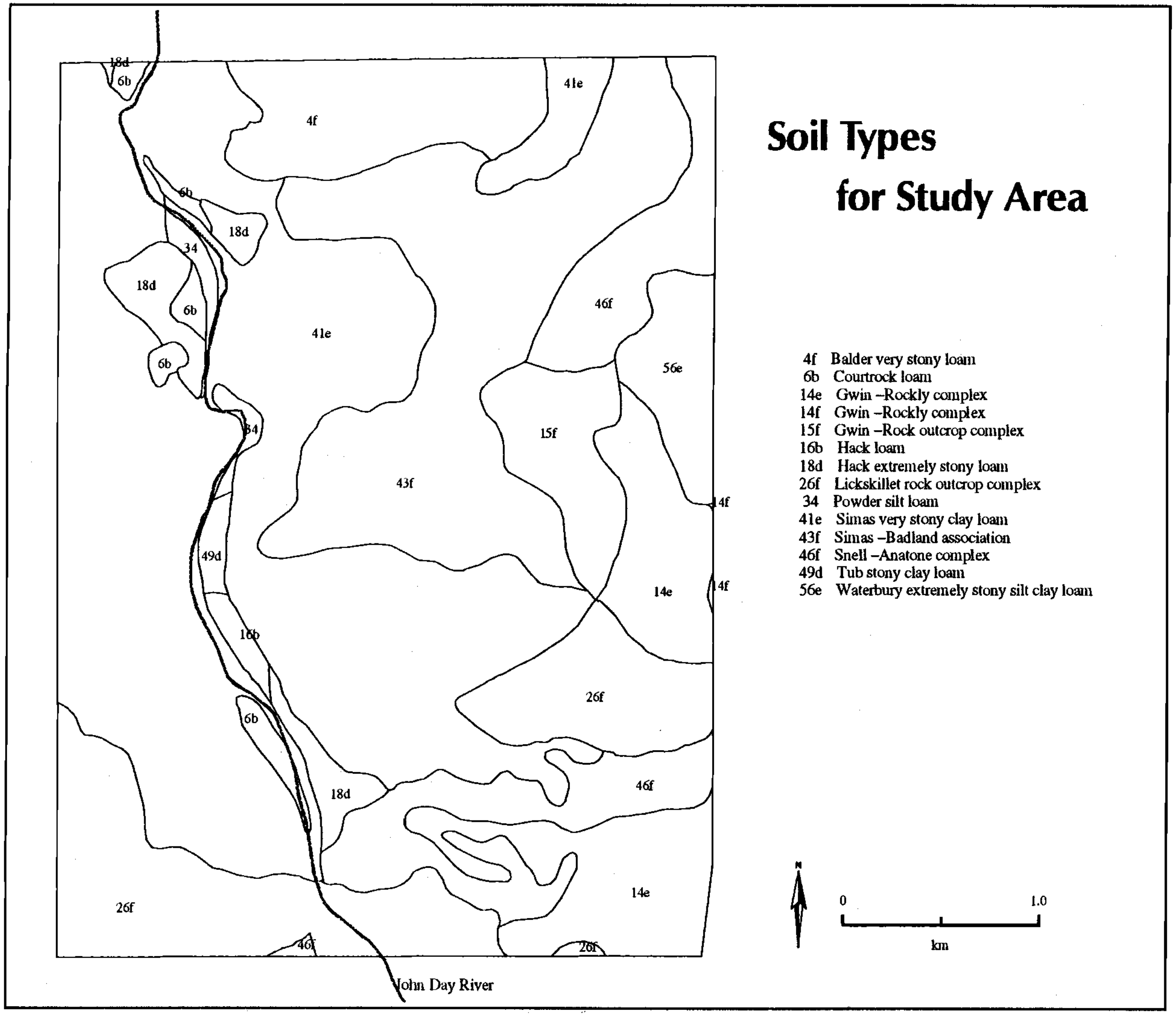

Figure A.1 Soil map of the study area (source: USDA, SCS 1981)

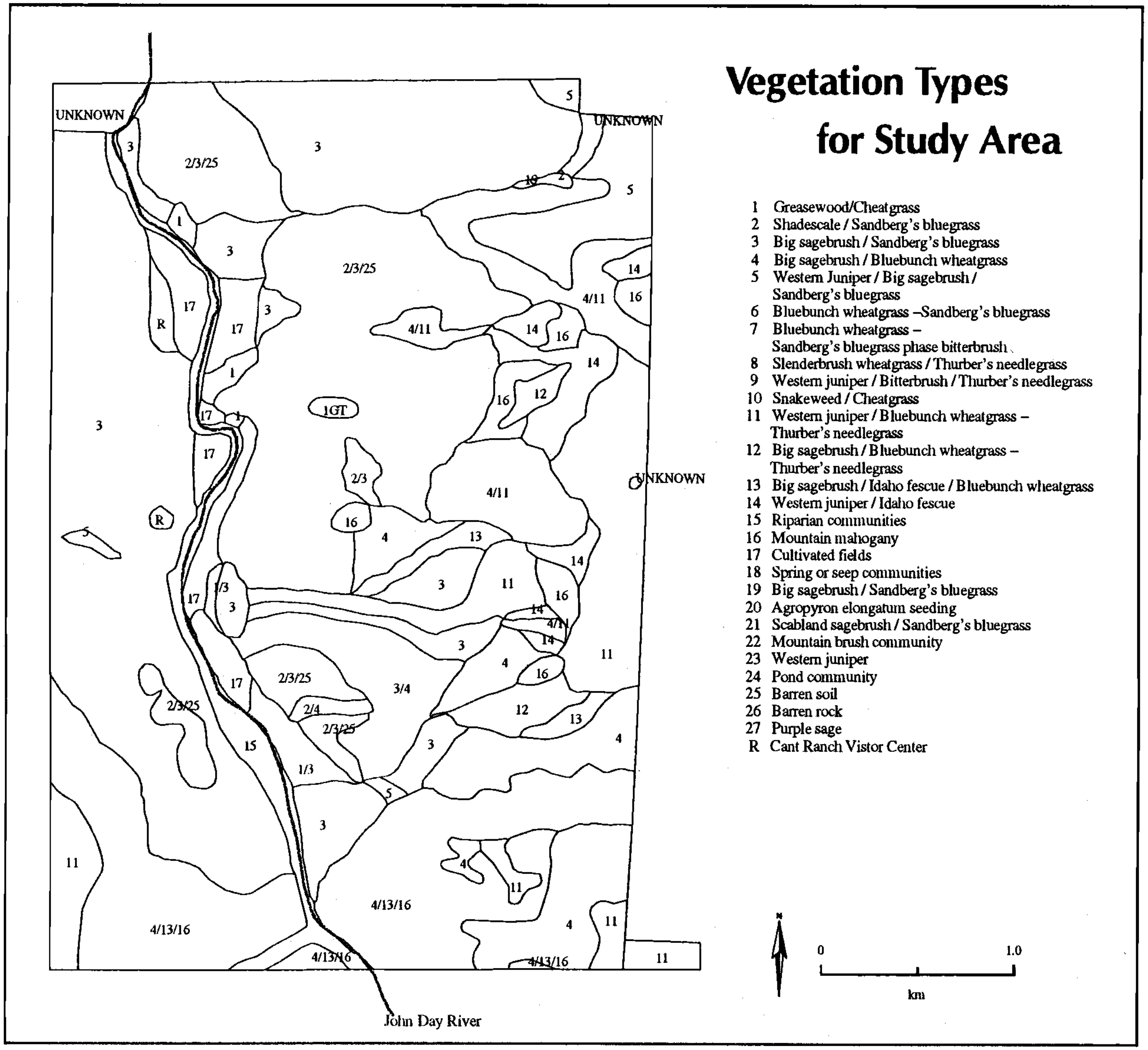

Figure A.2 Vegetation map of the study area (source: Youtie and Winward 1977)