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Western Juniper (*Juniperus occidentalis*) and Invasive Annual Grass Mapping in Eastern Oregon

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ON THE COVER

Juniper encroachment in central Oregon. Photo by Matt Noone.

CITATION

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Western Juniper and Invasive Annual Grass Mapping in Eastern Oregon

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Executive Summary

Significant ecological changes have occurred throughout the arid western rangelands since the arrival of settlers in the late eighteenth century. Western juniper (*Juniperus occidentalis*), a native woodland tree, has expanded its range from fire-sheltered rocky ridges to occupy millions of acres in Oregon, displacing sagebrush and bunchgrass communities. The full potential extent of western juniper in Oregon remains unknown. However it is known that juniper encroachment has had broad ranging negative impacts on overall rangeland health and local economies. Native shrubs and grasslands are often shaded out by juniper, leaving exposed bare soils prone to erosion. Western juniper is believed to use significantly more water than the native shrublands and grasslands, leading to lower stream flows and declines in fish habitat.

Along with juniper expansion, increases in exotic invasive annual weeds such as cheatgrass, medusahead rye and ventenata are occurring throughout eastern Oregon. Both the exotic weeds and juniper increase the frequency and intensity of fires and significantly decrease site productivity. These elements present difficult challenges to rangeland owners and managers.

In 2011, the Institute for Natural Resources – Portland (INR) entered into an agreement with the Natural Resources Conservation Service through the Cooperative Ecosystem Study Unit to assist in evaluation of a targeted watershed restoration area in central Oregon. The primary objective of the agreement was to use remote sensing methodologies and widely available data sets to establish baseline landscape conditions that could be utilized by land managers as a planning tool and a measure of restoration project treatment success.

Products and analysis developed by INR included: 1) A juniper percent canopy cover map for about 20 million acres in eastern Oregon and a juniper canopy cover increase/decrease map for a 17-year time interval between 1994 and 2011; 2) An exploratory analysis examining the feasibility of utilizing historic aerial photos to map historic juniper conditions; 3) A paired watershed analysis in Wheeler county examining outcomes of recent management activities; and 4) An exotic invasive annual map for 4.3 million acres spanning selected weed prioritization areas.

The project was focused on using innovative remote sensing methods to identify the areas with existing juniper and invasive species concentrations. The resulting maps were intended to provide land managers with a preliminary planning tool describing existing baseline conditions across the region to help evaluate the effectiveness of different restoration treatments and identify priority areas for treatments.

Mapping Western Juniper

History of Western Juniper in Oregon

Land use history, fire reduction, climate change and grazing have interacted to provide the means for western juniper (*Juniperus occidentalis*), a species native to the American West, to behave as an exotic invasive species within its home range. Juniper has been expanding into neighboring vegetation communities at a rapid rate for over a century. The expansion began with changing climatic patterns providing extra precipitation to eastern Oregon, allowing juniper to colonize areas where it was not traditionally present (Rowland et al. 2008). A dynamic situation of reduced fires from wildland fire suppression and the cessation of native Americans' frequent traditional burning compounded juniper's expansion. Additionally, the early European settlers brought large numbers of livestock, and the resulting heavy foraging often kept the fuel levels down to low enough levels to further reduce the frequency or spread of wildfires. In some areas, presence of livestock has resulted in an increased sagebrush canopy, creating a more favorable micro environment for juniper seed establishment.

Cowlin et al. (1942) reported in eastern Oregon there are an area of about 420,000 acres of juniper woodland defined as having 10% or more crown cover with an additional 1.2 million acres of savanna with less than 10% crown cover. A Forest Service Inventory in 1999 found this cover had increased to 3.3 million acres of juniper woodland and another 3.2 million acres of juniper savanna. Donnegan et al. (2008) predicted that at the continued rates of expansion, juniper is expected to encroach on 2 million additional acres in the next 40 years.

In the last century, this western juniper expansion has drastically changed the landscape and natural ecosystem functions in eastern Oregon, northeastern California and western Idaho. Although many of the interactions of the juniper invasion are not fully understood, research has indicated an overall deleterious effect upon the hydrological processes and on plant and animal communities. Significant decreases in the water table and stream flow (a single mature juniper will use 25-30 gallons a day from groundwater sources) have been observed (Miller et al 2005). Native shrub steppe and prairie forbs and grasses cannot survive in the shade in juniper woodlands, and as a result juniper cover reduces forage for livestock and wildlife. This often can increase erosion due to the now exposed soils that are easily erodible. Additionally, wildlife species such as sage grouse in the future may be put on the endangered species list due to loss of habitat from sage being out-competed by juniper. The juniper trees also provide birds of prey ideal perches to spot and hunt grouse and other species.

A dynamic set of environmental and cultural conditions has enabled juniper to successfully out-compete native shrubs, grasses and forbs on millions of acres where historically juniper had never grown. The long term implications of this transition are largely unknown. The Forest Service's periodic five-year forest inventories provide valuable information on broad scale changes occurring throughout our nation's forests; unfortunately they do not represent western juniper very well. To date no landscape scale remotely sensed monitoring efforts have been undertaken to evaluate juniper presence in different parts of Oregon. Past studies that have evaluated juniper encroachment have not occurred on the scale necessary for regional planning across multiple land ownerships.

Juniper Mapping Background

Prior to the current juniper products developed by INR for NRCS, no accurate, large scale baseline juniper canopy cover maps were available for land managers to use as a preliminary planning tool. There have been multiple mapping projects (e.g. GAP, LANDFIRE, and ILAP) in which juniper was mapped as a side product, but producing an accurate juniper canopy cover map was not a specific objective of these projects. For this research, a juniper percent canopy cover map was developed for two time periods: 1994 and 2011. These maps were then utilized to create a third juniper product that spatially identified areas with juniper increases and decreases. A hybrid approach utilizing spectral information from Landsat satellite imagery and textural information from high resolution aerial photography was used to model percent juniper canopy cover for over 20 million acres in eastern Oregon.

Traditional methods of remote sensing assume a particular landcover type has a unique signature which can be used to identify the feature across the landscape (Huang et al. 2009) . Mapping juniper is somewhat more complicated because juniper does not necessarily have a unique signature. Juniper woodlands are typically characterized by canopy covers less than 30%. As a result, the majority of the signature a medium resolution satellite sensor would be recording in a woodland for a single pixel would be a combination of grasses, shrubs, bare ground and rock. The spectral signature of juniper is essentially overwhelmed by the noise created by the other elements being reflected, which in an eastern Oregon landscape varies greatly depending upon seasonality, rainfall, elevation , soils and aspect. In order to overcome juniper's weak spectral signature at low densities, aerial photography textures metrics were created throughout the study area. Several studies have incorporated aerial photography in a similar means to mapping juniper, but these projects often focused on smaller study areas or on specific watersheds primarily due to the challenges of processing, manipulating and storing high resolution data. Sankey and Germino (2008) found Landsat integration with aerial photography to be an effective means to evaluate and measure juniper encroachment over a 20 year span in a 20,000 acre study area in Idaho. In the 20 year period they found juniper encroachment to have expanded 20-30%.

As has been demonstrated in other smaller scale studies, both Landsat satellite imagery and aerial photography can successfully be used and integrated using spectral mixing to detect juniper presence, as well as determine the developmental phase of juniper stands (Davies et al. 2010; Sankey and Germino 2008). Knowing the developmental phase (determined through density) is important because management strategies and effectiveness of restoration treatments differ among developmental phase (Davies et al. 2010). Density information will provide a cost effective and efficient method to inform and prioritize management decisions regarding removal and control of encroaching juniper stands.

Study Area

The study area for the NRCS juniper mapping portion of the project spans about 21 million acres across eastern Oregon. This study area covers portions of 14 counties in Oregon, and all of Wheeler and Crook counties. The final study area is the combined extent of three Landsat scenes, which were selected to cover key areas where juniper management activities occurs (Figure 1).

The study area is characterized as "high desert", where the majority of the landscape is between 1400 m and 1700 m elevation (Figure 2) and receives less than an average of 15" of precipitation a year (Figure 3). The study area covers a large portion of the Blue Mountains, and all of the Steens mountain range. The southern portion of the study area is considered part of the Northern Great Basin and is known to be a key habitat area for the greater sage grouse (*Centrocercus urophasianus*).

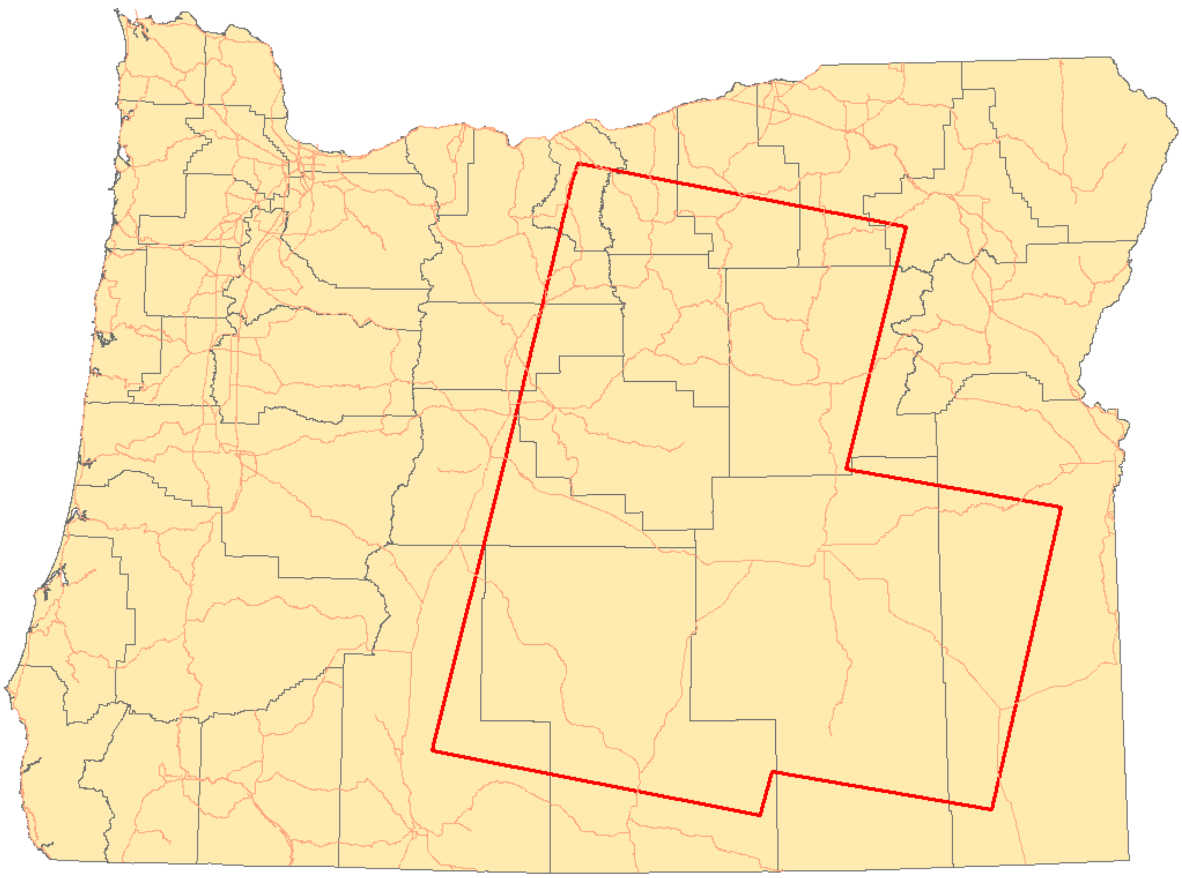

FIGURE 1. JUNIPER MAPPING STUDY AREA OUTLINED BY RED POLYGON.

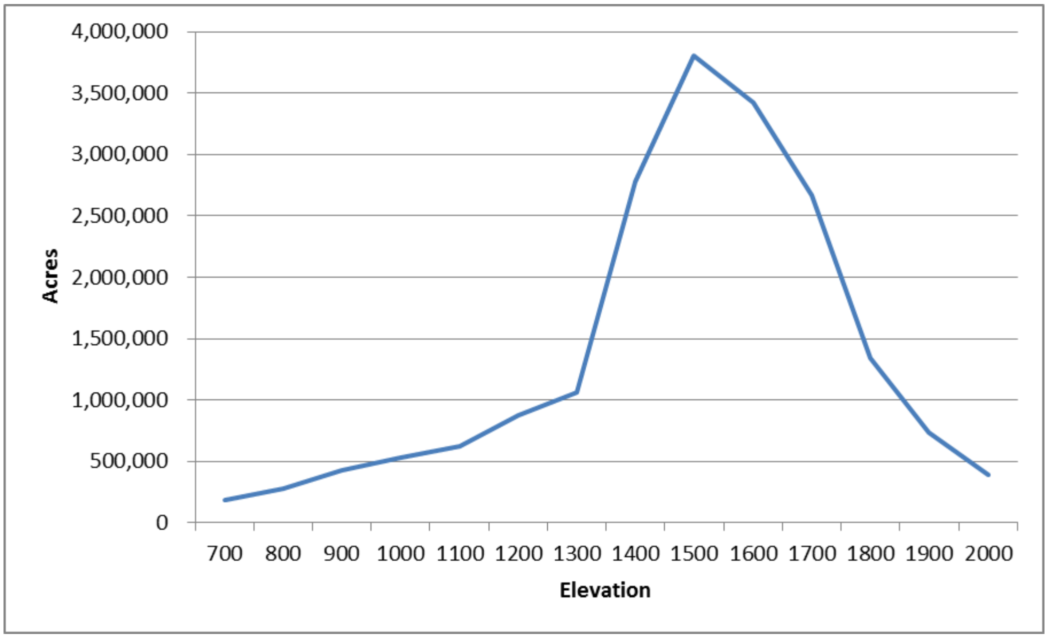

FIGURE 2. STUDY AREA ACRES BY ELEVATION ZONES IN METERS.

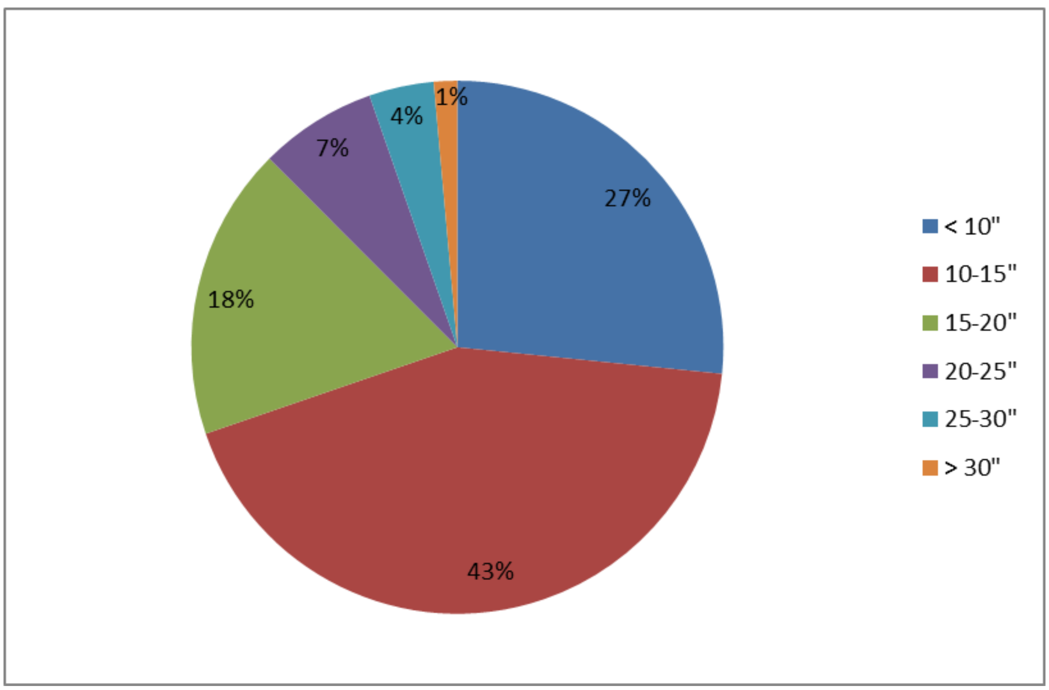

FIGURE 3. PERCENT OF TOTAL STUDY AREA ACRES BY PRECIPITATION ZONE.

Methodology

ERDAS Imagine was used for processing imagery and data layers while ArcGIS was primarily used to view and display the data. Python and batch processing were frequently used to execute bulk image processes. All map and data layers produced are in the common projection of NAD 83, UTM Zone 11N. The user-sourced, statistical software package R (http://www.r-project.org/) was used to model the predictive canopy covers. Precipitation data was obtained from PRISM and resampled to 30m resolution.

Imagery Acquisition and Preprocessing

National Agricultural Inventory Program (NAIP) aerial photography was flown in the summer of 2011 at 1-meter resolution with four spectral bands (red, green, blue, and infrared). The imagery was obtained as uncompressed quarter quad TIFF tiles from NRCS. Although the study area is primarily in UTM zone 11, there are portions of the study area lying in UTM zone 10. All TIFF files within the study area were reprojected if necessary into the common projection of UTM zone 11. TIFF files were then mosaicked in ERDAS Imagine with batch command processes.

Aerial photography used to create the 1994 juniper map was limited to imagery that was already spatially referenced and orthorectified. Statewide aerial photos were collected in Oregon many times prior to 1994, but unfortunately these have not yet been digitized or spatially referenced. Georeferencing earlier image dates was a possibility, but was unfeasible given the time frame of the project. The earliest referenced imagery available was flown in the 1994-1995 and 2000-2001 summer seasons. These black and white photos were flown at a 1:40,000 scale under the National Aerial Photography Program (NAPP). Although the 2000-2001 imagery was higher quality, the 1994-1995 imagery was used to map juniper to provide a larger time interval (17 years) to measure change. The NAPP aerial photos were digitally orthorectified into quads (DOQs) at 1-meter resolution, and were downloaded from the Oregon Geospatial Enterprise Office (GEO). NAPP imagery was then reprojected to a common projection of NAD 83 UTM Zone 11, and mosaicked.

Since January 2009, the USGS Landsat Satellite archive has been made available for download free of charge. This represented a milestone for remotely sensed monitoring projects and scientists who are no longer limited by the cost of imagery and are now free to expand the scope, scale and temporal depth of studies. The Landsat satellite family has provided the longest continuous recording of earth observation information and is of immense value to scientists all over the world.

The Landsat archive was searched for cloud-free, late summer imagery. Three Landsat 5 scenes for each of the years 1995 and 2011 were downloaded from the USGS GLOVIS website, http://glovis.usgs.gov/ (Table 1). Early summer and spring images were avoided to reduce noise associated with photosynthetically active grasses and shrubs. The Landsat imagery was reprojected to NAD 83, UTM Zone 11N to match other data layers. The Landsat TM images were converted to top-of-atmosphere reflectance values based on the Julian day and solar elevation at the time of image acquisition. A dark-object subtraction was then applied to provide a basic atmospheric correction. A topographic normalization algorithm modified from Twele (2006) was applied to correct for the influence of differential illumination with topographic aspect. Landsat scenes were then mosaicked. There were some unavoidable clouds in the 1995 Landsat imagery northeast of Lakeview.

LiDAR data flown in the Spring of 2011 for the Pine Creek Conservation Area was obtained from the Warm Springs Indian Tribe. This LiDAR data was later utilized to train the juniper predictive canopy cover model.

TABLE 1. LANDSAT SCENES AND IMAGE DATES USED.

Landsat Path/Row	1995 imagery	2011 imagery
44/29	8/21/1995	8/17/2011
44/30	9/21/1995	9/2/2011
43/30	8/30/1995	9/27/2011

Aerial Photography and Landsat TM Predictor Variables

Unbiased change detection between two dates requires comparable data sources to be used for each date. Our change detection and canopy cover modeling process for juniper cover relied only on comparable datasets available from each time period. In order to provide equivalent predictor layers for juniper cover modeling for the two time periods, the 4-band 2011 NAIP was simplified to a single band image by calculating the first principal component, resulting in an image that was comparable to the 1994-1995 black and white DOQ imagery. A principle component transforms a number of possibly correlated variables into a simpler single variable set and maintains the majority of the original information. A variety of high resolution texture metrics developed at INR, including Normalized Difference Texture Index (NDTI) and Maximum-Normalized Standard Deviation (MNSDT) were produced from the 1994-1995 DOQ and 2011 NAIP first principal components (see Nielsen et al. in press). NDTI metrics can be computed for any combination of two resolutions, and based on any single metric extractable from the imagery.

To normalize systematic texture shifts across photos due to view angle or topographic shading or between photos due to time of day or changing atmospheric conditions, we computed texture at multiple resolutions by degrading the raw imagery to varying degrees before computing a moving window variance. Variances computed at different resolutions (within a certain degree of similarity) are similarly affected by artifacts, but each pulls out distinct resolution-dependent information. Texture is computed at multiple resolutions and then combined in a pairwise fashion, with the resolution difference between the two typically being a factor of 2.5 to 3. This is the range where artifacts such as shadows mostly disappear but a significant amount of difference in the landcover-dependent information remains. This difference that remains is due to objects in the image occurring at a spatial scale intermediate between the two resolutions used; or because photo artifacts impact textures similarly across a range of pixel resolutions causing the artifacts to be canceled out by the combined metrics. NDTI pairs are combined analogously to the NDVI formula (Equation 1).

Initial experiments using a regular normal Standard Deviation texture or Gray Level Co-occurrence Matrix (GLCM) texture found that traditional texture metrics were impacted as much by variations in view angle and other contrast artifacts as by major changes in vegetation structure, whereas NDTI was generally immune to those artifacts. A particular combination of variances was optimized to identify changes in structure that occurred within a resolution range between the variances calculated at two different resolutions. Other resolution combinations would be more appropriate for mapping various vegetation types. With higher resolution half-meter imagery, we could contrast NDTI at 0.5m and 1.5m to try to pick up shrubs or the smallest junipers, although utilization of higher resolution imagery would significantly increase processing times and storage requirements.

The mapping process, although based on the 1-meter fine-scale information from air photos, was used at a more machine-friendly resolution of 30-meters. The fine-scale imagery was aggregated to 30-meter resolution using simple means of the metrics. Several vegetation indices were calculated from each of the Landsat mosaic images which aid in identifying landcover characteristics that may not be identifiable in the raw spectral bands of Landsat TM (Coppin and Bauer 1994). These indices were calculated in ERDAS imagine and included Normalized Differenced Vegetation Index (NDVI), Normalized Differenced Moisture Index (NDMI; Jin and Sader 2005) and Tasseled Cap Wetness (TCW) (Crist and Cicone 1984).

$$\frac{(\text{Focal SD at 1m} - \text{Focal SD at 3m})}{(\text{Focal SD at 1m} + \text{Focal SD at 3m})} = \textbf{NDTI 1m, 3m} \qquad \frac{(\text{Focal SD at 2m} - \text{Focal SD at 6m})}{(\text{Focal SD at 2m} + \text{Focal SD at 6m})} = \textbf{NDTI 2m, 6m}$$

$$\frac{(\text{Focal SD at 3m} - \text{Focal SD at 9m})}{(\text{Focal SD at 3m} + \text{Focal SD at 9m})} = \textbf{NDTI 3m, 9m} \qquad \frac{(\text{Focal SD at 6m} - \text{Focal SD at 15m})}{(\text{Focal SD at 6m} + \text{Focal SD at 15m})} = \textbf{NDTI 6m, 15m}$$

$$\frac{(\text{Global mean}}{\text{Focal max})} \times \text{Focal SD} = \textbf{SDNM}$$

EQUATION 1. NORMALIZED DIFFERENCED TEXTURE INDEX, AND STANDARD DEVIATION NORMALIZED BY LOCAL MAXIMUM FORMULAS.

LiDAR Training Data

Watershed Sciences collected LiDAR data in May 2011 for the Pine Creek Conservation Area and adjacent Bureau of Land Management (BLM) and National Park Service (NPS) lands and private inholdings. The original 3-dimensional point cloud dataset was gridded to 3-foot resolution bare earth and highest hit elevation rasters. INR performed a variety of quality control steps on the Watershed Sciences deliverables, including removing the powerlines as well as artifacts in the highest hit raster that occurred on very steep slopes in which cliffs were attributed as tall vegetation. In addition, a riparian area mask was produced to exclude hardwood riparian areas from being a potential juniper training source for juniper. The quality control process resulted in many very small areas of missing data, which were unavailable for use in training juniper cover models. In all <5% of the LiDAR data was excluded as a potential training source. The highest hit and bare earth elevation grids were then differenced to produce a vegetation height layer.

Western juniper represented the vast majority of the vegetation over seven feet in height within the LiDAR training data area. The exceptions were only at the highest elevations, where Douglas-fir (*Pseudotsuga menziesii*) and Ponderosa pine (*Pinus ponderosa*) were present in small amounts. Due to the negligible presence of other conifers, these areas were included in the model. All 3-foot resolution LiDAR pixels representing vegetation over seven feet in height and occurring outside the modeled riparian and other masked areas were treated as fully occupied by juniper. A moving window was then used to estimate the mean juniper canopy cover at a 30x30-meter pixel scale. The mean canopy cover value corresponding to the extent of each 30-meter cell in the image-based predictor layer was then extracted, resulting in a highly accurate percent canopy layer at 30-meter resolution. The LiDAR data was indirectly used as a training data source for building models to estimate juniper cover based on air photo and Landsat imagery metrics.

Random Forests Prediction

A random sample of 20,000 points was drawn from the LiDAR-derived canopy cover training data to provide a large amount of well-balanced training data for a RandomForest (RF) regression model that predicted desired attributes, in this case canopy cover. RandomForest modeling has become a popular tool to develop predictive vegetation maps because of its consistent and repeatable manner that utilizes a series of non-parametric computations to predict the likelihood of an object. RF uses a Classification or Regression Tree (CART; Breiman et al 1984, Breiman 2001) methodology to combine multiple replicate tree classifiers, each generated from a randomly selected subsample of the original predictor datasets (see Table 2 for predictor layer list).

The RandomForest prediction is a summary of the predictions of the individual trees. The class predicted by the plurality of the classification trees in the RandomForest is the overall prediction. RF has the capability to utilize both categorical and continuous predictor variables and to incorporate complex relationships between variables (Garzon et al. 2006, Phillips et al. 2006). RF generally uses only base data and imagery, rather than any previously classified data, to remove past classification error or bias. The RF regression model produced a continuous probability estimate of juniper canopy cover across the study area at a 30-meter pixel resolution.

The RandomForest model classification trees based off the 2011 predictor variable values were then saved. A second RandomForest model was run using the comparable 1994/5 predictor variables and the modeled classification trees from the 2011 juniper canopy cover model. Maintaining comparable predictor data sources was essential to enable the classification trees created from the original model to accurately predict canopy cover from the 1994/5 data set.

TABLE 2. PREDICTOR VARIABLES USED IN MODELING JUNIPER.

Predictor Variables	
NAIP principle component	Landsat band 3
NAIP NDVI	Landsat band 4
NDTI Sdnorm	Landsat band 5
NDTI 1m,3m	Landsat band 6
NDTI 2m,6m	Landsat NDMI
NDTI 3m,9m	Landsat NDVI
NDTI 6m,15m	Landsat brightness
Landsat band 1	Landsat wetness
Landsat band 2	Landsat greenness

Mask and Classified Juniper Map Creation

The output raster from the juniper canopy cover model had digital numbers ranging from 1-100. These values represented the predicted percent canopy cover for each pixel. The model predicted canopy cover estimates for the entire study area, including areas where juniper canopy cover estimates were not particularly logical, such as water, conifer (pine and Douglas-fir) forest, agriculture and developed lands. For various reasons, these areas at times resembled textures or the reflectance of juniper and were therefore modeled as juniper. A mask was created to eliminate these areas where juniper would not be present.

Numerous large fires have occurred throughout the forested areas between the two mapping time periods. To prevent these burned areas in forest lands from being mapped as juniper or juniper change, a mask was created for both of the mapping time periods. Similarly, a wetland/agricultural land mask was created from the 2011 imagery. This wetland/agricultural class was also used in the 1994/5 mask because the multispectral and color-infrared (CIR) band from the 2011 NAIP had a significant advantage over black and white imagery for mapping these areas of high photosynthetic activity.

To create the masks, training points were created via photo interpretation. Around one hundred training points were created for each mask class to be mapped: water, agriculture, wetlands, and conifer forest. Using the same predictor variables as the juniper canopy cover mapping model, a RandomForests model was run in classification mode. A 3x3 focal majority filter was then applied the masks to eliminate scattered pixels and smooth the data. Several additional landcover classes (barren, developed, and agriculture) were taken from the National Land Cover Dataset (NLCD) and burned into the mask. For data display and presentation purposes, western juniper canopy cover was binned into 5% increments from 5% to 50% canopy cover. Mask classes were then burned into the binned juniper classes. Final map classes, class descriptions and class source can be seen in Table 3. Due to shrubs and geological variation that created textures that can resemble juniper, the binned juniper class 0-4% cover was re-labeled as the non-juniper class. Although the model predictions were generally accurate, it was not expected that the model would be able to differentiate these extremely low cover areas.

TABLE 3. LANDCOVER CLASS DESCRIPTIONS AND SOURCE.

Class	Description
Water	River/pond/lake bodies of water
Agriculture	Agricultural areas burnt in from NLCD
Wetland	Areas of high infrared reflectance, lush vegetation, riparian areas.
Forest	Modeled areas of deciduous or (non-juniper) coniferous trees
Sagebrush/Grasslands	Annuals, shrubs, sagebrush or grasslands
1-10% Juniper Canopy Cover	Modeled juniper class
10-15% Juniper Canopy Cover	Modeled juniper class
15-20% Juniper Canopy Cover	Modeled juniper class
20-25% Juniper Canopy Cover	Modeled juniper class
25-30% Juniper Canopy Cover	Modeled juniper class
30-35% Juniper Canopy Cover	Modeled juniper class
35-40% Juniper Canopy Cover	Modeled juniper class
>40 % Juniper Canopy Cover	Modeled juniper class

Juniper Change Map

A map identifying and quantifying juniper canopy cover change between the two time periods was created by differencing the independent continuous canopy cover maps from the two time periods. To eliminate exaggerated commission errors, changes in canopy cover of less than 10% between the two time periods were ignored. Findings from the accuracy assessment supported this decision. In general juniper canopy was only accurate at a presence/absence level, or when +/- 10% canopy cover was considered an acceptable level of certainty. The juniper change map has three classes: juniper increase (>10% increase), juniper decrease (>10% decrease), and no change (<10% change). Areas within the conifer forest mask for both mapping periods were not mapped as change. The specific causal factors associated with areas mapped as juniper decrease or increase were not investigated due to a lack of information available in the imagery to determine the change vector.

Canopy Cover Accuracy Assessment

To be able to utilize a map in an appropriate way its strengths and weakness must be quantified and evaluated. To do this, we assessed the accuracy by generating stratified random points (about 1450) throughout the map. Each point was buffered to a $90m^2$ block. The resulting polygons were used as sampling points for the accuracy assessment.

The Remote Sensing Applications Center (RSAC) has developed an aArcMap extension called Digital Mylar (http://www.fs.fed.us/eng/rsac/digitalmylar/) that provides templates of various canopy covers of varying crown diameters over a selected area that can be overlaid on digital aerial photography to provide a frame of reference to assist with canopy cover estimates (via photo interpretation) for a particular polygon (see Figure 4). A trained image interpreter familiar with the eastern Oregon landscape then assigned juniper percent canopy cover estimate for each of the polygons for the two time periods. The canopy cover values assigned to the polygons ranged in 10% increments.

Bias in the accuracy assessment is minimized by having the image interpreter assign canopy cover estimates “blind” or unknowing of what the mapped classes are.

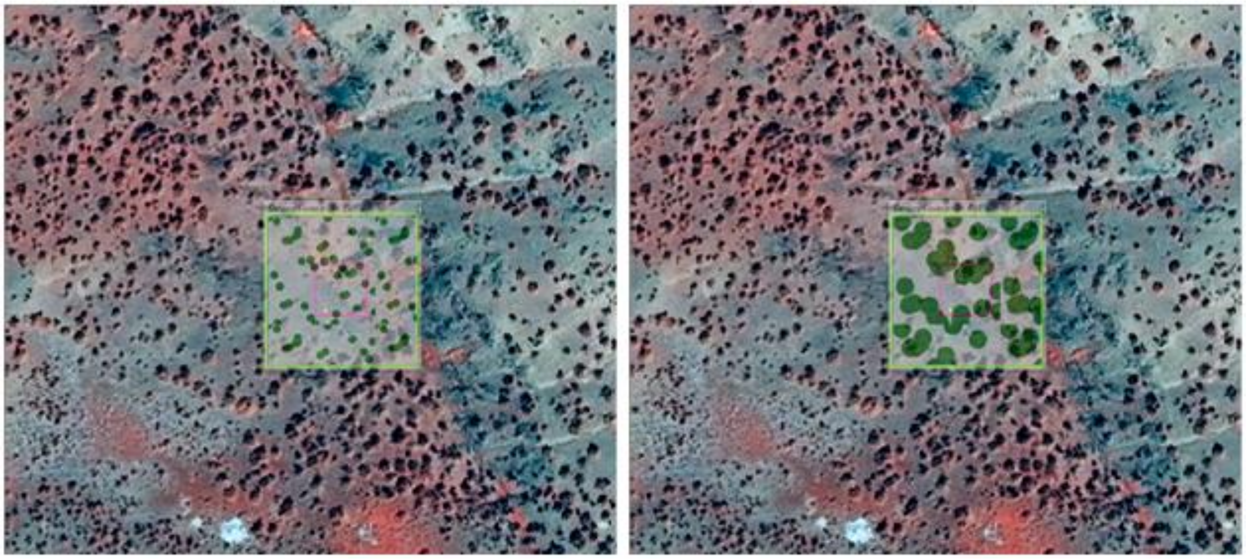

Figure 4. 90m^2 polygons used for canopy cover photo interpretation with Digital Mylar canopy cover templates overlaid on aerial photos. The left image shows a 10-20% canopy cover with small crown diameter trees while the right image shows a 40-50% canopy cover with trees of a larger crown diameter.

The Digital Mylar templates used varied depending on the woodland structure and cover of the canopy. The main template class used to determine cover was the pole (small crown diameter) template, which often represented the structure and spacing of the juniper woodlands better than any of the other crown classes. The 1994/5 imagery was most useful when making calls for covers of 45% canopy cover or less. At higher canopy covers, the greater presence of shadows made it difficult to determine appropriate cover values. Both the infrared and true color 2011 NAIP helped determine whether a juniper was dead or living. All black objects that appeared to be trees in the 1994 DOQ were generally assumed to be alive.

A zonal statistics function using the polygons was run on the continuous juniper canopy cover raster that extracted the mean canopy cover value from the nine 30m pixels within each polygon. The mean canopy cover was then rounded to the nearest canopy cover increment class. The rounded canopy cover from the raster was compared with the canopy cover estimate of the aerial photography determined by the image interpreter. The results from the comparison were then put into an error matrix. Accuracy statistics were calculated that evaluated canopy cover classes individually and as a whole.

Juniper Change Accuracy Assessment

The juniper change map's accuracy was assessed in a similar manner to the canopy cover map. Randomly generated 90m by 90m polygons (the equivalent of nine 30m pixels) were created and stratified by the three change map classes: >10% increase, >10% increase and no change (<10% change). A technician cycled through each plot, and by examining imagery from the two different time periods made a decision of the direction of change or no change. In total 1049 plots were photo interpreted for the change map assessment. Although the accuracy assessment was only looking at canopy cover changes greater than 10%, extra information was recorded in the photo interpretation that provided details about the plot or image quality. These notes could then be used to filter plots where image quality was an issue.

The juniper change canopy cover calls were stratified into 5 cover change classes as follows:

0- 0% cover change
1- 1-10% cover change
2- >10-20%
3- >20-50%
4- >50%

The interpreted polygons were then compared against the map. The 0% and 1-10% canopy cover change class were considered as no change in the error matrix.

High density regeneration following stand replacement fires were difficult to categorize into a cover change class; these estimates were made as well as possible. Shadows and blurriness in the 1994 DOQ made determining some polygons' change direction difficult, especially in the increase or no change categories as not all juniper cover could be accurately interpreted with the shadow effects. It was noted when these situations occurred and caused doubt in the estimate. When image quality from either time period limited the photo interpreter's confidence in the direction of the change, the plots were excluded from the error matrix.

Results

Canopy Cover Accuracy Assessment

The error matrix revealed the sources of error and the reliability of individual map classes in the landcover map. The statistics included the overall agreement, representing the correctly classified interpretation points divided by the total number of interpretation points. They also included the omission error related to the producer's agreement, and commission error related to the user's agreement. Commission error relates to when a particular map class is over-mapped while omission represents the likelihood a class is under mapped (Equation 2) (Congalton and Green, 1999).

EQUATION 2. EQUATIONS USED TO CALCULATE USER'S, PRODUCER'S AND OVERALL ACCURACIES FOR MAPS.

Equation A.1. Overall agreement

$$= \frac{\sum_{i=1}^{k} n_{ii}}{n} \quad \text{where } n_{ii} = \text{the points correctly classified}$$

Equation A.2. Producer's agreement

$$= \frac{n_{jj}}{n_{(+j)}} \quad \text{where } n_{jj} = \text{value in diagonal and } n_{+j} = \text{column total}$$

Equation A.3. User's agreement

$$= \frac{n_{ii}}{n_{(i+)}} \quad \text{where } n_{ii} = \text{value in diagonal and } n_{+i} = \text{row total}$$

Traditionally, thematic landcover map classes were assumed to be mutually exclusive and exahustive. However, often objects that are being classified tend to change gradually in their compotisition and occur at a continuem. Due to this continuem of variation many, vegetation mapping projects utilize what is called a fuzzy accuracy assessment where increased flexibility is allowed for the treatment of map classes in regard to accuracy and allows for the increased ambiguity with particular classes. With fuzzy accuracy, landcover classes can be considered as a partial members of a class (Woodcock and Gopal, 2010).With the juniper canopy cover map it was decided that +/- 10% canopy cover would be considered in agreement. This fuzzy assessment was used for all map classes except for the 0% canopy cover class because it was vital to know how well juniper presence and absence is mapped. Overall the fuzzy map accuracy for the 2011 canopy cover map was 88%, while overall accruacy of the 1994-1995 canopy cover map was 83%. The yellow cells in the error matrix represent areas that were included in the fuzzy accuracy. User's and producer's accuracies were fairly well balanced, meaning the errors of omission and comission were roughly equal (Table 4).

Table 4. Error matrices for 2011 and 1994/5 juniper canopy cover maps. Instances where the mapped and the observed cover (truth) agree run down a diagnoal (green cells) in the matrix. yellow cells represent acceptable agreements (+/-10% from photo interpritation). Accuracy for each class is calculated by dividing the total instances for a particular class by the number of correlating samples.

	2011 Photo Interpreted Cover							
2011 Mapped Cover	**0%**	**10-20%**	**20-30%**	**30-40%**	**>40%**	**Total**	**Producer's Accuracy**	**Fuzzy Accuracy**
0%	403	22	11	7	1	444	91%	91%
10-20%	32	44	74	19	2	171	26%	69%
20-30%	15	32	76	86	32	241	34%	80%
30-40%	3	9	48	102	136	298	34%	96%
>40%	1	1	9	45	234	290	81%	96%
Total	**454**	**108**	**218**	**259**	**405**	1444		
User's Accuracy	89%	41%	35%	39%	58%			
Fuzzy Accuracy	89%	70%	91%	90%	91%			

Overall fuzzy accuracy: 88%

	1994 Photo Interpreted Cover							
1994 Mapped Cover	**0%**	**10-20%**	**20-30%**	**30-40%**	**>40%**	**Total**	**Producer's Accuracy**	**Fuzzy Accuracy**
0%	424	36	26	8	9	503	84%	84%
10-20%	22	51	98	43	13	227	22%	66%
20-30%	2	12	64	123	79	280	22%	71%
30-40%	6	6	19	60	184	275	22%	96%
>40%		3	11	25	120	159	75%	91%
Total	**454**	**108**	**218**	**259**	**405**	1444		
User's Accuracy	93%	47%	29%	23%	30%			
Fuzzy Accuracy	93%	58%	83%	80%	75%			

Overall fuzzy accuracy: 82%

Juniper Change Accuracy Assessment

The juniper change map had an overall accuracy of 73% which was less accurate than the juniper canopy cover maps. The overall accuracy was impacted by the very low user's accuracy for the juniper increase class (17%). The user's and producer's accuracies for the juniper decrease and no change classes were all >74% (Table 5).

TABLE 5. ERROR MATRIX FOR THE JUNIPER CHANGE MAP.

	Photo Interpretation				
Mapped	**No Change**	**Increase**	**Decrease**	**Total**	
No Change	**559**	19	59	**637**	88%
Increase	142	**29**	2	**173**	17%
Decrease	56	2	**181**	**239**	76%
Total	**757**	**50**	**242**	**1049**	
	74%	58%	75%	Overall Accuracy: 73%	

Juniper Canopy Cover Map, 1994 and 2011

In 2011, 3,198,363 acres of juniper were mapped throughout the total study area, equal to about 17% cover. Compared to the 1994/5 time period this amounted to an overall decrease of juniper canopy cover of 118,515 acres, or a 4% decrease in total cover. During the 17 study period, juniper acreage decreased by 10% on private lands but increased by 2% on federal lands (Figure 5). Similar amounts of juniper are distributed on federal and private lands, however in the study area there is nearly twice the amount of acres that are federally owned (Table 6). Much of the federal land is Forest Service land where due to its shade intolerance juniper is not able to compete with the mixed conifer forest species, yet juniper is increasing on federal lands and decreasing on private lands.

It appears that decreases in juniper have occurred uniformly across the landscape, whereas juniper increases have occurred primarily between 800-1200m elevation (Figure 6). At around 1500m elevation extensive juniper stands switch over to conifer forests. Although juniper peaks in distribution at 1500m it should be noted that overall forested acres within the study area are also greatest at 1500m elevation (Figure 6). In the other elevation zones, there were no significant differences in juniper mapped between the two time periods. In addition to looking at where juniper was occurring in respect to elevation, where juniper was occurring in regards to annual precipitation was examined. Twice as much juniper was mapped in the 10-15" precipitation zone than the next closest precipitation zones of <10" or 15-10". As precipitation increases above 10-15", juniper acres rapidly decrease due to their shade intolerance and rapidly increasing dominance of conifers (Figure 7).

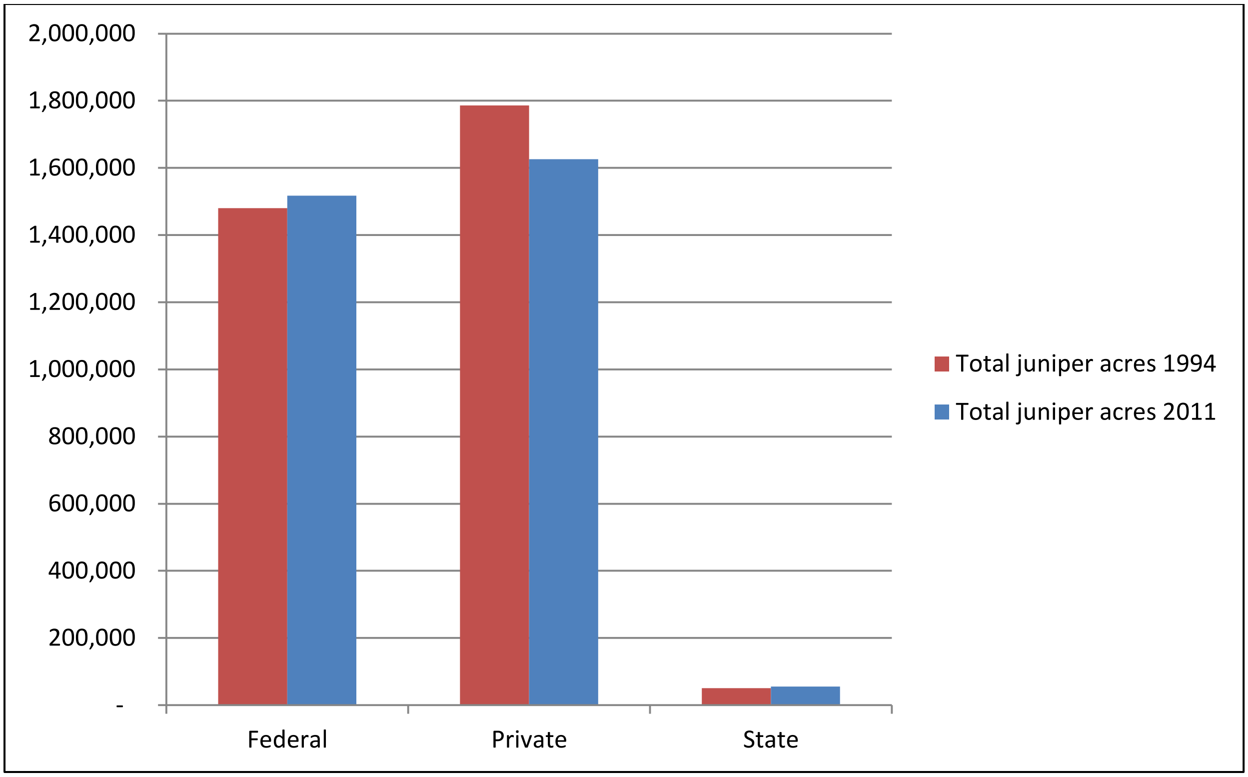

Figure 5. Total juniper acres by juniper landowner class in 2011 and 1994 and 2011.

Table 6. Total juniper acres by juniper landowner class.

	Federal	Private	State	Total Acres
Total acres 2011	12,419,465	7,427,839	533,301	20,380,605
Total juniper acres 2011	1,517,309	1,625,804	55,251	3,198,363
Total juniper acres 1994	1,480,007	1,786,340	50,531	3,316,878
Decreased acres	(37,302)	160,536	(4,720)	118,515
Percent decrease	-2%	10%	-9%	4%

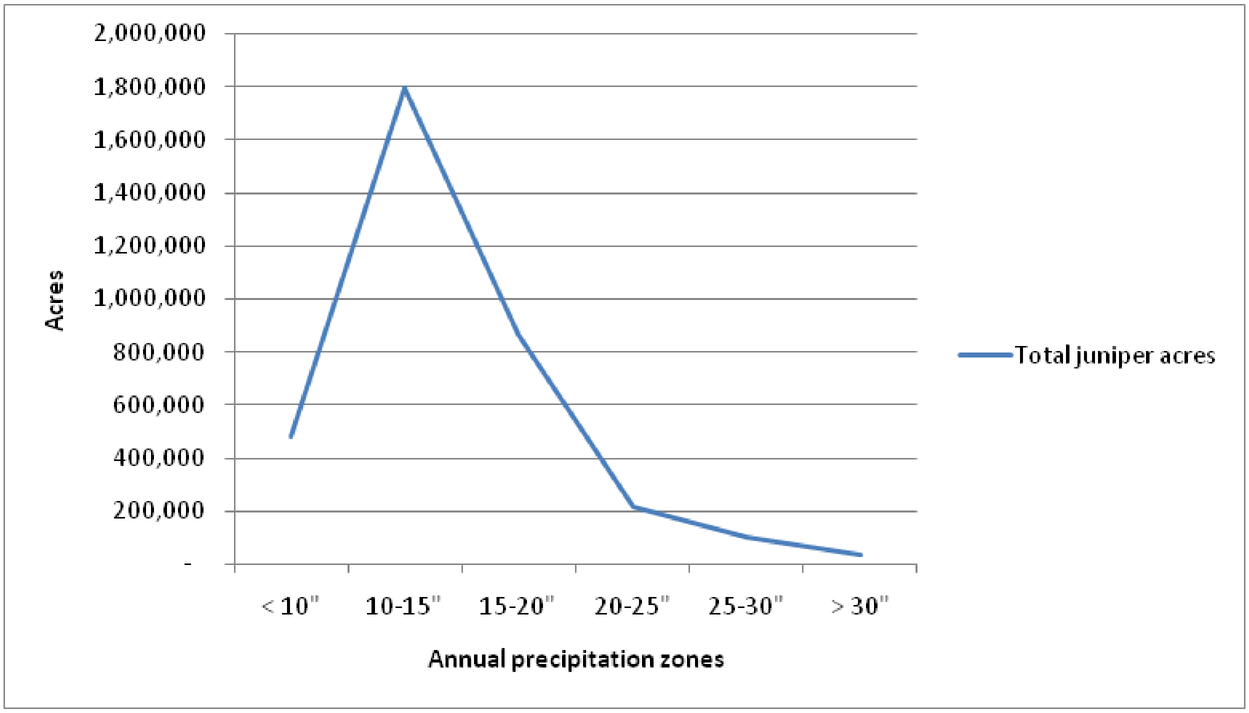

Figure 6. Acres of juniper in 2011 by annual precipitation zone.

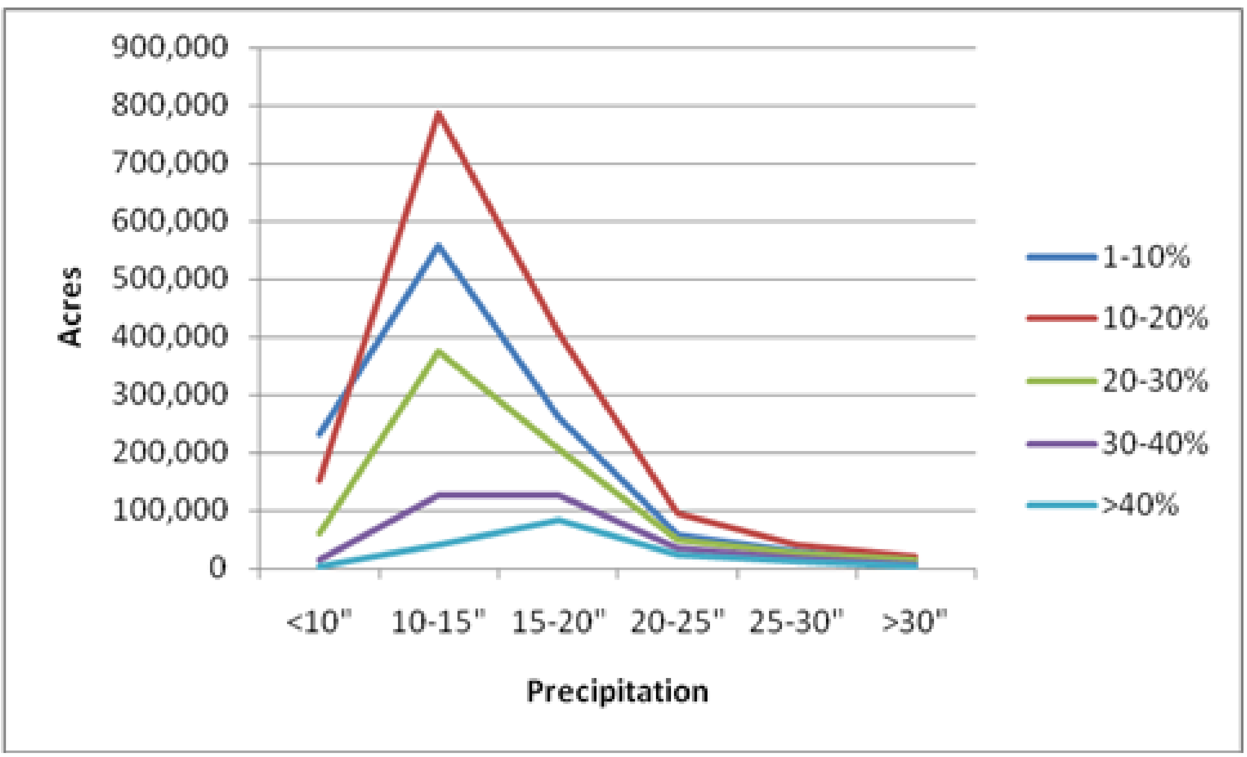

Figure 7. Juniper canopy cover by precipitation zone.

The acreage of juniper mapped in the study area was compared with juniper mapped by the 1990 Gap Analysis Project (GAP) and H.J. Andrews historic juniper map of 1936. In the study area the 2011 juniper map includes 1.5 million more acres of juniper than the GAP map, and 2.3 million more acres of juniper than the H.J. Andrews map (Table 7).

TABLE 7. ACRES OF JUNIPER MAPPED IN STUDY AREA IN COMPARISON TO GAP AND HJ ANDREWS HISTORIC JUNIPER MAPS.

	Total acres mapped	Also mapped in NRCS
HJA	1,211,091	756,599
GAP	2,050,609	1,304,818
NRCS map	3,198,878	

Juniper Change Map

A total of 45,000 acres within the study area were mapped as juniper that increased by >10% canopy cover, and 167,000 acres were mapped where juniper canopy cover decreased by >10% canopy cover. The majority of juniper increase occurred at elevations between 1500m and 1600m, while the >10% juniper decrease had a bimodal distribution with peaks at 1500m and 800m (Figure 8). The majority of juniper increase and decrease occurred in areas that received between 10-15" of precipitation, which is also the precipitation range where the majority of current juniper exists (Figure 9). Of possible interest, Of the 167,000 acres mapped as greater than 10% juniper decrease, 36,000 acres (or 3%) were also mapped as juniper in the H.J. Andrews 1936 map. Although juniper distribution comparisons with the H.J. Andrews historic map are interesting to consider, no firm conclusions can be made when comparing the historic map to the current data due to inherent differences in the ways the datasets were created.

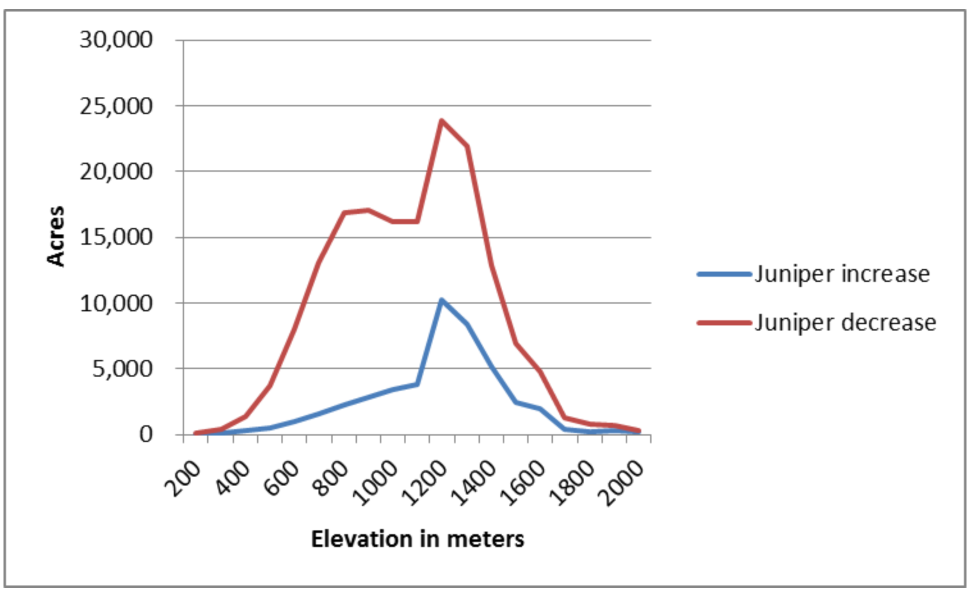

FIGURE 8. JUNIPER > 10% JUNIPER INCREASE AND DECREASE BY ELEVATION BAND

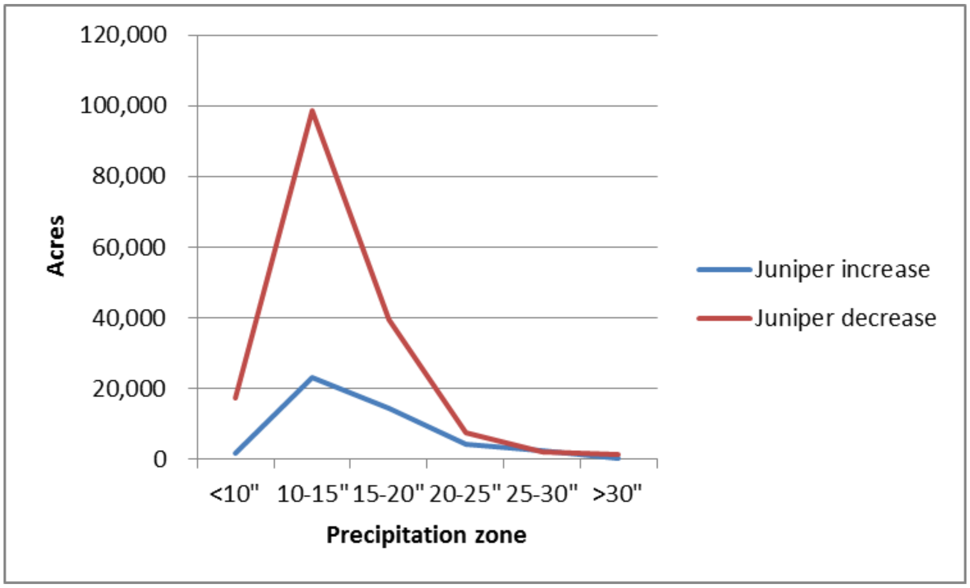

FIGURE 9. ACRES OF JUNIPER INCREASES AND DECREASES BETWEEN 1994 AND 2011.

Discussion and Conclusions

Accuracy Assessment

While the term accuracy assessment is frequently used, it may be more conducive think of the accuracy assessment as more of an agreement assessment. The term accuracy assessment assumes that the true canopy cover for a 90 by 90 m polygon is actually known. In our case canopy cover was photo interpreted by technicians, and there were inherent limitations to interpreting the exact canopy cover, even with the aid of the Digital Mylar templates. Shadows and image quality were the source of the majority of photo interpretation error. It is also likely that some error can be attributed to potential biases of the photo interpreter.

The error matrix (Table 4) shows an overall trend that juniper is being somewhat consistently mapped at about 10% higher canopy cover than the interpreter had observed, however with the fuzzy accuracy, classes +/- 10% of the photo interpritation are considered to be partial class members and in agreement. The 1-10% juniper classes tended to have the lowest user's and producer's accuracies for both of the time periods. However, it is more critical to be able to map juniper presence and absence, which was accurately mapped. It may have been beneficial to have included additional photo interpreted plots in the 1-10% canopy cover class, which had fewer photo interpretation plots than other classes. Using the fuzzy accuracy assessment approach, the overall accuracy of the 2011 juniper distribution map was 88%.

The fact that the agreement is higher in the more recent 2011 juniper canopy cover map is likely due to the higher quality of the imagery. It was difficult to differentiate between objects and their shadows with the1994/5 black and white DOQ imagery. Additionally the 1994/5 DOQ imagery had several processing issues resulting from the data distributor's resampling techniques. Some of the existing DOQ imagery quads had periodic pixels of no data that were scattered through the imagery. Consistency of the 1994/5 imagery varied greatly with some areas being clean and crisp and other areas being blurry or having cloud cover or haze. The 2011 imagery was generally much more consistent throughout the study area.

Because the juniper models were parameterized using LiDAR data from Pine Creek Conservation Area, it is reasonable to assume that areas within the study area further from Pine Creek may have lower accuracies. Juniper conditions vary throughout its range and it can be assumed that conditions in the Pine Creek area only represent a portion of this variability. In the future this effect could be ameliorated by supplementing the training data with additional LiDAR datasets from other parts of the study area, if available.

Areas mapped as >10% decrease of juniper cover on the change map had a reasonable level of accuracy at about 75%. Change detection in rangelands is a much more difficult task than monitoring changes in forested areas where landscape changes are much more abrupt such as a timber harvest or forest fire. Given the challenges of quantifying subtle changes in a rangeland environment and the issues with photography quality in the 1994/5 imagery, the overall change map accuracy of 73% can be looked at in an acceptable light.

The juniper change map does not represent gradual changes that are occurring throughout the study area, rather it represents where some of the larger impact changes have occurred. Many of the changes in juniper canopy cover that have occurred across the landscape probably represent changes in canopy cover from crown closure within the stand, these subtle changes are frequently less than a 10% change and would not have been mapped as change. Also prescribed and natural fires that occur across the landscape often are not stand replacing, leaving some live junipers behind. Juniper increases were difficult to map because juniper increases happen at a very slow pace and it is rare to observe significant increases over a 17 year time period. The low accuracies of the juniper increase class demonstrate the difficulties in mapping juniper increase over this relatively short time interval. It was not expected to map juniper increases accurately, however despite the low accuracy the class may still be useful for identifying some of the areas of recent juniper expansions.

The 1936 H.J. Andrews juniper map provides a good general distribution of historic juniper during the early twentieth century. However the tools and information available to the Andrews crews in the 1930s made it impossible for them to map isolated patches of juniper, or to map juniper at the resolutions desired by the INR team. There is also no real gauge to measure its accuracy. However it appears that the largest areas dominated by western juniper in 2011 but absent from the 1936 map occur in Wheeler and Crook counties, where most of the juniper is fairly young and still in low stand densities where it is codominant with other vegetation. Also, somewhat surprisingly, 36,000 acres mapped as juniper in 1936 were mapped as >10% juniper decrease in the 2011 change map. Given the fact that fires occur infrequently in old growth juniper stands, it is likely that much of this mapped juniper was removed intentionally as part of restoration efforts. This may be related to the fact that early juniper removal efforts did not distinguish between pre- and post- settlement juniper (Miller et al. 2008). Identifying historic juniper habitat locations can help ensure that sound juniper removal activities take place in the appropriate areas, and that historical old growth juniper is protected.

Juniper Distribution

Determining the boundary between juniper woodlands and forest was difficult because the pure juniper stands begin to fade into mixed conifer stands as elevation and precipitation increase. Although juniper can grow at higher elevations its shade intolerance makes it a minor component in these areas. Although no general rule was applied for determining when an area should be mapped as juniper or forest, forested areas have a strong spectral signature (unlike that of juniper) so it was presumed that even a small component of forest would result in a pixel being classified as forest by the model. Therefore it was deduced that juniper pixels in the NRCS maps primarily represent pure stands of juniper, rather than a mixture of other conifers such as white fir, ponderosa and lodgepole pine. Mapping the areas of mixed juniper and conifer forest would require a different approach.

The total juniper distribution was greatest at the higher elevation zones of its range. Juniper reached its peak distribution at 1500 meters, while at higher elevations its occurrence decreased rapidly due to a shift in climatic gradient that favors other conifer species. This higher elevation decrease agrees with existing literature that documents western juniper ceases to form extensive stands at around 1525 meters in Oregon (Dealy et al. 1978). It should also be noted that the peak of juniper distribution at 1500m elevation coincides with the fact that the majority of the study area acreage also occurs around 1500m elevation. The juniper distribution summarized by annual precipitation shows that there is nearly twice as much juniper acres in the 10-15" precipitation zone than the <10" or the 15-20" precipitation zone. This also corresponds with Driscoll (1964), who states that juniper only forms extensive stands in a narrow precipitation band between 9-14".

Acres of juniper increased on federal and state lands between 1994 and 2011 although the increase was slight. However, acres of juniper decreased significantly (by 10%) on private lands. It is thought that private landowners are removing juniper more quickly than on federal lands. This may be due to economic pressures that encourage private land owners to keep their lands productively viable for livestock and the existence of a successful program of incentives and technical assistance that is provided by various federal and state agencies to remove juniper on private lands.

Figure 10. Western Juniper on the slopes of Pine Creek.

Exploratory Mapping of Historic Juniper Distribution

Introduction and Background

Miller et al. (2005) state that although much has been learned about western juniper biology, ecology and management in the last several decades, a knowledge gap of current inventories and historic juniper populations are limiting the ability to manage juniper on an ecosystem basis. State, federal and private landowner efforts have been in place to restore the landscape to its past condition for 50 years now, and recently restoration efforts have been ramped up to prevent the greater sage grouse from being listed on the endangered species list. Management goals to restore vegetation to a prior state of natural or historic vegetation conditions require baseline information detailing the objectives that managers should aim for. The early treatments to control juniper woodlands in the 1960s often did not differentiate between pre-settlement and post-settlement juniper. Historical distribution information can aid in preserving pre-settlement juniper while identifying areas of recent juniper expansion for potential mitigation.

FIGURE 11. CLASSIC EXAMPLE OF JUNIPER ENCROACHMENT FROM MILLER ET AL. 2005.

As part of the NRCS juniper mapping project an exploratory analysis was done to detect the feasibility and effort required to create historic distribution juniper maps. Suggestions on the appropriate methodology and techniques used to carry out historical mapping in the most time and cost efficient manor are also discussed. Historical aerial photography from 1951 was used to map juniper distribution for a selected study area to form a baseline juniper map. The same methodology discussed in the Mapping Western Juniper section was applied to the historic imagery: this methodology can be applied to essentially any vertical aerial photo that is spatially referenced and flown at comparable scales. In the previous section, the juniper change time interval of 17 years was found to be adequate to map juniper decreases which are often more abrupt than juniper increases. However due to the slow growing nature of juniper in the juvenile stage, a greater time interval would be required to accurately map juniper increases. Through utilization of historical imagery juniper encroachment can be adequately mapped.

The Landsat MSS (80m) satellite archive's temporal depth dates back to 1972. However the juniper mapping work in the preceding section showed that even with the newer and higher resolution Landsat TM (30m) sensor, juniper's spectral signature was insufficient to independently map juniper accurately. The spectral signatures of surrounding vegetation often overwhelm the signal recorded. Higher resolution satellite sensors such as SPOT (10m) may have greater success with mapping juniper, but there is limited temporal availability, and the imagery is often expensive. Additionally, higher resolution sensors typically have scene sizes that are far too small in area to map juniper on a landscape or regional scale.

For these reasons, historic aerial photography remains the most viable option to map juniper distributions from the past. Fortunately, aerial photography provides great temporal depth and is also often available to the public free of charge. Given that juniper encroachment often occurs slowly, and predates satellite imagery availability, aerial photography is an ideal medium through which to measure longer term changes across the landscape (Hudak and Wessman 1998). The main drawback to using historic aerial photos to make vegetation maps is that most historical air photos are not in a digital format. Older aerial photography is usually available only in black and white, meaning that in spite of its high resolution and quality, traditional image classification methods based upon reflectance of objects at various wavelengths are not possible. This leaves only textural information and relationships amongst pixels as the driving factor for classification methods.

Study Area

The study area for the baseline historical juniper map included approximately 150,000 acres in Wheeler County, spanning six 10-digit HUC watersheds: John Day Gulch, Lower Pine Creek, Rhodes Canyon, Rowe Creek and Shawn Canyon. A large portion of the study area consists of conservation lands managed by the National Park Service, the Confederated Tribes of the Warm Spring Indian Reservation, and the Bureau of Land Management. These lands are managed primarily to restore or maintain healthy ecological functions and conditions. The eastern portion of the study area is composed mainly of private lands, with landowners working to restore vegetation and improve forage for livestock. The area had historically been grazed by sheep, and later cattle since it the first European settlers arrived in the late 1800s.

Methods

A detailed search through the aerial photo archive at the University of Oregon Library revealed scattered aerial photo coverage from 1930-1940, although much of the imagery from before 1940 are oblique photos (aerial photos taken from an angle). Oblique imagery is not useful for image classification due to distortion and displacement. Before 1930, aerial photography coverage was almost non-existent. The mid 1940s-1950s was the earliest time period in which almost complete aerial photo coverage of eastern Oregon is available. This imagery is black and white and flown at the 1:20,000 scale by the U.S. Department of Agriculture. Additional widespread photo coverage of eastern Oregon exists at various scales for multiple time periods after this. Despite aerial photography being a relatively new practice in the 1950s, the quality and consistency of the historic photos is often very good. The problems when working with historical aerial photos are: 1) historic aerial photos are not in a digital format, 2) aerial photos are not spatially referenced, and 3) the footprint of an individual photo is relatively small, often making spatial referencing of the aerial photos very time consuming.

However, we identified a few approaches to reduce the obstacles to working with older aerial photos. For example, traditional aerial photographs have significant forward overlap (about 60%) and lateral overlap (30%) between photos (for stereo viewing), which allowed us to scan every other photo in a flight line while maintaining complete ground coverage (see Figure 12 for flight line example). This cut down scanning time by half. Determining the scanning resolution was an important decision; scanning at too low of a DPI (Dots Per Inch) resulted in the loss of valuable information from the original photographs, while scanning at a too high of a resolution resulted in very large file size rasters that were difficult to store and use. When scanning at high DPIs, there will eventually be a point where no more additional information can be obtained from the photos. For this project, we used a 250 DPI for scanning the imagery; this yielded digital imagery with a ground pixel size of 2m. The final mosaic was resampled to 1m for modeling purposes. The ideal scanning resolution for mapping western juniper with 1:20,000 scale photos would have been 505 DPI, which results in a 1m ground distance resolution (Table 8). This would result in final products with the equivalent resolution as the recently flown digital aerial photography such as NAIP. Mapping smaller scale vegetation such as sagebrush would likely require scanning at higher resolutions depending on the scale of photos.

Additionally, by utilizing Photoshop, a mosaic of up to 20 or possibly more aerial photos can be automatically mosaicked with a tool that is meant for creating panoramic photos called "Photomerge". By creating large mosaics in Photoshop (that are still not spatially referenced), a skilled technician can spatially reference a 20 image mosaic in about the time it would take to reference a single image. Single image referencing is often more difficult due to the potential for lack of quality tie points (features such as road intersections, buildings, some water features and sometimes trees). Images were referenced in ERDAS imagine using 15-25 tie points. The Photoshop Photomerge tool enables making juniper or other historic vegetation type maps feasible by reducing the time that would otherwise be required to spatially reference individual photos.

With a 1:20,000 scale imagery, rough photo estimates for the size of a Landsat scene (8.5 million acres) would require about 3,000 photos. An inch on a photo at this scale is equivalent to about1,666'

(20,000/12”), and a typical aerial photo is often 9” by 9” or about 5,165 acres. Imagery flown at a 1:40,000 scale (1”=3333’) would have a footprint of 20,661 acres. It is likely that at scales much smaller than 1:60,000 mapping success may decrease due to the reduced resolution of the imagery.

Georeferencing photos in batches of about 25 for a project of this scale would require referencing of around 120 images. For scales smaller than 1:20,000 scanning and georeferencing time significantly decreases because photo footprint size increases, although it is unlikely various shrub communities could be differentiated at such a scale. The earliest available small scale photography for the state of Oregon is from the 1960s and 1970s, though utilizing this photography would have decreased the temporal depth of the historic map.

Identical texture metrics from the Mapping Western Juniper section were calculated on the 8 bit black and white 1951 imagery mosaic and the principle component 2011 NAIP. A RandomForest regression model was run on the 2011 imagery using a LiDAR derived canopy cover map as training data. Decision trees from the 2011 model were saved and then applied to the 1951 imagery. Predictor variables and resolutions of the 2011 and 1951 imagery were comparable to provide a consistent data source for decision trees to make appropriate canopy cover predictions.

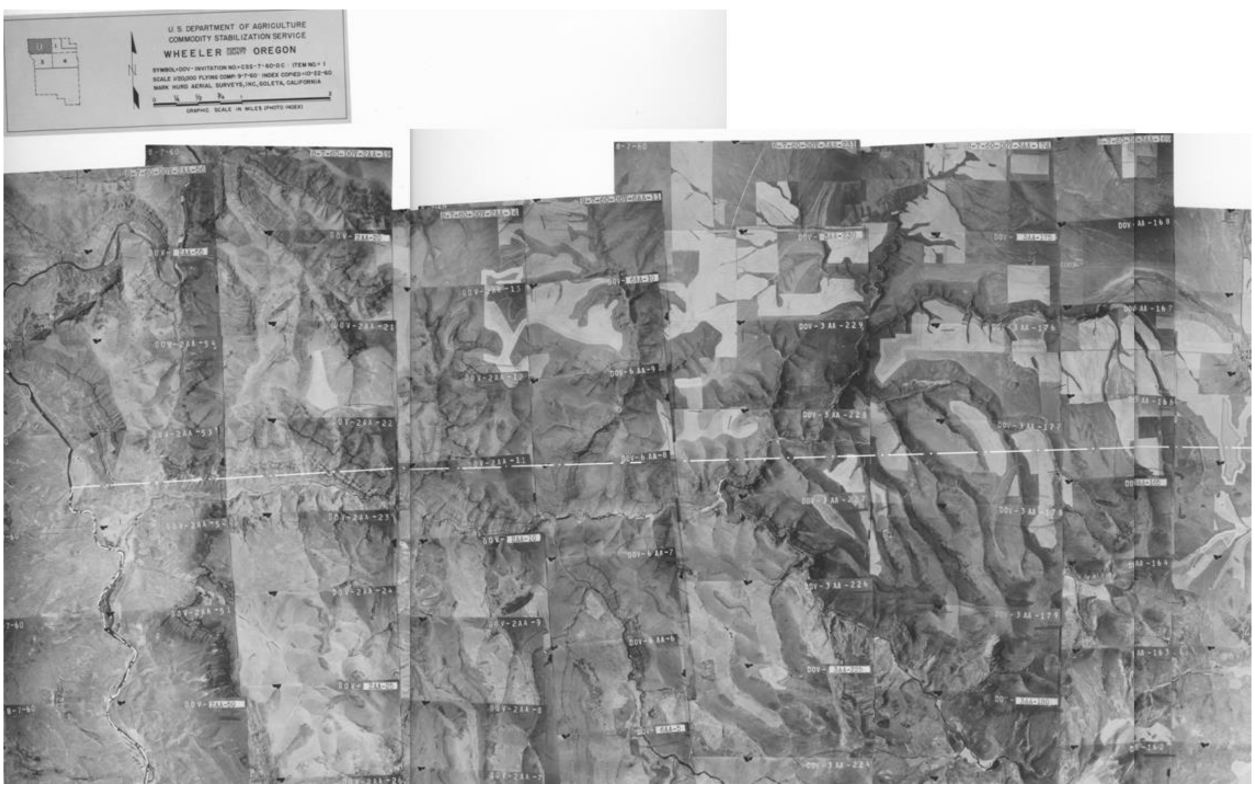

FIGURE 12. EXAMPLE OF FLIGHT LINES FROM 1951 IN WHEELER COUNTY.

Table 8. Ground pixel size and historical aerial photo collections.

To calculate ground pixel size:

(photo scale / resolution in dpi) /	12	= ground pixel size in feet
(photo scale / resolution in dpi) /	39.6	= ground pixel size in meters

Scan resolution in DPI:	300	600	1200	1800	2400	
Scan resolution in microns:	84	42	21	14	10	
Photo Scale						Example of aerial photography at given scale:
2400	0.202	0.101	0.051	0.034	0.025	
3000	0.253	0.126	0.063	0.042	0.032	
4800	0.404	0.202	0.101	0.067	0.051	
6000	0.505	0.253	0.126	0.084	0.063	C-ECE-74
9600	0.808	0.404	0.202	0.135	0.101	OHP
12000	1.010	0.505	0.253	0.168	0.126	BLM, ODR
15000	1.263	0.631	0.316	0.210	0.158	
15840	1.333	0.667	0.333	0.222	0.167	WVP
20000	1.684	0.842	0.421	0.281	0.210	USDA 1947-1970
24000	2.020	1.010	0.505	0.337	0.253	PO
30000	2.525	1.263	0.631	0.421	0.316	USGS (many)
40000	3.367	1.684	0.842	0.561	0.421	USDA 1979/80
60000	5.051	2.525	1.263	0.842	0.631	MET
70000	5.892	2.946	1.473	0.982	0.737	High Alt
80000	6.734	3.367	1.684	1.122	0.842	HAP81/82

Ground pixel size in meters

(yellow box) - indicates most common scale

Results

In total 63 historic photos were successfully scanned and subsequently mosaicked in several batches with Photoshop using the Photomerge tool. A typical Photomerge took approximately 20 minutes on a computer with 3.2 Ghz and 4 GB of RAM. Additional RAM would likely decrease the mosaic processing time, and increase the number of photos the computer can include in a mosaic. The aerial photograph mosaics were then georeferenced by creating tie points from a reference image.

Juniper was successfully mapped and visually inspected for accuracy, which was determined to be sufficient. Time constraints did not allow for an accuracy assessment with the historic juniper map however it visually appears to have similar accuracy to the 1994/5 juniper map. Figure 13 and Figure 14 demonstrate mapped areas of juniper expansion and juniper removals throughout the 60-year time period for the sample study area in Wheeler County.

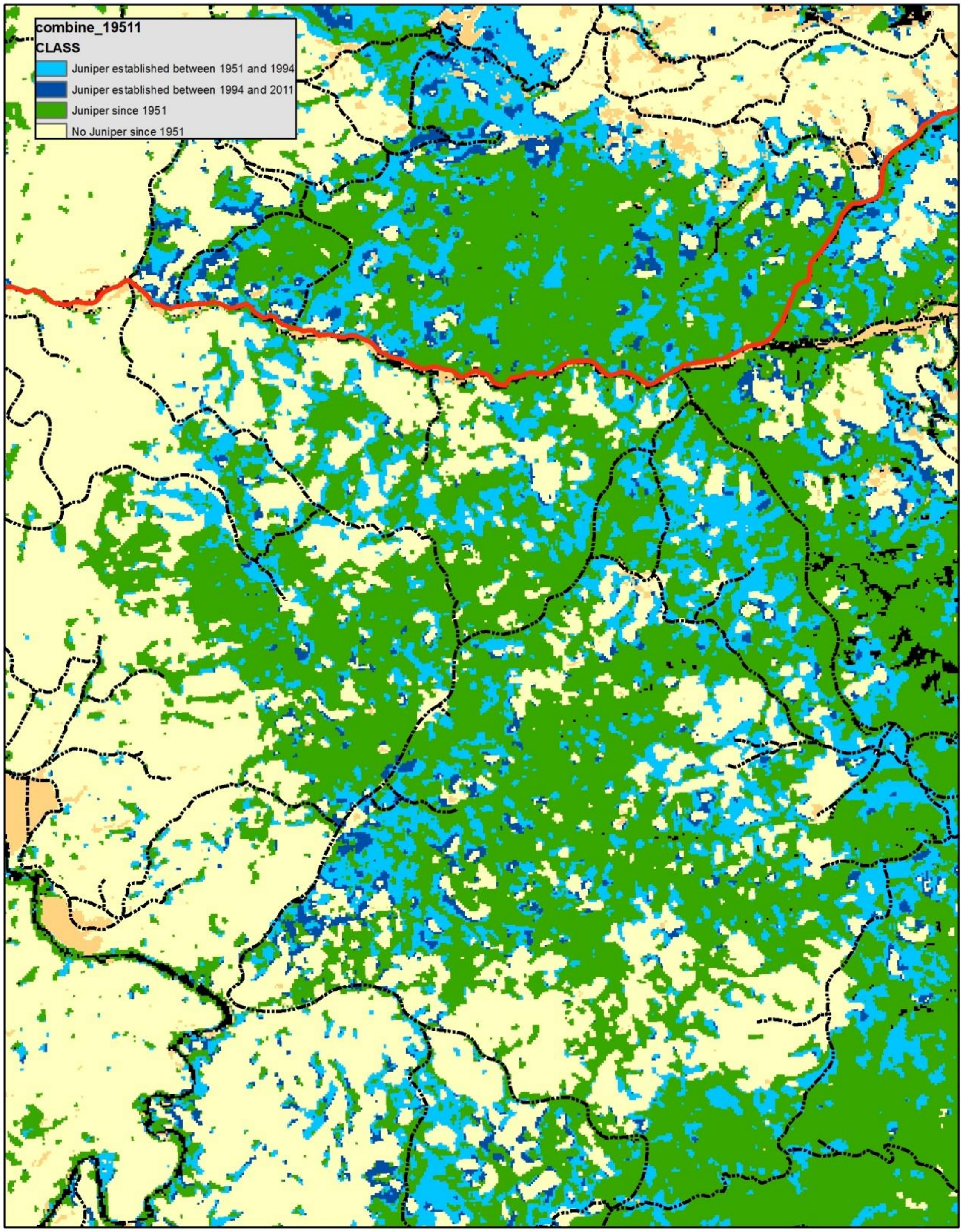

FIGURE 13. JUNIPER DISTRIBUTION FROM 1951 TO 2011 IN THE PINE CREEK CONSERVATION AREA.

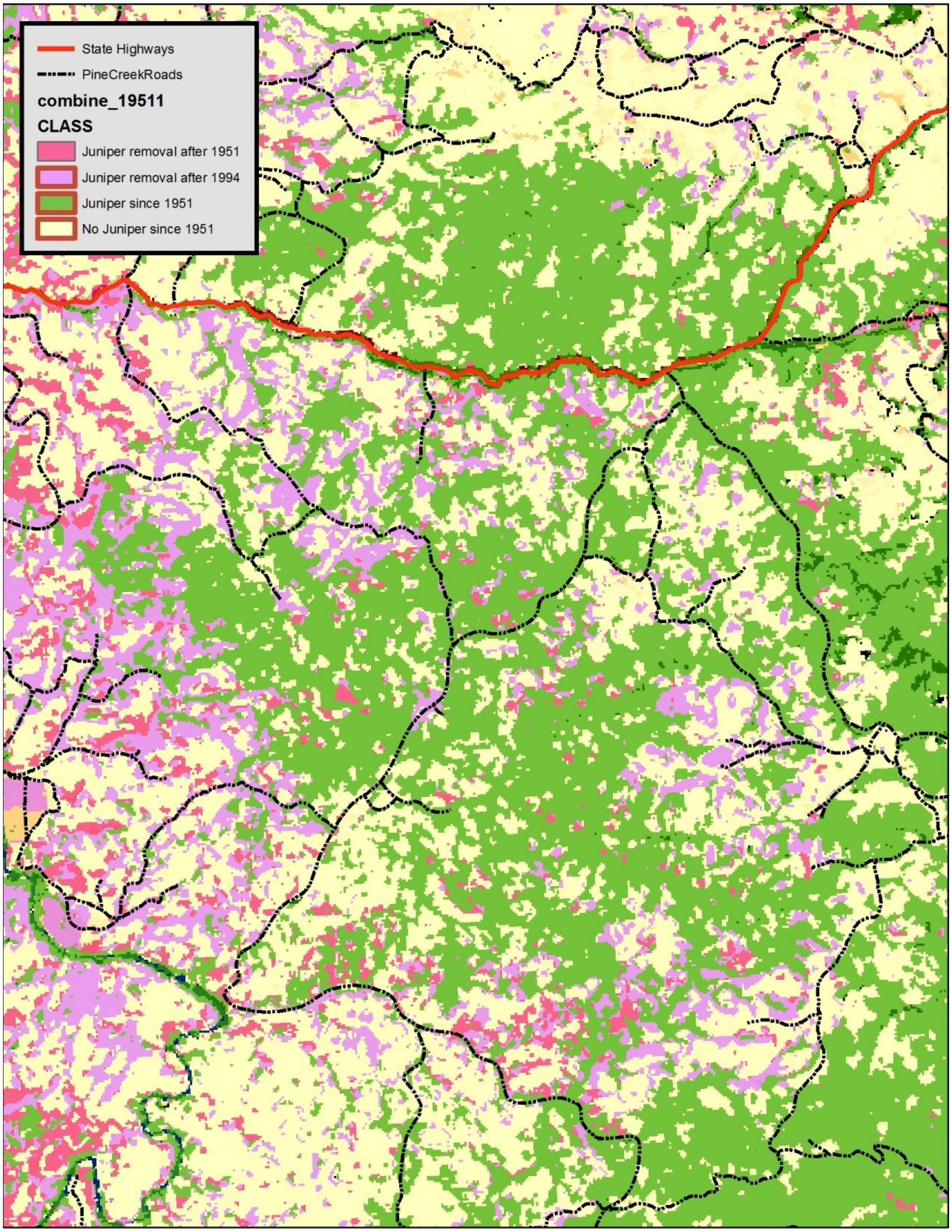

Figure 14. Juniper removal from 1951 to 2011 in the Pine Creek Conservation Area.

Discussion

Scanning (digitization) of aerial photography is a very important step that effects the utility of these photos in mapping projects. High quality scanners are recommended, or if these are not available, professional scanning services charging a standard fee per scan that are then provided on digital DVD outputs can be easily found. These professionals often have expensive scanners that are beyond the price range of the non-professional user. Although utilization of a professional scanning service would provide the highest quality scans, this is not necessary to map western juniper.

When converting aerial photos into digital rasters, images may be scanned at various DPI, which determines the overall resolution of the rasterized photo. Pixels will have a grey value digital number (DN) represented by an 8-bit value ranging from 0-255 (white-black). The greater the DPI, the more information that can be preserved in the original photograph, but there is a point of diminishing returns where an increase of DPI will begin to significantly increase scanning time and file size output while providing eventually little, or no, increases in preserving detail from the original image.

Finding the ideal scanning resolution depends on the scale the aerial photography was flown at and the desired ground pixel size. In our study area, it was desirable to have aerial photography with 1-meter resolution to match the resolution of the NAIP. With a scale of 1:20,000, a scanning DPI of 505 was required to result in 1m ground pixel size (see Table 8 for formula to calculate ground pixel size). The greatest improvement to the methodology would be to have the initial scanning carried out at 505 DPI (the equivalent of 1m resolution) opposed to the 250 DPI resolution used for the project. Results regarding mapped juniper increases and decreases, and no change in juniper distribution produced through this exploratory historical mapping process can be found in the paired watershed analysis section.

The Photoshop Photomerge tool is invaluable for digitizing historic imagery. The mosaic software was also able to remove existing fingerprints and successfully delete most of the fiducial marks (flight registration or reference points) and flight index numbers. The automatic deletion of this information with Photomerge only works when the digitized photo has no border or room around the edges. Scanning procedures can be established to avoid a border being created in the scan process, or borders can be cropped later on. With a computer with some extra RAM (>4 GB), Photomerge can consistently mosaic 20 or more frames at a time.

Georeferencing remains the most time consuming process in creating historic landcover maps from aerial photos, although a trained technician will quickly increase efficiency with practice. It should be noted that aerial photos were not ortho-corrected (corrections for displacement). As the distance from nadir increases, the image displacement will also increase. Changes in elevation throughout the image will also add to displacement. However for mapping purposes, it is assumed that the displacement that occurs is not large enough to significantly alter the results. Proper ortho-correction of photos would likely require significantly more time input.

Since juniper control measures were instituted by both government and private landowners in the 1960s, using historical imagery from the 1950s provides a good picture of the landscape before major juniper control treatments. If historical juniper distribution data is required for the time period at the arrival of European influence, the use of Global Land Office (GLO) data is recommended. The GLO surveys began and 1851 and continued to the early 1900s until all township and range grid lines were surveyed. The surveys are the earliest record of landscape conditions prior to major Euro-American settlement and influence. By extrapolating information from witness trees and environmental and vegetation conditions one can produce a spatial map estimating historic conditions (Christy and Alverson 2011).

Invasive Annual Grass Mapping

FIGURE 15. CHEATGRASS IN EARLY JUNE BEFORE SENESCENCE.

Introduction

Invasive exotic annual grasses have significantly altered ecosystems throughout the western United States. In the Pacific Northwest over the last century, invasive annual grasses have decreased overall rangeland health causing an annual estimated economic impact of over 2 billion dollars a year (DiTomaso 2000). In eastern Oregon, there are three specific exotic invasive annuals which are the focus of this study: cheatgrass (*Bromus tectorum*), medusahead rye (*Taeniatherum caput-medusae*, referred to as medusahead in this report), and ventenata (*Ventenata dubia*).

Cheatgrass was one of the first introduced exotic grasses to become widely distributed in the western United States. Today it can be found in all 50 states and is estimated to have infested over 100 million acres throughout the US (Noujdina and Ustin, 2008). Cheatgrass often is the dominant or a codominant plant in many rangeland and semi-arid areas. Cheatgrass aggressively invades sites where there have been disturbances or defoliation events. The presence of cheatgrass can often lead to increased fire frequencies and altered fire regimes, which support the maintenance of non-native species and conditions (Menakas et al. 2003).

Medusahead was also first observed in the United States over 100 years ago. Over the last several decades it has dramatically increased its range and economic impacts. Ten years ago, there were an estimated 2.3 million acres of medusahead in the 17 western states (Rice 2005). Similar to cheatgrass, medusahead typically colonizes sites where the perennial vegetation is damaged or weakened. Often these sites include areas already infested with cheatgrass or other non-native annuals (Furbush 1953, Miller et al. 1999). When dominant, medusahead can create a dense, silica-rich thatch that prevents native grasses and forbs from germinating, often creating a dense monoculture over time.

A more recent threat is ventenata, another aggressive exotic annual grass first reported from the 1950s in Washington, which appears to be increasing its distribution throughout eastern Oregon in the last decade. Ventenata has disturbingly been observed outcompeting medusahead (Northam and Callihan, 1994) and has the ability to become established in not only disturbed sites, but sites dominated by bunchgrass and native forbs.

The main economic concerns associated with invasive annual grasses are decreased land productivity, especially in the summer and fall, the corresponding reduction in available forage potential, and increased fire risk. Cheatgrass, ventenata and medusahead are only palatable for livestock and wildlife when they are young and green, which generally is only for a few weeks in early spring. The long, generally sharp awns in cheatgrass and medusahead cause livestock to avoid it once seeds have set (Rice 2005). In many areas, these annual grasses often outcompete and replace native vegetation and reduce cultivated crops yields, especially when livestock concentrate in areas, due to the presence of salt, water or fence lines. Once established, these exotic grasses can create dense monocultures that significantly increase the fuel load leading to more frequent fires with greater intensity. The new fire regime in turn reduces the shrub and bunch grass communities, which are unable to reestablish themselves as quickly as the annuals.

These grasses, along with other introduced annual grasses, have the advantage of being able to begin their growing season prior to native grasses and forbs, and also can germinate in the fall when conditions are suitable. The annuals' head start in the growing season reduces water available in the soil for native vegetation. Soil structure breaks down with the replacement of the deep rooted bunchgrasses resulting in erosion. Once these annual grasses are firmly established in large patches it is extremely difficult to remove them and costly to restore the landscape to its native species composition and health.

The INR developed an invasive annual weed map in eastern Oregon to provide an early detection mechanism. Such a map could be used to direct management efforts that could significantly reduce the spread of annuals to new regions and increase management activity success (DiTomaso 2000). Having baseline information that shows where invasive annuals occur can provide land mangers a tool for prioritizing future restoration and eradication projects and identifying areas where weed problems remain treatable. Due to the similar physiology and spectral appearance of these three weeds, the three weed species were lumped together and mapped as one group for modeling purposes. The unique phenological traits of these annual grasses enable their detection using remote sensing methods. This is cheaper than sending out ground crews to search for patches on the ground, and allows mapping in areas that are difficult to access. Additionally, when done correctly, remotely sensed inventories can be reproducible and consistent.

FIGURE 16. EXAMPLE OF CHEATGRASS COLONIZING EXPOSED SOIL UNDERNEATH BURNED JUNIPER CANOPIES AFTER A FIRE EVENT.

Study Area

The study area for the invasive annual map was determined by the availability of weed training data and the extent of a Landsat scene. The final study area was 4.3 million acres, spanning portions of Wheeler, Crook and Grant counties in eastern Oregon throughout the Blue Mountains range (Figure 17). The invasive annual weed map had a smaller extent than the juniper maps because annual grass phenology would vary significantly in a single season across such a large geographic region (Hulbert 1955; Klemmedson and Smith 1964). The study area is in central Oregon, running from Prairie City west almost to Prineville, and includes much of the John Day River basin. The climatic characteristics of the study area are hot dry summers with mild wet spring and winters; this climate pattern is similar to that of the Mediterranean climate in which these invasive species evolved. This similarity in climates is thought to be part of the reason these particular invasive grasses have been so successful in becoming established and outcompeting native vegetation.

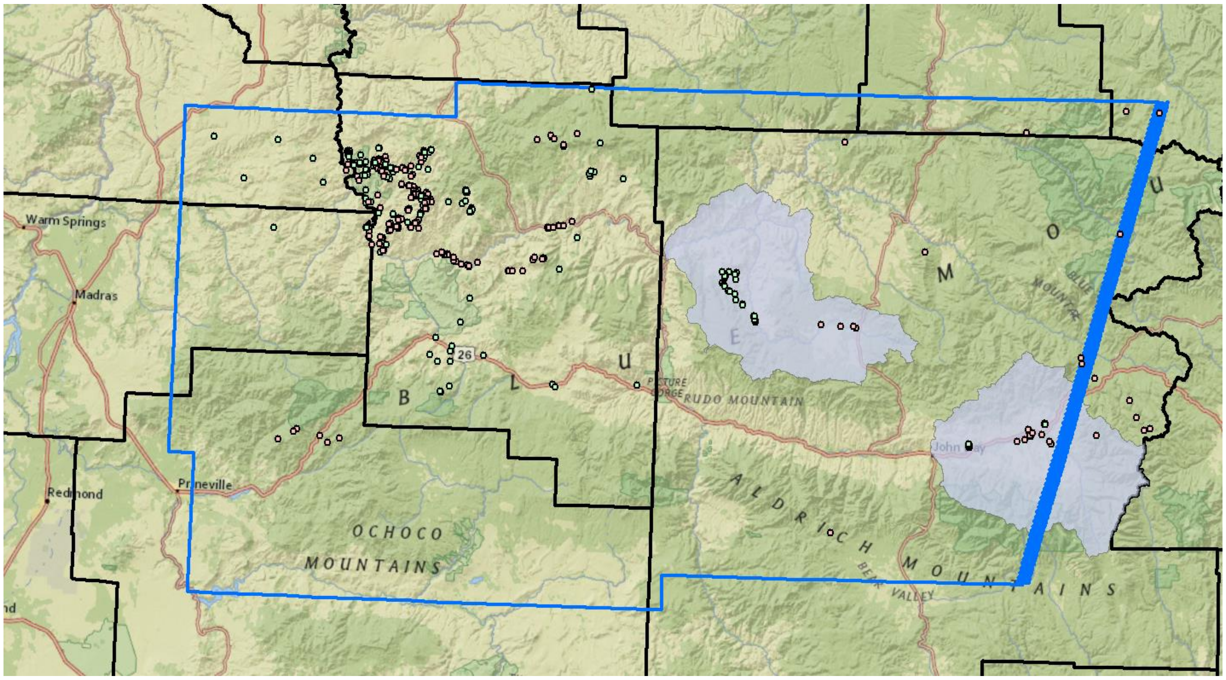

FIGURE 17. INVASIVE ANNUAL GRASS STUDY AREA BOUNDARY (BLUE OUTLINE). THE PALE BLUE POLYGONS REPRESENT NRCS MAPPING PRIORITY AREAS. TRAINING DATA POINTS COLLECTED ARE REPRESENTED BY GREEN DOTS WHICH ARE POSITIVE OCCURRENCES OF ANNUAL GRASSES, AND PINK DOTS REPRESENT NEGATIVE OCCURRENCES.

Methods

The approach to modeling invasive annual grasses was to obtain remotely sensed imagery from multiple time periods throughout a growing season. The annuals are then differentiated from the native vegetation based on seasonal phenological differences between the native and invasive vegetation. These particular annuals become photosynthetically active several weeks prior to the majority of the native vegetation and also senesce several weeks before the native vegetation becomes active. Additionally, they often form large monoculture patches across the landscape. Specifically, medusahead is known for leaf litter that composes very slowly and builds up over time making it particularly distinguishable in summer months. As much training data for both positive and negative occurrences was gathered from the imagery and existing plot data, and then a RandomForest regression model was run to predict the presence or absence of annuals throughout the study area.

Image Acquisition and Preprocessing

Due to the nature of the patchiness of annual grasses, a high resolution sensor with frequent overpasses, such as SPOT (10m), would be ideal for annual invasive grass mapping. A 30m pixel resolution sensor would likely be unable to capture the smaller areas of infestations which may be key target areas for land managers for early preventative treatments. However, due to a number of factors, using high resolution imagery was not feasible this project. The most important of these factors was the small size of SPOT scenes (900,000 acres), the large size of the weed prioritization areas, and the geographical distance of many of these areas from the majority of the training data. Therefore, Landsat

5 imagery (30m resolution with about an 8.5 million acre scene size) was instead utilized to map the larger area. Figure 18 compares SPOT and Landsat imagery resolution and scale.

In order to attempt to capture some of the smaller, more isolated patches of invasives that a 30m resolution sensor is unlikely to detect, NAIP aerial imagery from 2009, 2011 and 2012 at 1m resolution was also included in the annual grass model as predictive layers. Statewide NAIP (uncompressed tiff) collections were acquired from NRCS. These NAIP quarter quad tiles within the study area were mosaicked, and image ratios were calculated from the 2011 and 2012 NAIP and included as predictive modeling layers along with the individual bands. The predictor layers were then degraded to a 10m resolution to reduce computing demand.

In all, 5 different dates of Landsat imagery were obtained from the USGS Glovis website (http://glovis.usgs.gov/). Landsat 5, 25 years over its life expectancy, ceased acquiring images in 2011, resulting in no satellite images from 2012 being available for use in the modeling process. The Landsat images acquired were from a three year time window (2009-2011). This window was necessary to enable capture of cloud-free imagery at particular phenological stages (spring, late spring and summer). It is assumed that the benefits from using early spring imagery from 2009 outweighed any possible datedness of the imagery.

The satellite image digital values were converted into reflectance values, and a dark object subtraction was applied to correct for atmospheric conditions. Images were then topographically normalized in order to correct for differences in illumination throughout the landscape. Landsat imagery was then resampled to a 10m resolution consistent with the NAIP predictive layers.

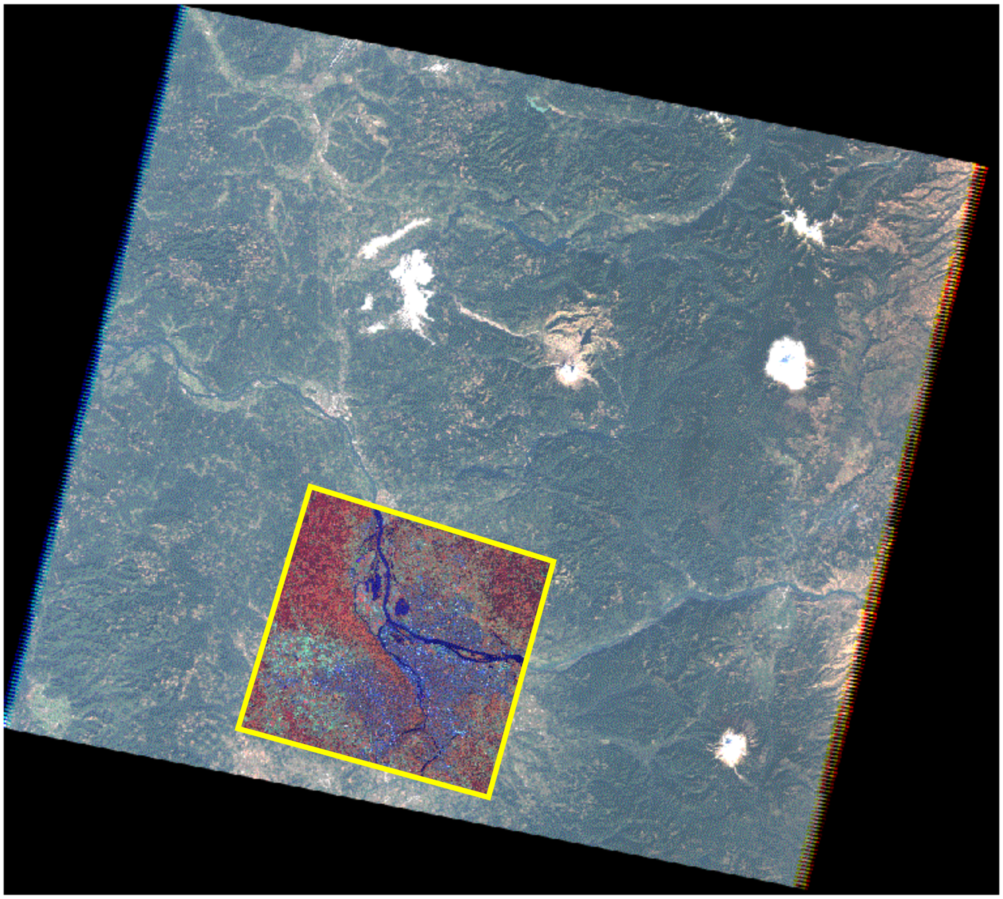

FIGURE 18. A HIGH RESOLUTION (10M) SPOT SCENE (ABOUT 900,000 ACRES, OUTLINED IN YELLOW) COMPARED TO A MEDIUM RESOLUTION (30M) LANDSAT SCENE (ABOUT 8.5 MILLION ACRES).

Training Data

Positive and negative occurrences of annuals were collected and compiled from a variety of sources, including plot data collected from the Pine Creek Conservation Area in 2011-2013, the iMapInvasives database (http://www.imapinvasives.org/) and field data collected by NRCS collaborators in the 2012 field season. Training data from PCCA had cover estimates of annuals; only plots that contained >50% invasive annual weeds were utilized for positive occurrence points. Some of training data was provided as polygons; in these instances random points were generated inside of these polygons and added to the training data point shapefile. Additional negative training points were manually placed through photo interpretation for distinct landcover types such as forest, water or agricultural lands in which the targeted annual grasses never occur. In all, there were 475 training points, about half negative and half positive occurrences. Often training data obtained did not differentiate between the three species of invasive annual weeds mapped.

Modeling

As described in earlier sections, RandomForest modeling is useful in predicting vegetation and species distributions for many reasons. For the invasive annual grass map, a RandomForest (RF) model was run to predict the distribution of annual grasses across the study area. The model relied on digitized polygons and point locations collected from field observations as training data. The predictor datasets used for this part of the project are included in Table 9. The RF regression model produced a continuous probability estimate of annual grasses at a 10-meter pixel resolution. This annual grass prediction raster was then grouped into 10 classes of increasing likelihood of annual grass occurrence.

TABLE 9. PREDICTOR VARIABLES USED IN ANNUAL GRASS MODELING.

Date	Band/index
2009 NAIP	Blue
2009 NAIP	Green
2009 NAIP	Red
2011 NAIP	Blue
2011 NAIP	Green
2011 NAIP	Red
2011 NAIP	Infrared
2012 NAIP	Blue
2012 NAIP	Green
2012 NAIP	Red
2012 NAIP	Infrared
2011 NAIP	NDVI
2012 NAIP	NDVI
4/21/2009 , Landsat 5	Tassel cap brightness
4/21/2009 , Landsat 5	Tassel cap greenness
4/21/2009 , Landsat 5	Tassel cap wetness
4/21/2009 , Landsat 5	Blue
4/21/2009 , Landsat 5	Green
4/21/2009 , Landsat 5	Red
4/21/2009 , Landsat 5	Near infrared
4/21/2009 , Landsat 5	Short wave infrared (1)
4/21/2009 , Landsat 5	Short wave infrared (2)

Date	Band/index
7/13/2010 , Landsat 5	Blue
7/13/2010 , Landsat 5	Green
7/13/2010 , Landsat 5	Red
7/13/2010 , Landsat 5	Near infrared
7/13/2010 , Landsat 5	Short wave infrared (1)
7/13/2010 , Landsat 5	Short wave infrared (2)
8/14/2010 , Landsat 5	Blue
8/14/2010 , Landsat 5	Green
8/15/2010 , Landsat 5	Red
8/16/2010 , Landsat 5	Near infrared
8/17/2010 , Landsat 5	Short wave infrared (1)
8/18/2010 , Landsat 5	Short wave infrared (2)
6/14/2011 , Landsat 5	Blue
6/14/2011 , Landsat 5	Green
6/14/2011 , Landsat 5	Red
6/14/2011 , Landsat 5	Near infrared
6/14/2011 , Landsat 5	Short wave infrared (1)
6/14/2011 , Landsat 5	Short wave infrared (2)
8/17/2011 , Landsat 5	Blue
8/17/2011 , Landsat 5	Green
8/17/2011 , Landsat 5	Red
8/17/2011 , Landsat 5	Near infrared
8/17/2011 , Landsat 5	Short wave infrared (1)
8/17/2011 , Landsat 5	Short wave infrared (2)

Results

Throughout the 4.3 million acre study area, 350,000 acres (8%) were mapped as likely to be occupied by invasive annual grasses. **Error! Reference source not found.** shows an example of the map results for an area near Monument. Proportional occurrence of invasive annuals was greater on private lands (12%) than federal lands (2%). State lands were found to have the highest relative percentage of invasive annuals, but the state also owned significantly less lands than other landowner groups in the study area (Table 10). There was a similar percent occurrence of annuals on mapped areas of juniper decrease between 1994 and 2011 (14%) and areas where no changes in juniper canopy cover were detected (14%) (Table 11). Between 700 and 1300m in elevation, the percent of area occupied by annuals was greater than 10%. At elevation higher than 1300m, percentage of annual grass cover predictably decreased due the transition into forested areas and increased precipitation (Figure 20, Table 12). An accuracy assessment was not completed for the invasive annual grass map, due to fiscal and time constraints.

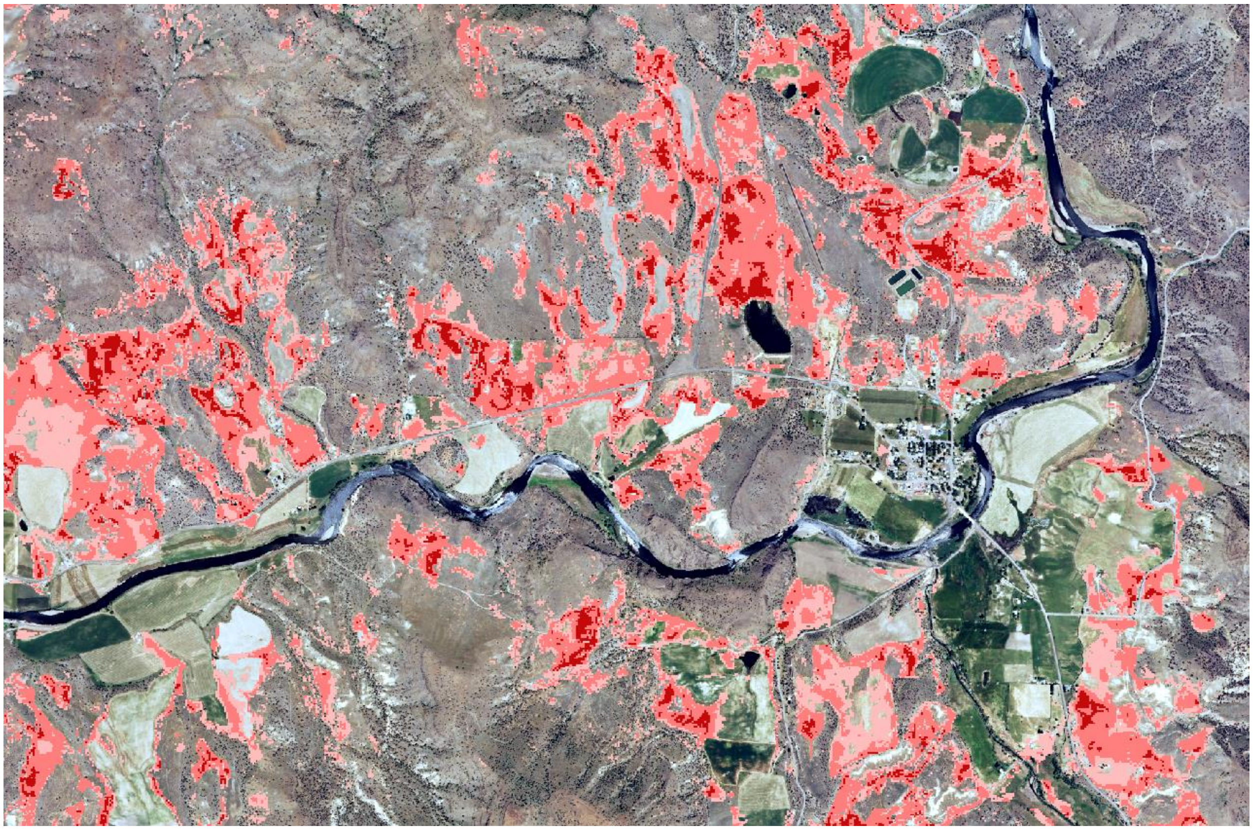

FIGURE 19. EXAMPLE OF INVASIVE ANNUAL MAP NEAR MONUMENT, OR. DARKER SHADES OF RED REPRESENT HIGHER PROBABILITY OF INVASIVE ANNUAL GRASSES.

TABLE 10 PERCENTAGE OF ANNUALS BY OWNERSHIP.

Owner	Public	Private
Percentage with annual grasses	8%	16%
Acres with annual grasses	50,408	295,457
Total Acres (non-forest)	667,987	1,802,503

TABLE 11. ANNUALS WHERE JUNIPER DECREASED AND ANNUALS ON NON-FORESTED LANDS WITH NO CHANGES IN JUNIPER PRESENCE.

	Rangelands	Juniper decrease
Percentage with annual grasses	14%	14%
Acres with annual grasses	2,364,005	111,013
Total Acres (non-forest)	333,735	15,754

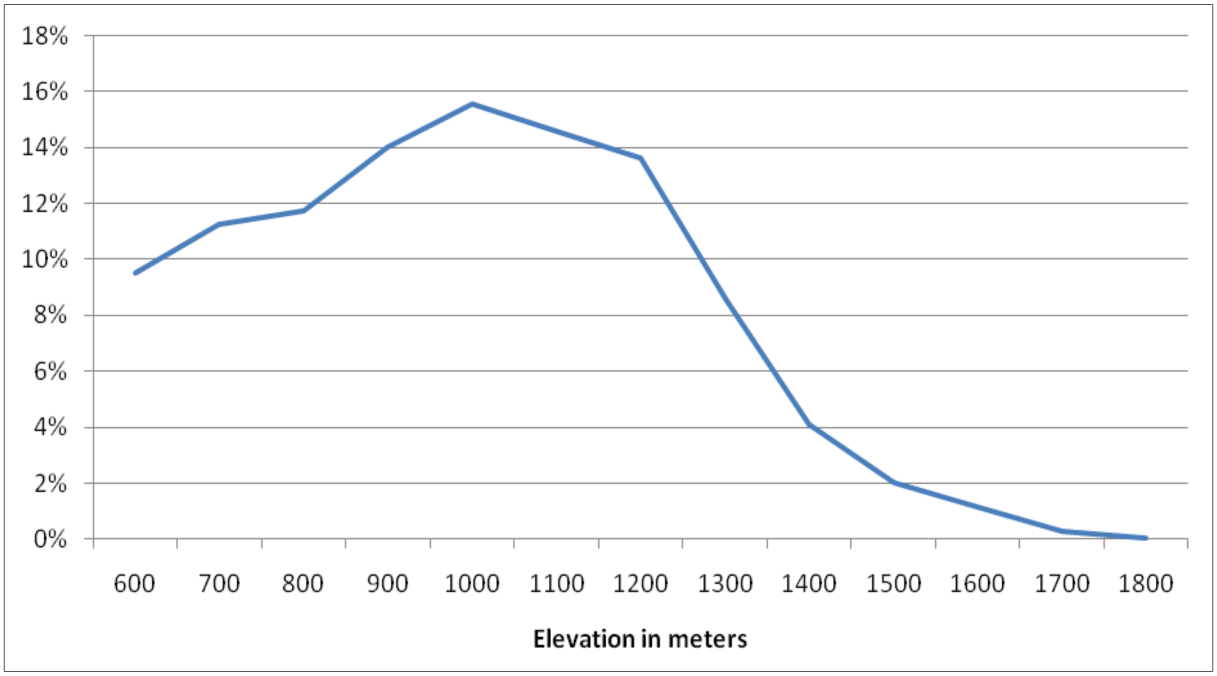

Figure 20. Percent of study area that was mapped as invasive annuals by elevation.

Table 12. Annuals by precipitation zone.

Precipitation Zone	<10"	10-15"	15-20"	20-25"	25-30"	>30"
Percentage of zone with annuals	0%	15%	9%	0%	0%	0%
Acres with annual grasses	2,439	218,101	124,953	3,946	75	-
Total Acres (non-forest)	59,574	1,446,669	897,464	52,441	24,430	5,727

Discussion

Noujdina and Ustin (2008) found in a study in central Washington that overall accuracy of detecting cheatgrass increased significantly when using more than a single time period of when an annual grass may be distinguishable. Although an accuracy assessment was not completed on the annual grass map produced, using multiple image dates is likely to have significantly improved the modeled output accuracy. Differences in precipitation and temperatures between various growing seasons makes the peak periods when annual species are detectible different from year to year. Geography, aspect and elevation add to the variability and timing needed to identify the appropriate image capture date. With Landsat data's 16 day repeat coverage period and unfortunate timing and cloud cover, it is possible that a peak "green up" image for a particular year may not be captured at all. Eastern Oregon is known for its dry summers, making it much more likely to obtain a cloud free image when annual grasses have senesced. The images from 8 different dates should cover the range of possible season to season variance and possible vegetation conditions. The high resolution NAIP imagery is flown on cloud free days in the summer time every few years, making it a good predictor to confirm invasive annual grasses once they have senesced.

Although invasive annuals appear to be occurring significantly more frequently on private lands than public lands, this may be because many of the federal lands in the study area are more mesic forested areas that do not support these annual grasses. Interestingly, areas mapped showing juniper declines had the same percentage of annuals as areas where there was no change in juniper cover. Juniper declines resulting from fires or mechanical disturbances can create conditions supporting invasion of annuals, but this did not appear to be the case with this map. Invasive annuals had a greater percent coverage at lower elevation than at higher elevations, supporting the notion that these elevations are generally more suitable for annual grass survival and expansion. The decrease in annuals around 1,300 meters in elevation likely corresponds to the significant increase in juniper at around 1,300m or the presence of forests above this elevation (see **Error! Reference source not found.**).

As mentioned above, an accuracy assessment was not completed for the invasive annuals map for several reasons. With a total of about 475 training points, a selection of points could have been left out of the training data and used to evaluate the accuracy of the model, however the benefits of including additional training plots in the model outweighed the potential to evaluate the map accuracy. A photo interpretation accuracy assessment was also ruled out as a possibility due to invasive annual weeds not being clearly identifiable or distinguishable visually. A field based approach accuracy assessment was not plausible due to the time and expense. Until a proper accuracy assessment is carried out on this product, land managers may want to use caution before generalizing information from this product.

Lastly, we would like to put a special notice that although ventenata has been established in the Northwest for multiple decades, more recently it has been spreading at alarming rates. The most alarming characteristic of ventenata is its apparent ability to outcompete other invasives and its potential to become established in previously undisturbed areas. Given ventenata’s aggressive nature it is recommended to implement a strategy of containment and treatment. Determining baseline distribution of current occurrences is a positive first step (Figure 21). Given ventenata’s later green up onset, mapping ventenata separately from other invasives annuals should be explored.

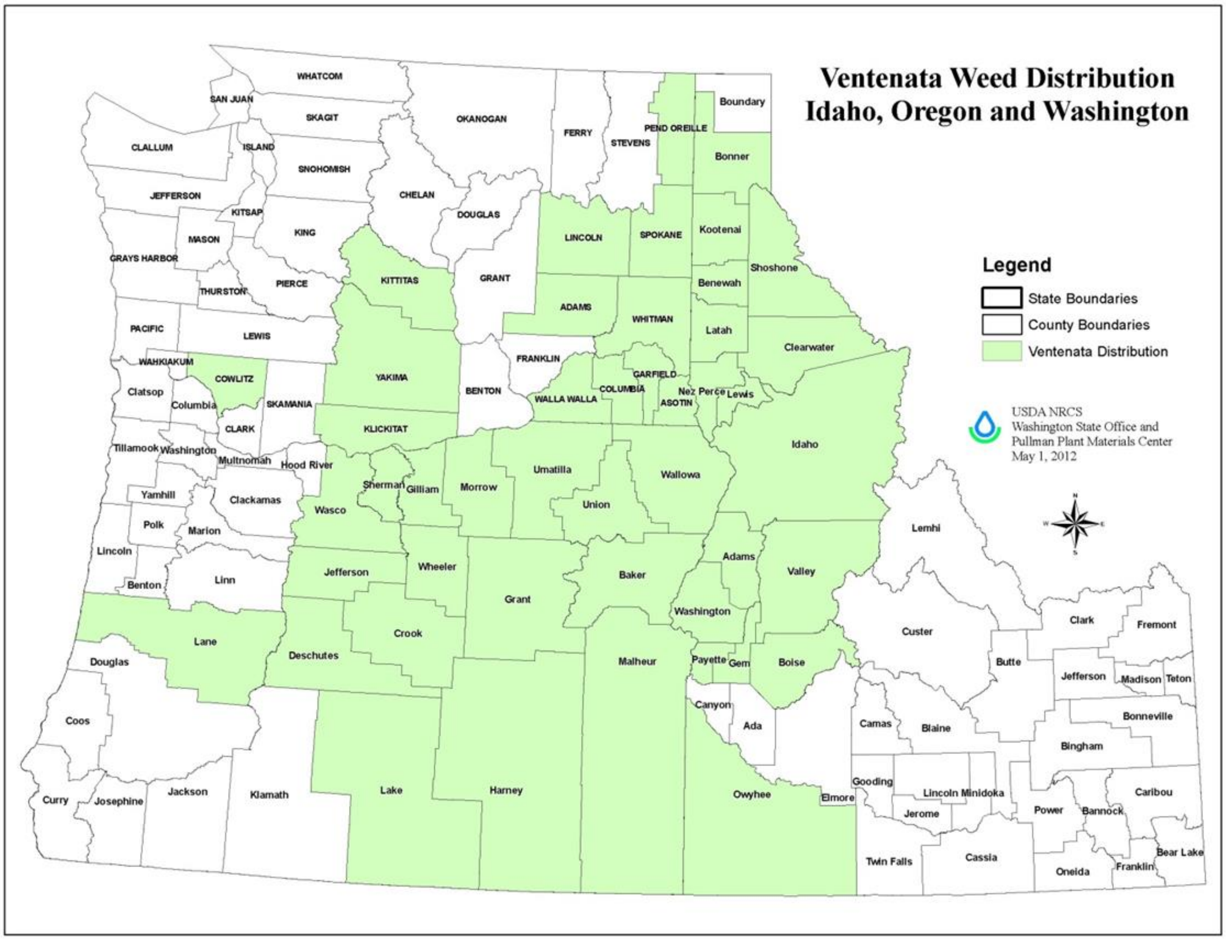

FIGURE 21. VENTENATA DISTRIBUTION MAP IN OREGON AND WASHINGTON.

Rowe Creek and Pine Creek Paired Watershed Analysis

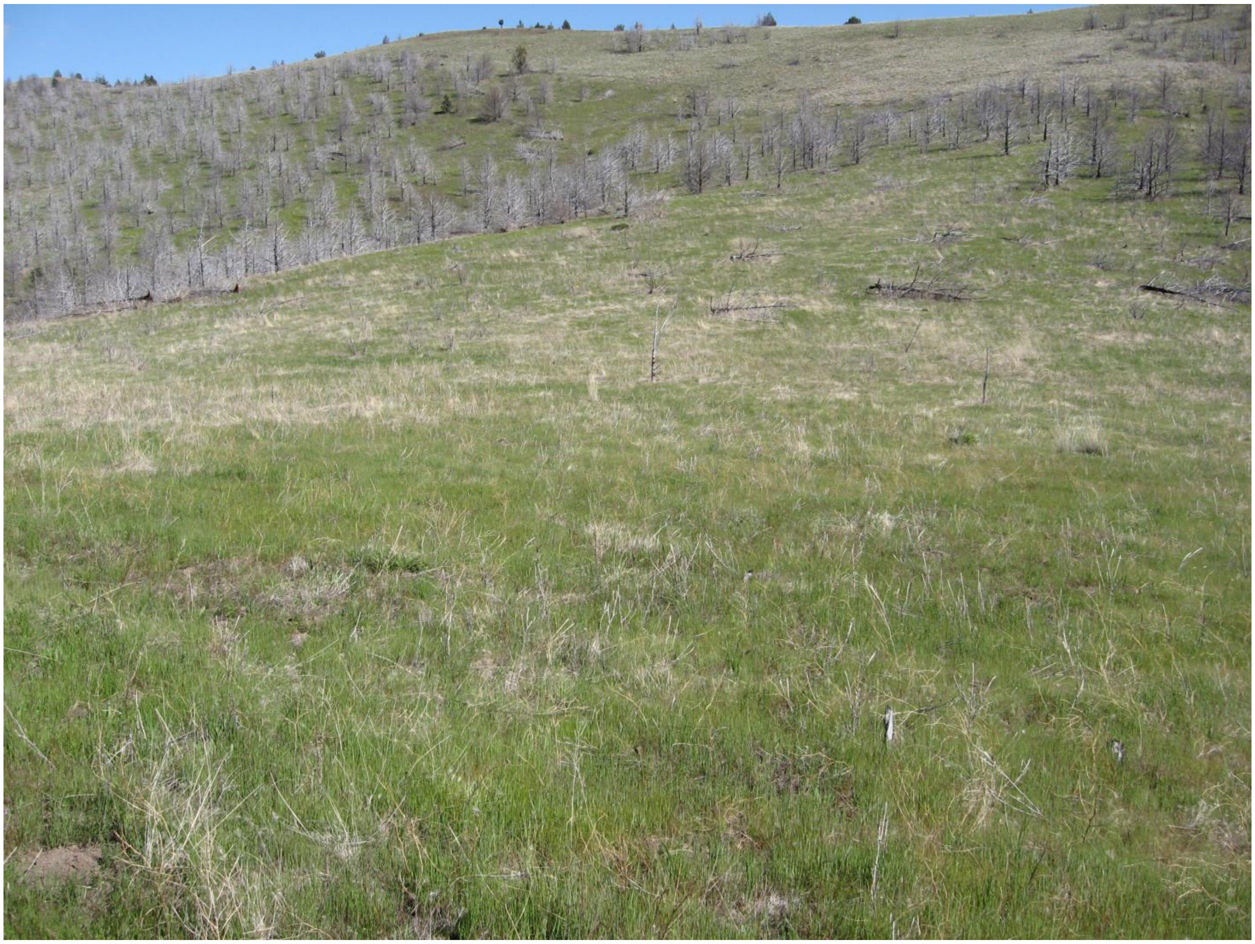

FIGURE 22. ONE OF SEVERAL FIRE EVENTS THAT OCCURRED OVER THE LAST DECADE AT PINE CREEK CONSERVATION AREA.

Introduction

Extensive conservation and restoration activities have been underway in the adjacent Pine Creek and Rowe Creek watersheds. The watersheds currently have very different ownerships, livestock utilization, and somewhat different restoration objectives. Much of the Pine Creek watershed is managed as a conservation area with a goal of increasing wildlife habitat, while the Rowe Creek watershed is largely privately owned and the majority of the owners are interested in improving the forage available for their livestock while increasing the sustainability of their livestock operations. Removing or reducing western juniper cover and increasing bunchgrass cover are primary management goals in both watersheds. Because significant restoration resources are being spent in different ways in both watersheds to obtain similar same goals, they present an excellent opportunity for a paired watershed study.

Juniper control techniques have changed over time, from bulldozer chaining to cutting and more traditional prescribed burning. In much of Rowe Creek, western juniper is harvested and milled to create fence posts and various lumber products. In Pine Creek most of the juniper has been killed through prescribed fires or wildfires. A thorough evaluation of the effects of different juniper removal methods and long term outcomes of past and current efforts would aid landowners in the decision making process of specific removal techniques. Unfortunately, detailed maps showing what juniper removal methods are implemented in exactly which areas are not available. However, since management is largely consistent within the Rowe and Pine Creek watersheds, a general comparison can be made.

The majority of the Pine Creek watershed (approximately 40,000 acres) was acquired from a private rancher in 2000 by the Confederated Tribes of the Warm Springs Reservation as part of their settlement with the Bonneville Power Administration (BPA). The Tribe agreed to create the Pine Creek Conservation Area (PCCA) and manage it to help replace the wildlife lost from Bonneville's Columbia River dams. BPA provides funding to the tribe to manage the property to increase wildlife habitat for their targeted species. Their initial objectives included reducing the western juniper dominance in the watershed and improving the riparian vegetation in the watershed. After acquiring the property, PCCA removed all livestock, established a program to control weeds, and developed an MOU with the Bureau of Land Management to allow for prescribed burns and controlled wildfire management on the property. While prescribed burning has been fairly limited, almost half of the PCCA area was burned by wildfires since the property was acquired, and about 20% has had multiple wildfires.

In the PCCA monitoring report to the BPA, Berry (2006) reported that upland vegetation was probably the most important factor affecting wildlife habitat and watershed function. In order to evaluate changes in upland vegetation conditions occurring as a result of tribal management, staff at the PCCA worked with INR to establish permanent vegetation monitoring plots in 2001. In 2011, PCCA staff requested a 10 year update from INR to evaluate vegetation changes and to inform PCCA management.

The PCCA study included revisiting 55 detailed vegetation baseline plots that were selected to reflect the full range of diversity of the different plant communities or vegetation types located in the conservation area. Plots were either placed well within a homogenous area of a particular community, or through the transition zones between communities. The work also included additional effort to provide a more accurate vegetation map, and to use LiDAR to accurately map the distribution of western juniper in the conservation area. This project was completed in January of 2012.

The Natural Resources Conservation Service (NRCS) had observed that the rangeland sustainability was being compromised in the Rowe Creek Watershed, due primarily to the invasion of western juniper into uplands and riparian habitats, and the expansion of medusahead and ventenata. The juniper was of concern due shading reducing forage and wildlife habitat, and to stream impacts, primarily accelerated erosion and decreasing late season water availability. Also, there was concern that the native grasses and shrubs would decrease in cover due to both juniper expansion and to the spread of medusahead and ventenata. Lastly, the Oregon Department of Environmental Quality had completed a Total Maximum Daily Load water quality evaluation which identified increased stream temperature as the limiting factor impacting quality in the main stem of the John Day. This created additional concern as Rowe Creek drains into the John Day River and could negatively affect the fish habitat and recreational endeavors that take place there if nothing is done. As a result, NRCS obtained national funding to establish the Rowe Creek watershed as a Targeted Watershed, making additional research and restoration funds available.

Study Area

The primary focus of the project was southwestern Wheeler County. The general study area included all of the area in Rowe Creek, Lower Pine Creek and Upper Pine Creek sub-watersheds, as well as the parts of Rhodes Canyon, the John Day Gulch and Shaw Canyon sub-watersheds that are located in Wheeler County and are north or east of the John Day River. It included all of the Pine Creek Conservation Area, composed of the majority of Lower Pine Creek, Upper Pine Creek and Rhodes Canyon, as well as all of the Rowe Creek Targeted Watershed (Figure 23).

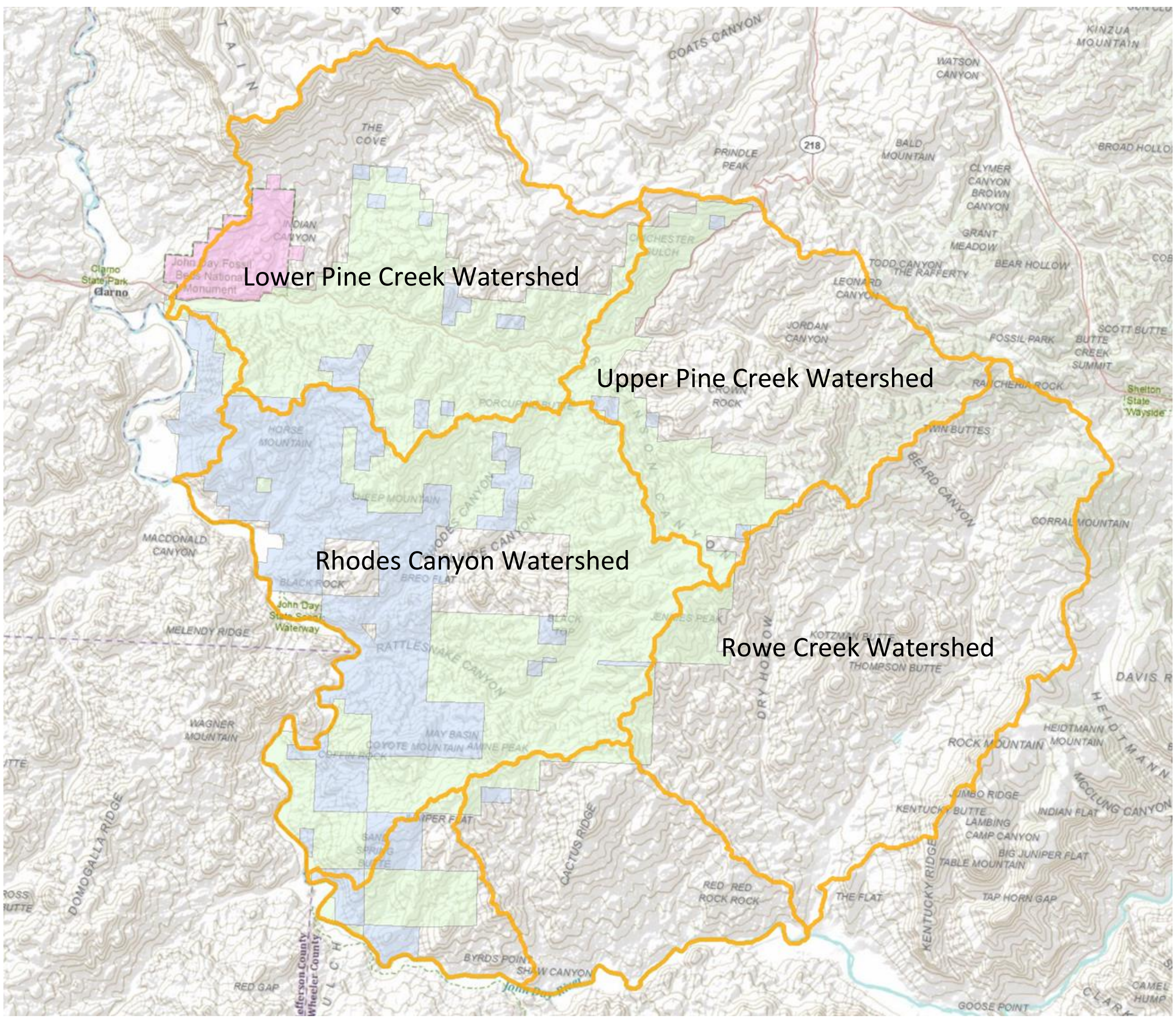

FIGURE 23. CENTRAL OREGON WATERSHEDS IN THE PINE CREEK CONSERVATION AREA (GREEN) AND THE NRCS TARGETED WATERSHED. BLM LANDS ARE IN BLUE. THE PINK IS THE CLARNO UNIT OF THE JOHN DAY FOSSIL BEDS NM.

Rather than doing a standard paired watershed study, we chose to compare adjacent watersheds from Central Oregon, along the mainstem of the John Day River. In this study, the primary comparisons were made between the Rowe Creek Targeted Watershed and both the Lower Pine Creek and the Rhodes Canyon Watershed. The Lower Pine Creek watershed is most similar to Rowe Creek, includes the small Clarno Unit of the John Day Fossil Beds National Monument, the northern portion of the PCCA, and some private lands. The majority of wildfires that have occurred anywhere in the large study area have been concentrated in this watershed; so many observed differences may have been a result of these fires. A little more than half of this watershed has been excluded from livestock since 2000, and there have been extensive efforts to restore riparian conditions there.

The Rhodes Canyon Watershed has been almost entirely in conservation management, but the tribal lands are managed for wildlife, and the somewhat extensive BLM lands have been designated as a Wilderness Area, and are also currently not used for livestock grazing. There are some small private inholdings in this watershed which currently are used for cattle, but these are relatively small. The northern portion of the Rhodes Canyon was part of two burns, but the majority of the area was not significantly impacted by wildfires. And unlike the other watersheds evaluated, Rhodes Canyon includes over 10 miles of the John Day River, but only two small streams and no mid-elevation conifer forests. The Upper and Lower Pine Creek watersheds and the Rowe Creek watershed are fed by higher elevation douglas-fir and ponderosa pine forested watersheds.

Methods

Aerial photo textures were calculated on 1m resolution aerial photography from 1951, 1994 and 2011. Aerial photography was then degraded to 30m resolutions. Predictor variables for these three juniper maps did not include satellite imagery because the study period predated satellite sensor data. All texture predictor variables were then clipped to the identical extent, and pixel cells were aligned (snapped). LiDAR data flown for PCCA in 2011 was used as a source of training data for a RandomForest model to create predictive canopy cover estimates for each pixel.

To allow for the watershed comparisons, the juniper maps from the three time periods were then classified into binary maps of either juniper present or no juniper present. Canopy cover under 5% canopy cover was considered no juniper, while canopy covers >5% were mapped as juniper. It was generally assumed the model could not accurately predict canopy covers less than 5%. At less than 5% canopy cover, geological features and shrub layers such as sage brush could have textures similar to very light juniper canopy cover. Unlike the juniper map for the larger Central Oregon study area described in the Mapping Western Juniper section, a landcover mask was not applied to these final watershed juniper maps, since there was not a significant amount of conifer forest or developed lands present in the four small sub-watersheds evaluated. The differences in annual grass cover was measured based on the results of the modeling described in the annual grass section, applied to each of the watersheds and the ownerships in the different watersheds.

Results and Discussion

Juniper Cover and Change

The current cover of western juniper in the watershed areas is shown below in Figure 24. The distribution, shown in black, shows a patchy distribution but is clearly concentrated in the upper parts of the watersheds. The green areas are those dominated by Ponderosa pine and Douglas-fir.

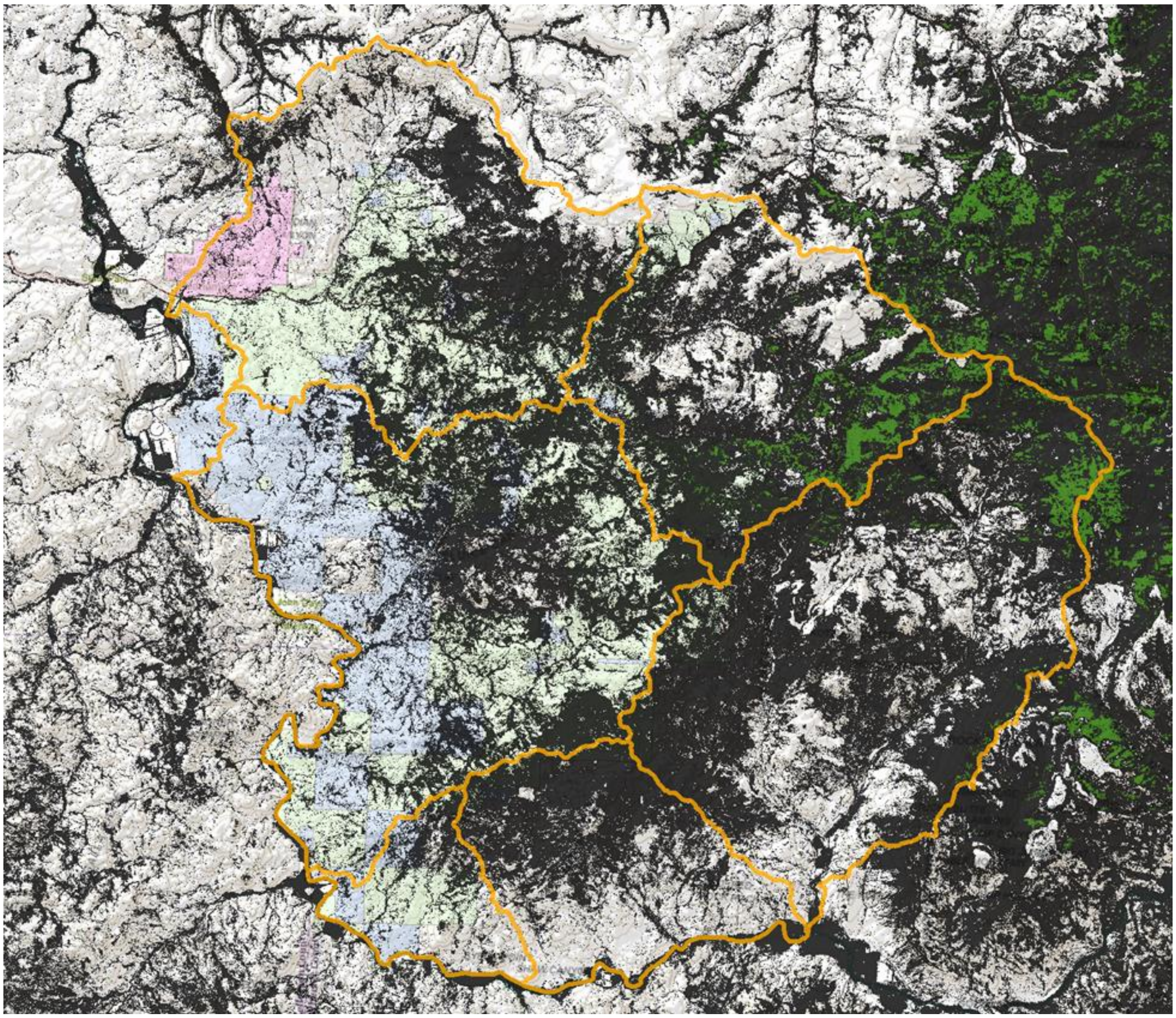

FIGURE 24. CURRENT WESTERN JUNIPER DISTRIBUTION (IN BLACK) AND PINE/DOUGLAS-FIR DISTRIBUTION (IN GREEN) IN THE EVALUATED WATERSHEDS.

There were significant differences in western juniper distribution in the four watersheds, which can be seen in Table 13 below, and more clearly in Figure 25 on the following page. These show Rowe Creek and Upper Pine Creek still with the majority of the area dominated by juniper, much of it 60 years old or older. This is not the case for Lower Pine Creek and Rhodes Canyon watersheds, which have generally less juniper and have shown larger declines.

Table 13. Summary of juniper change by watershed.

Watershed	Juniper Changes	Acres
Upper Pine Creek	Juniper 20-60 years old	3,000
Upper Pine Creek	Juniper less than 20 years old	856
Upper Pine Creek	Juniper greater than 60 years old	10,164
Upper Pine Creek	Juniper not present	3,416
Upper Pine Creek	Juniper decrease in the last 20 years	459
Upper Pine Creek	Juniper decrease between 20-60 years ago	333
Rowe Creek	Juniper 20-60 years old	4,190
Rowe Creek	Juniper less than 20 years old	785
Rowe Creek	Juniper greater than 60 years old	17,518
Rowe Creek	Juniper not present	3,806
Rowe Creek	Juniper decrease in the last 20 years	2,315
Rowe Creek	Juniper decrease between 20-60 years ago	668
Lower Pine Creek	Juniper 20-60 years old	2,885
Lower Pine Creek	Juniper less than 20 years old	767
Lower Pine Creek	Juniper greater than 60 years old	6,786
Lower Pine Creek	Juniper not present	7,435
Lower Pine Creek	Juniper decrease in the last 20 years	2,682
Lower Pine Creek	Juniper decrease between 20-60 years ago	2,355
Rhodes Canyon	Juniper 20-60 years old	4,229
Rhodes Canyon	Juniper less than 20 years old	910
Rhodes Canyon	Juniper greater than 60 years old	10,621
Rhodes Canyon	Juniper not present	7,864
Rhodes Canyon	Juniper decrease in the last 20 years	4,395
Rhodes Canyon	Juniper decrease between 20-60 years ago	1,922

The best way to understand the differences between the watersheds is to look at the amount of western juniper in different stand ages, which reflects how much new juniper arose at each of the three time periods. This is shown in the pie charts that make up Figure 25. Because Upper Pine Creek is mixed ownership and has the only large areas of conifer forests, it is the least useful to examine when comparing how management, ownership and history impacts juniper distribution in Central Oregon. Differences between Rowe Creek and Rhodes Canyon probably best reflect management and ownership differences over the last 10-15 years. In Rowe Creek, over 75% of the watershed has more than 5% cover of western juniper, while only 51% of Rhodes Canyon and 45.5% of Lower Pine Creek have significant juniper cover.

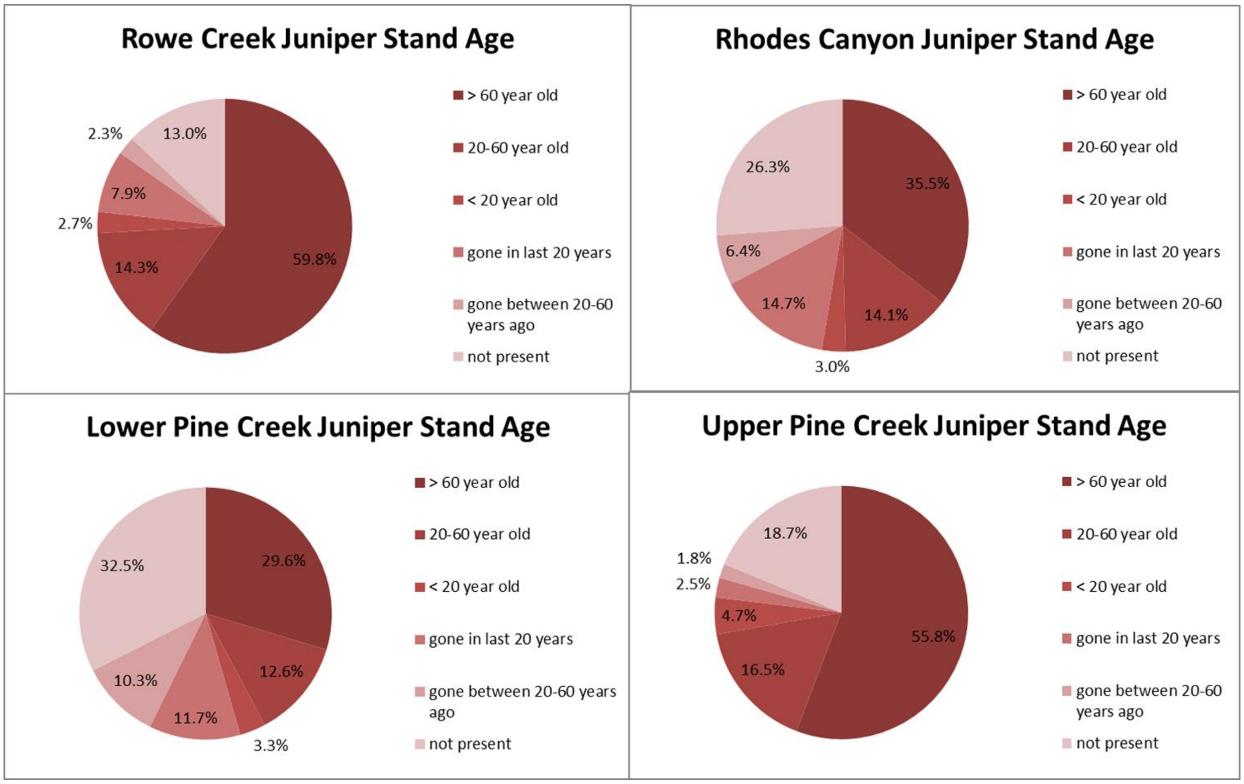

Figure 25. Western juniper stand initiation dates based on historic and current mapping in the four paired watersheds.

The lower cover of juniper at Lower Pine Creek and Rhodes Canyon are certainly the result of the series of wildfires and the limited prescribe burns that have occurred at the site since it was acquired by the Warm Springs Tribe. While this certainly helped meet the objectives of the managers, it is quite difficult to attribute this to their intention, since luck probably had very much to do with the distribution and spread of the fires. However, given that PCCA had developed a fire plan that included fighting fires at the margins of the site whenever possible, the managers do deserve credit for the very significant juniper declines. In addition, the fact that livestock and fences have been removed and that there are no homes in the area makes both fire suppression and management more straightforward.

In spite of the this, a comparison of the area of juniper removed in the last 20 years is the best indication of the success of recent restoration efforts, and for this area, the differences between Rowe Creek (7.9% recent removal, most of which have probably occurred in the last five years) and Lower Pine Creek (11.7%) or Rhodes Canyon (14.5%) are not as significant, especially when considering the almost total absence of large wildfires in Rowe Creek. Given recent invasion rates, removing 8% of the juniper or 2,300 acres every five years will certainly make a very significant difference in the impacts and the productivity of the watershed, especially if the removals are focused in the areas where the understory is likely to quickly recover.

Annual Grass Cover

The second group of watershed comparisons related to difference in annual grass cover between the four watersheds. As was the case in the juniper comparisons, the data used were described in the annual grass mapping section of this report. In looking at annual grasses, there were noticeable differences between the watersheds that appeared to be related to ownership patterns within the watersheds in addition to the environmental differences in the watersheds. This can be seen in Figure 26 below, which compares the differences in the area dominated by annual grasses in the four watersheds, and the percentage of each ownership in which annual grasses were important.

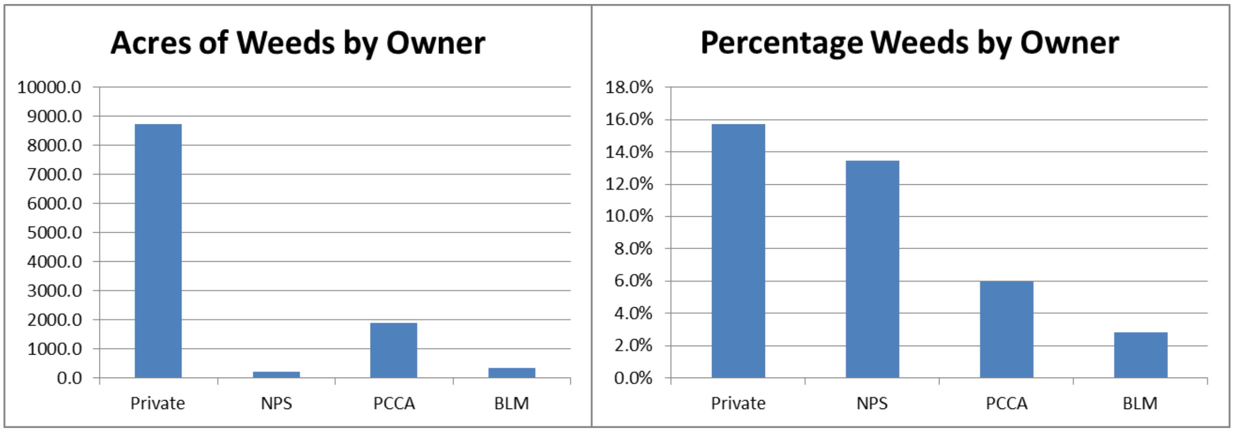

FIGURE 26. WEEDS BY OWNERSHIP IN ALL FOUR OF THE PAIRED WATERSHEDS.

The fact that the area dominated by annual weedy grasses was greatest on private lands is not that meaningful, since the majority of the overall four-watershed area was privately owned. However, the fact that the percentage of weeds on private lands was significantly higher than that on the BLM and PPCA lands may be significant. The high value for the Clarno Unit of the John Day Fossil Beds National Monument is probably not meaningful, since the area is so small, and because the native annual forbs that naturally occur on the widespread ash beds may be a confounding factor. In Figure 27 below, both the area and percentage of annual grasses is shown by ownership within each watershed.

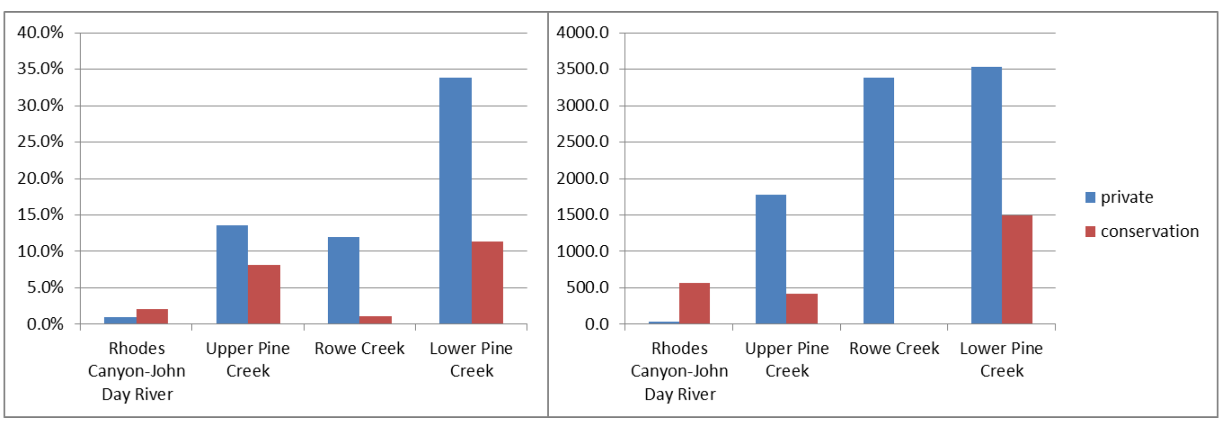

FIGURE 27. ANNUAL GRASSES BY OWNERSHIP AND WATERSHED.

Figure 27 does appear to show significant differences between the lands in the study area managed primarily for conservation and the private lands managed for livestock production. For this figure, the BLM, PCCA and NPS ownerships were combined, since in these watersheds livestock happens to be excluded from all public and tribal ownerships. This occurs because BLM ownership is in established wilderness that is managed cooperatively with the Pine Creek Conservation Area primarily to support wildlife and recreation. Two things can be seen in these comparisons, which also can be seen on the map showing the distribution of the introduced annual grasses in the study area (Figure 28). First, there does appear to be more significantly more annual grasses in the private lands in the study area, as well as on private lands in the mixed private-public ownerships watersheds such as the Lower Pine Creek watershed . Secondly, the annual grass distribution tends to be patchy.

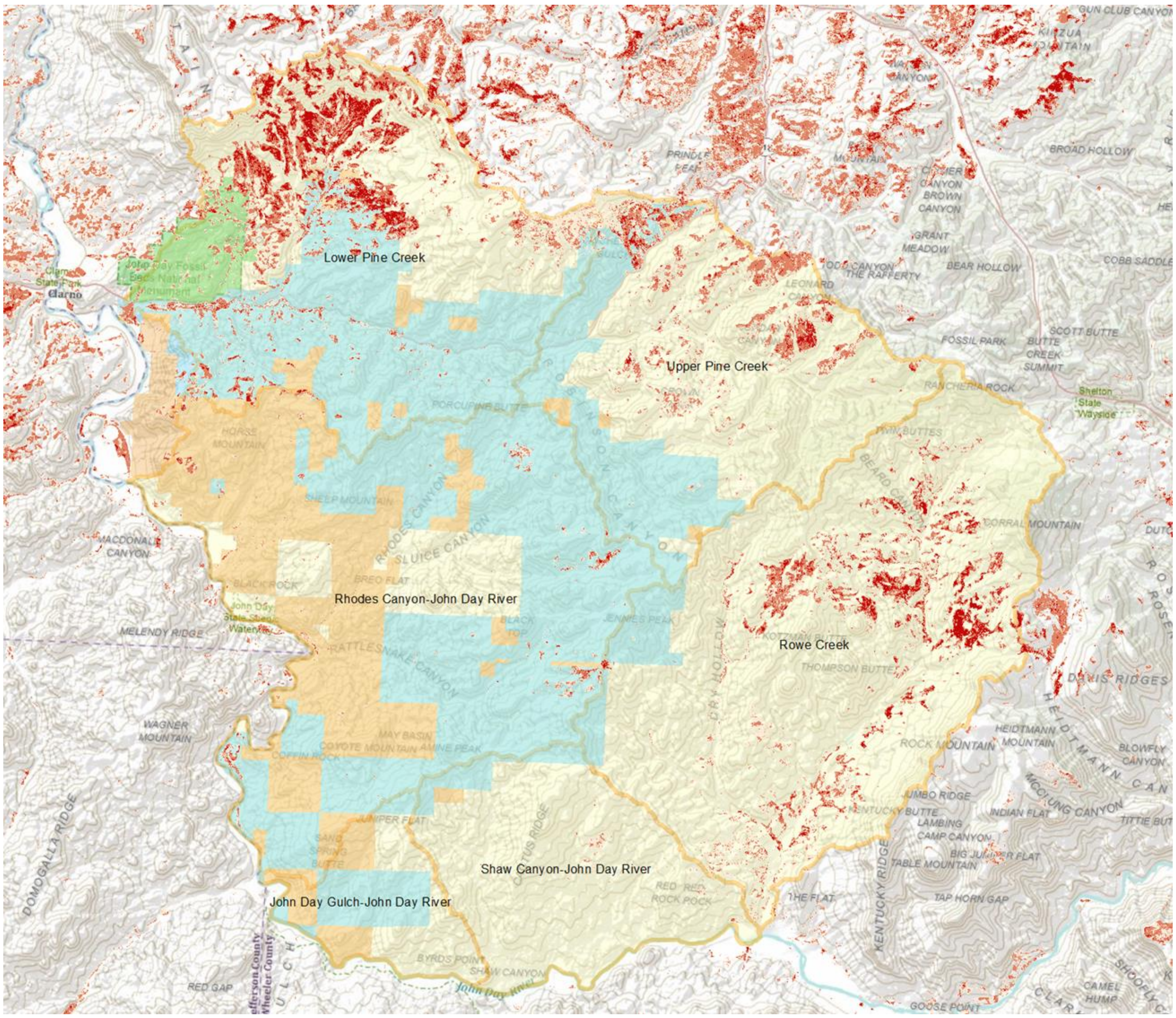

Figure 28. Predicted annual grass cover (red) and ownerships in the paired watersheds. In this map, PCCA is in blue, BLM in Orange, Clarno Unit of John Day Fossil Beds are in green, and private lands in yellow.

When looking at the distribution of annual grasses in the Lower Pine Creek Watershed, the densest concentrations occur in the private lands north of Highway 218, in areas which have experienced wildfires. However, areas in the Rhodes Canyon Watershed that also experienced the same fires appear to have much less of these species. It is possible that this difference is due to differences in post-fire management, with the Rhodes Canyon watershed areas having livestock excluded following fires, and the private lands in the Pine Creek watershed being grazed following the fire. It is also possible that the Lower Pine Creek private lands had higher concentrations of annual grasses before the fires because of their proximity to perennial streams, and the fire allowed these annual grasses to increase. Or it could be a combination of these factors.

We did not evaluate the combination of juniper declines, annual grasses and fires in this study, largely due to limitations in time and money. In the Lower Pine Creek Watershed and the Rhodes Canyon Watershed, patches dominated by annual grasses almost always represent either abandoned farmed or improved pasture sites, or areas of dense livestock concentrations due to the intentional placement of salt licks or water troughs. This has been reported to be the case in the larger patches at Rowe Creek as well. However, this is not really the case on the privately owned south slopes in Lower Pine Creek, where the annuals seem to be dominating large, rocky sites that have not been previously farmed. Clearly, more research needs to be done in this area.

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INR would like to thank NRCS staff for collecting point locations of invasive annual grasses in addition to providing funding, support, and feedback throughout the project. The Warm Spring Tribes provided invaluable invasive annual training data from field work that was collected on the Pine Creek Conservation Area between 2011-2013, in addition to providing the LiDAR data that was used to train the predictive juniper mapping models. We would also like to thank Lindsey Wise (Institute for Natural Resources staff) for taking the time to thoroughly edit and review the report.

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Deliverables

The data structure of the spatial data created and delivered as part of this project is included below:

Root Directory	References and Products	Sub Directory 1	Sub Directory 2	Data file names	Date file description
NRCS_data	GIS_reference	Accuracy_assessmnet		NRCS_sample_polygons_021313l.shp	Randomly generated photo interpreted plots in 1994/5 and 2011 for the juniper canopy cover accuracy assessment
		Extent_boundaries		invasive_annual_extent.shp	Outline/extent of final invasive annual map
				juniper_cover_extent.shp	Outline/extent of final juniper canopy cover map extent
				paired_watersheds.shp	Paired watershed study area
				PCCA_BLM_NPS_boundary.shp	Conservation lands in the paired watershed
				Weed_Priority_Areas.shp	Weed priority areas from NRCS
		Gap_juniper		gap_JUOC.img	Areas that GAP map mapped as juniper (30m resolution)
		HJ_andrews_juniper		HJA_JUOC_1936.img	Historic juniper map from 1936 (30m resolution)
		Landsat		1995_landsat_mosaic.img	1995 Landsat mosaic of three TM scenes in eastern OR
				2011_landsat_mosaic.img	2011 Landsat mosaic of three TM scenes in eastern OR
		Mask		1994_mask	Mask created to exclude areas of non-potential juniper (created off 1995 data)
				2011_mask	Mask created to exclude areas of non-potential juniper (created off 2011 data)
		Training_data	Annuals	annual_training_pts.shp	Annual training points compiled from PCCA, NRCS and iMAP field data collections
			Juniper	lidar_pnts.shp	Randomly generated juniper canopy cover training points, canopy cover derived from LiDAR data at PCCA
			Mask	modeling_mask_training_points.shp	Photo interpreted points generated to mask out areas of non potential juniper
	Products	Historical_juniper	Aerial_photos	1951_mosaic.img	Scanned 1951 aerial photos that have been mosaicked and georeferenced (paired-watershed study area)
				1980_mosaic.img	Scanned 1980 aerial photos that have been mosaicked and georeferenced (paired-watershed study area)
				2000_mosaic.img	2000 DOQ's mosaiced downloaded from Oregon Geospatial Office (paired-watershed study area)
			Classified_juniper_map	juniper_canopy_cover_1951.img	Modeled juniper canopy cover for 1951 (paired watershed study area)
			Images	decrease.png	Map of juniper decreases between 1951-2011 (paired watershed study area)
				increase.png	Map of juniper increases between 1951-2011 (paired watershed study area)
				watershed.png	Graphic showing juniper changes by watershed (paired watershed study area)
		Invasive_annual_weed_data	Classified_annual_map	invasive_annuals.img	Classified invasive annual map, depicts only the top 90% occurrence likelihood of annuals (4.3 million acre study area)
			Continuous_annual_map	NRCS_annuals_predict.tif	Raw output from invasive annual weed modeling - values range from 1-100, with low values representing least likely weed occurrence and higher values representing higher probability of weed occurrence.
		Juniper_data	Classified_juniper_maps	juniper_canopy_cover_1994.img	Classified juniper map from 1994, modeled output has had mask burnt into it
				juniper_canopy_cover_2011.img	Classified juniper map from 2011, modeled output has had mask burnt into it
			Continuous_juniper_maps	1994_canopy_cover.img	Raw output from 1994 juniper canopy cover modeling - values range from 1-100 and represent % canopy cover
				1994_canopy_cover_mask.img	Raw output from 1994 juniper canopy cover modeling - values range from 1-100 and represent % canopy cover (1994 mask has been burnt in)
				2011_canopy_cover.img	Raw output from 2011 juniper canopy cover modeling - values range from 1-100 and represent % canopy cover
				2011_canopy_cover_mask.img	Raw output from 2011 juniper canopy cover modeling - values range from 1-100 and represent % canopy cover (2011 mask has been burnt in)
			Juniper_change	juniper_change.img	Continuous canopy cover maps were differenced, changes of >10% increase or decrease were reclassified into the subsequent change classes, differences <10% were mapped as no change
		Report	ppt	NRCS_INR_debriefing.ppt	Juniper mapping, historic mapping, paired watershed study and invasive annual weed mapping PowerPoint
			doc	Mapping juniper and invasive annuals in eastern Oregon.doc	Final report