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Southeast Idaho Disasters II

Using Earth Observing Systems to Characterize Juniper Invasion and Assess Changes in Soil Moisture within Cheatgrass Dominated Sites Relative to Wildfire Susceptibility in East Idaho

DEVELOP Technical Report
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I. Abstract

The expansion of juniper from their original rocky terrain into herbaceous communities alter fire regimes and increase fire severity not only in Idaho but throughout the Great Basin and Intermountain West. As the range of juniper expands, they begin to co-dominate communities resulting in the die-off of shrubs, grasses, and forbs. Wildfires, coupled with the presence of invasive plant species like cheatgrass, are primary drivers of change in semi-arid savanna ecosystems. By comparing soil moisture changes in cheatgrass dominated sites with sagebrush dominated sites, this project will provide maps and graphs that will aid project partners in understanding why vegetation is departing from its native habitat and help with vegetation conservation efforts. This project looked at the historical changes in juniper distribution from 1985 to 2015. Imagery from Landsat 5 and 8 was gathered in 5 year increments in August or September was combined with different topographic and climatic data to characterize juniper expansion. The maps produced provide land managers with the most current information on juniper encroachment and support decision making regarding the management of junipers.

Keywords
Juniper (Juniperus spp.), Juniper Encroachment, Cheatgrass, Wildfire Susceptibility, Soil moisture, Idaho, Landsat, SMAP

II. Introduction

Overview

Two of the most pronounced vegetation changes throughout the Intermountain West is the expansion of Juniper (*Juniperus, spp.)* and the invasion of *Bromus tectorum L.,* a noxious weed, commonly known as cheatgrass. Both of these species are primary drivers of change in native semi-arid savanna ecosystems and play a large role in changing fire regimes. Though fire often plays an essential role in wildland ecology and helps maintain natural processes, too many occurrences of wildfire can induce a loss of biodiversity, disrupt ecosystems, and deplete resources (Oppenheimer 2012; Whisenant 1990). A study by Balch et al., conducted in 2013 found that cheatgrass-dominated landscapes were four times more likely to ignite than native vegetation types. Recent estimates have placed contemporary juniper stands at 18 million hectares (Williams et al. 2014). This increase in fuel loads combined with the fine under-story fuels like cheatgrass and other herbaceous material, has changed fire regimes and amplified the severity of wildfires throughout this region (Miller 2005; Miller & Wigand 1994).

Juniper is native shrub species that has expanded from its traditional fire-safe habitats into fire-dependent communities as a result of climatic fluctuations, grazing patterns, and wildfire suppression efforts (Ansley & Wiedemann 2008; Barney & Frischknecht 1974; Dennison et al. 2014; Miller & Tausch 2001; Noson et al. 2006). The driving mechanisms for the increase in junipers is unknown and understanding the historical conditions and locations of juniper will help in understanding drivers of recent change (Miller 2009). Researchers have discovered that phases of juniper encroachment are directly linked to juniper dominance over other ecological processes (Davis et al. 2010). As woody plants encroach on savannas there are high ecological consequences such as changes in soil chemistry and lower species richness (Sahara et al. 2015).

Past methods have included using various remote sensing data in correlation to ground truthing. Most ground truthing is conducted by using the line-intercept method which measures the amount and type of vegetation that crosses a study line (Caratti 2006). Remote sensing studies use a variety of data including Landsat and LIDAR (Campell et al. 2012; Chen et al. 2011; Noone et al. 2013; Sankey et al. 2010; Sankey & Germino 2008). Studies have focused on spectral reflectance (Bradley & Fleishman 2008; Campbell et al. 2012; Lupton 2008), near-infrared (NIR) (Everitt et al. 2001) and object-based image analysis (OBIA) (Davies et al. 2010; Roundy et al. 2015) to identify juniper encroachment.

Researchers suggest that cheatgrass dominates 2.5 million ha (6.2 million acres) of former sagebrush-grass rangelands in southern Idaho and roughly 10.1 million ha (25 million acres) in the Great Basin (Pellant et al. 2004; Laycock 1991). This plant is flammable 4 to 6 weeks sooner than native plants and is susceptible to wildfire 1 to 2 months longer than native perennials (Platt & Jackman 1946); this has effectively extended the fire season and has caused landscapes to burn more frequently (Chen & Weber et al. 2001; Mealor *et al.* 2013; Pellant 1996; Stewart & Hull 1949).

In semi-arid climates, spring water and vegetative cover dictate the following growing season water use. Both juniper and cheatgrass are reducing the amount of water that native plants can use based on their root structure. Junipers draw from the deeper reserves over the winter period at depths (>200cm) effectively reducing the amount of soil moisture during the growing season (Mollnau et al. 2014). Cheatgrass is a self-pollinating winter annual and can germinate in the fall or early spring. Its root structure primarily grows in the winter and can out compete native species for water at shallow depth during the next growing season (Harris 1977; Melgoza & Nowak 1991). By using up available resources before native species, cheatgrass can limit or stop the germination process and diminish root length densities of nearby vegetation. (Melgoza & Nowak 1991) Multiple studies have shown that cheatgrass will out compete native perennial species for soil resources (Cline et al. 1977; Harris 1977; Melgoza & Nowak 1991). It is well recognized that surface soil moisture measurements are significant and can be used for a number of ways, such as agricultural production forecasting, drought prediction, and ecosystem health monitoring (Link, C. et al., 2016).

Objectives

There were two objectives of this study; the first was to characterize juniper encroachment by analyzing 30 meter Landsat imagery from 1985 to 2015 and the second was to assesses temporal changes in soil moisture in cheatgrass dominated sites and compare that to sagebrush dominated sites over the 2015 growing season; April 1st through September 30th.

Study Area

The study area includes the semi-arid savanna rangelands and mountainous forest regions of Southeast Idaho. The ecology of this region encompasses the Snake River Plain, an area classified as a 'cold desert' that sustains much of the plant and animal life unique to this area.

Figure 1 - Study area and extent within Idaho. Image from Landsat 8 OLI

Project Partners

This project falls under the Disasters NASA National Application Area. We worked with the Bureau of Land Management (BLM), Idaho Fish and Game, and Carabou Targhee National Forest to gain a better understanding of where junipers are encroaching and why they are moving into those areas. The BLM is the primary end user for this project. Recent efforts to manage juniper expansion has included mechanical treatments such as thinning (removing a proportion of trees within a dense stand), limbing (removing the lower limbs on all trees within a stand to reduce the potential for a fire to enter the crown), and shredding juniper stands (C. Burger, personal communication, October 27th 2015). These efforts have limited success in part because pre- and post-treatment of juniper density is unknown.

Similarly, cheatgrass invasion is a concern for our end-users and the broader wildfire management community. Currently, there are no active cheatgrass management plans in Idaho.

III. Methodology

Data Acquisition

Satellite Imagery

Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) imagery was acquired from the United States Geological Survey's (USGS) Earth Explorer for WRS-2 Path 39 Row 30 and WRS-2 Path 39 Row 31. Seven images were downloaded in five year increments from 1985 to 2015. August or September imagery was chosen because evergreens are easily distinguishable compared to the less photosynthetically active vegetation.

Level 3 Global Daily Passive Radiometer data from the Soil Moisture Active Passive (SMAP) satellite was visualized using NASA Worldview to make sure the images covered the study region. Seventy-seven images were downloaded using EOSDIS Reverb | ECHO from April 15th to September 30th 2015.

Classification Sites

Five classes of land cover vegetation were analyzed: juniper mix, bare ground, mixed forest, cheatgrass, and sagebrush/herbaceous. The juniper mix classification included: Western Juniper, Utah Juniper, Pinyon-Juniper, and Rocky Mountain Juniper. The mixed forest classification included: Conifer, Douglas-Fir, Pine, Spruce, Aspen, Maple, and Mahogany.

The classification dataset were created by digitized points from the 2009, 2011, 2013, and 2015 National Agricultural Imagery Program (NAIP) imagery, Landsat 8 derived Modified Soil-adjusted Vegetation Index (mSAVI2), and a classified cheatgrass map from Clinton et al., 2010. These data were correlated with 2014 Caribou-Targhee National Forest mid-level vegetation data from RSAC and *in situ* data from the BLM for Pleasentview and Samaria areas that identify Aspen, Conifer, Maple, and Brush stands to correctly identify species type. Also, included in the classification dataset were in-situ point data from the University of Georgia's Center for Invasive Species and Ecosystem Health, 2013 BLM summer field season, and Idaho State University GIS Training and Research Center's 2014 and 2015 summer field season. Using the historic fire dataset compiled by NASA and the GIS TReC center at ISU, vegetation points were removed that may have burned prior to running a classification tree on each Landsat image.

Precipitation and Temperature

ArgiMet daily precipitation and mean daily air temperature data was downloaded for April to September 2015. These data incorporate the growing and fire season in Idaho. The data was averaged by month (Appendix A).

Supplemental Imagery

Surface Management Agency (SMA) data, created in 2015, was acquired through the NASA RECOVER program. This data was chosen for the ability to distinguish between privately and publically owned lands. US Forest Service Remote Sensing Application Center (RSAC) mid-level vegetation data, created in 2015, was acquired through the United States Forest Service. This data was chosen to help identify and verify vegetation type.

Data Processing

Soil Moisture Model

SMAP's Level 3 Soil Moisture Passive algorithm includes soil moisture data, ancillary data, and quality assessment flags; these data are currently in Beta-release and measures brightness temperature and soil moisture in a hierarchical data format (O'Neill, P.E., et al., 2015). Seventy-seven images were downloaded and clipped to the windowed study area (20,325 km²).

Juniper Encroachment Data

The seven Landsat images all had less than 10 % cloud cover and were mosaicked together using IDRISI TerrSet. Corrections for atmospheric effects were applied using the Cos(t) model; while calculations to derive surface reflectance from multispectral bands were computed using the IDRISI TerrSet Landsat archive import model. 30m slope and aspect were derived from the National Elevation Dataset. Prior to running the CTAs mSAVI2, and Tassel Cap Transformation (TCT) brightness, wetness, and greenness (Huang et al. 2002), Normalized Difference Vegetation Index (NDVI), Near Difference Bare Soil Index (NDBSI), and topographic variables were standardized by ensuring all data were projected to WGS 84 UTM zone 12N. Standardization of rows and columns was accomplished by applying a window of 20,325 km² (7,847 miles²) that did not extend past the boundary of any image used in the classification tree analysis CTA.

Juniper Prediction Model

TerrSet Land Change Modeler for Ecological Sustainability (LCM) was used for predicting potential juniper change. Prior to running the LCM a digital elevation model (DEM) of the study area was entered into the initial parameters sessions. Formatting of the CTA legends was done by using the harmonizing function in the LCM.

Data Analysis

Soil Moisture Model

A total of 12 pixels encompass our study region. These pixels were turned into a grid and given an identification number (Figure 2). The national vegetation classes within the GAP dataset were reclassified into 9 land cover categories and zonal statistics was performed to determine percent cover of the different land cover categories within a given pixel. The pixels that had land classifications with at least 20% difference between the majority land cover and the next dominant class were averaged by month and analyzed to see how one pixel may act differently than another based upon vegetation type.

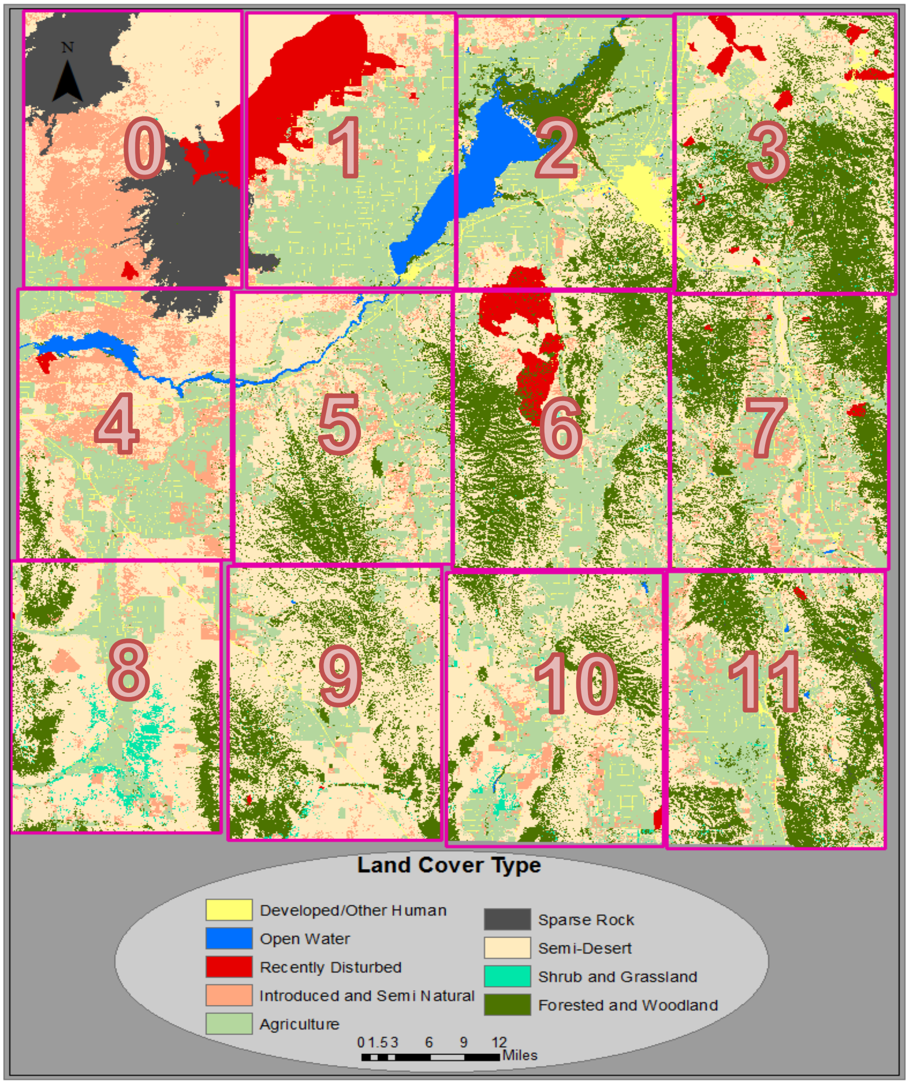

Figure 2 – SMAP pixels overlaid with GAP land cover data

Juniper Encroachment Data

Classification tree analysis is a supervised, decision-tree based classification method described as being data driven and nonparametric (Miller & Franklin, 2002). Individual pixels are classified based upon spectral signatures exposed by the various vegetation indices through a random subset of the classification dataset. The Gini split method and a 5% auto-pruning were specified in the classification. The Gini splitting rule was selected in an attempt to find the largest homogenous category in the data and isolate the remainders (Zambon et al., 2005). Training and validation datasets were randomly divided using ArcMap Subset Features data management tool with 60% used to train the model and 40% used to validate the model.

Binary juniper raster's were created by extracting the classified junipers from the CTAs. These raster's were added together to create one feature class. This feature class showed areas of intersection from multiple years with value of one to seven (Appendix B). Strong intersections were determined to be between four and seven years of agreement and were combined with topographic variables slope and aspect. The binary juniper raster data was also used to better visualize juniper growth between years (Appendix C).

Juniper Prediction Model

A map of transition from sagebrush to juniper was created under the Change Analysis section of the LCM. A sub model from sagebrush to juniper was made in Transition Sub-Models. This transition map was then used as an input variable in the Variable Transformation Utility (VTU), using evidence likelihood transformation variable. The output for the VTU was then tested and driver variables were added to the model as a dynamic land cover with distance operation. The Multi-Layer Perceptron (MLP) was run under default parameters and a Transition Potential dataset was created. Markov Chain model was specified with a 2015 prediction date in the Change Demand Modeling. Using a Logical and soft prediction aggregation type the sagebrush and juniper model was run. To test this model CTA's from1990 and 2010 were used as inputs and the model forecasted to 2015, where we had a known classifications.

IV. Results & Discussion

Results

Soil Moisture Model

Of the 12 pixels 5 met the criteria for further analysis. Pixels 1 and 2 were determined to be dominated by agricultural vegetation with a 26.68% and 21.57% difference between the next vegetation category of semi-desert shrub and grassland. Pixels 8, 9, and 10 were classified as semi-desert shrub and grassland with 40.12%, 40.24%, and 31.31% variation between this class and agricultural (8 and 10) and forest woodland (9) as the next dominant categories. With the exception of pixel 5, with a 17% difference, all of the other pixels had less than 10% variability between the dominant cover and the next vegetation category (Appendix E).

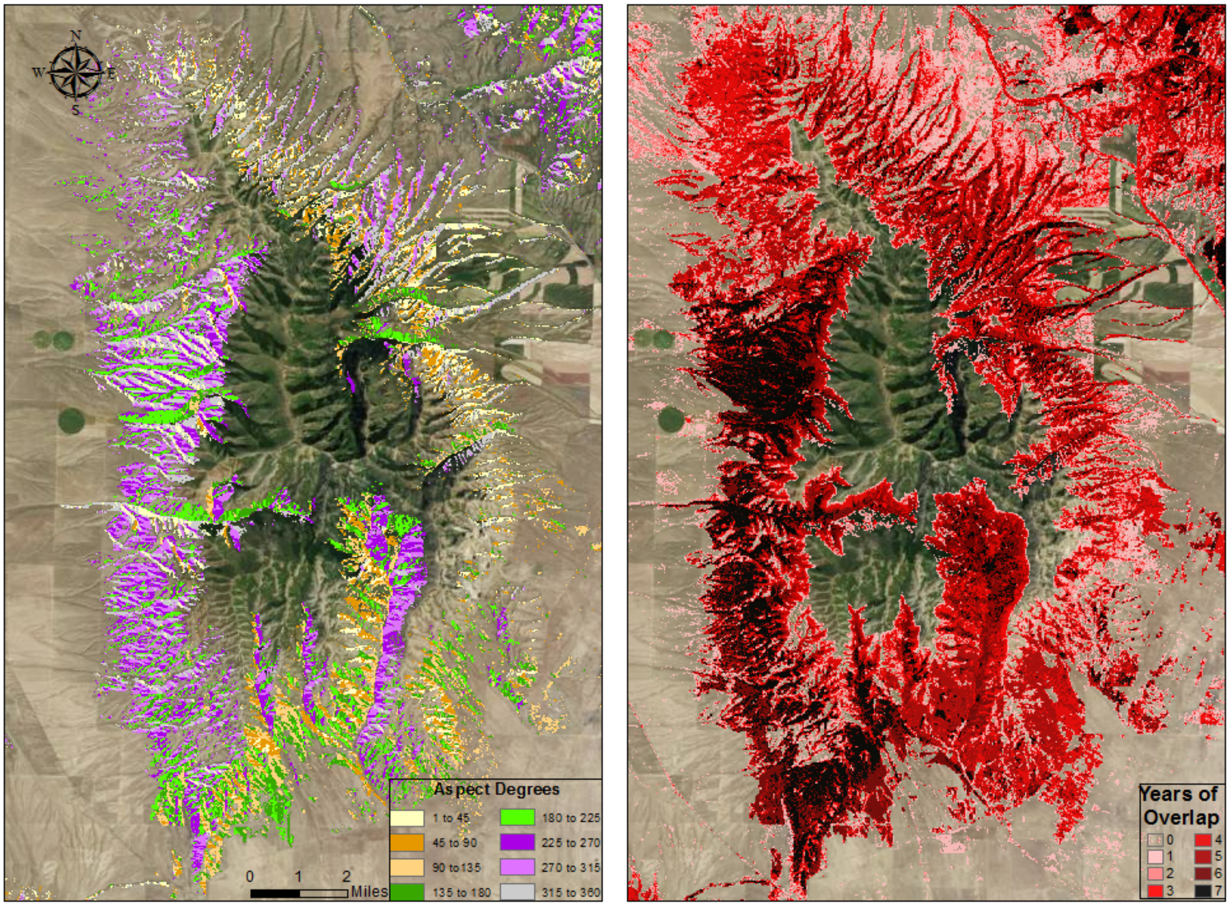

Figure 3 – Zoomed in image caparison of combined juniper locations and aspect

Juniper Encroachment Data

This project found that although juniper can and does grow on all aspects, this species seems to prefer south western slopes from roughly 180 degrees to 315 degrees (Figure 3). This could be because there is less competition from larger species such as Douglas Firs that typically grow on northern facing slopes. As a result juniper is a powerful player on the landscape because it is competing against smaller plants like sagebrush. In just a few years' time juniper is taller than other surrounding species and will soak up more sunlight and grow deeper roots used to grab soil water in the winter thus edging out nearby species.

The intersecting binary raster's were used to identify juniper movement between years. Years that were seen to have a lot of growth were compared to the juniper intersection raster to see if the data was an outlier or if there was true change. The reduction of juniper from 1985 to 1990 was noticeable. After comparing these results with the juniper agreement raster many of the areas that had been classified juniper in 1985 were not classified as such in any other year. Therefore it was concluded that these areas were most likely misclassified. Another noticeable change occurred between 2010 and

2015.The 2010 and 2015 intersecting raster's classified less juniper in an area Pocatello, ID. Comparing this area with the historic fire dataset it was found that this was the area of a large wildfire in 2012.

Juniper Prediction Model

Validation was run on the prediction model for 2015 using the LCM. The initial coverage layer was the 2010 CTA results with the 2015 prediction land cover validated against the 2015 CTA. The output showed that sagebrush to juniper prediction had correlation with validation layer within the given data set. The results of the 2015 model were inconclusive therefore a model could not be created to predict change into the future with any certainty.

Discussion

Soil Moisture Model

This project was not able to determine any changes in soil moisture based upon specific vegetation types due to the large pixel size of the SMAP passive sensor but differences between land cover types can be seen (Figure 2). The huge spike in June in the agricultural pixels may be a result of farmers starting to use irrigation on their crops. The sharp drop in soil moisture from May to June in the semi-desert shrub and grassland pixels led to concerns within the fire community about heavy fuel loading especially in the finer fuels. But July brought lightning storms accompanied by rain and as a result there were few fires in this study region in 2015. The addition of finer resolution soil moisture data from GPM could be leveraged to further understand changes in soil moisture between vegetation types. MERRA, although still in beta testing, should be

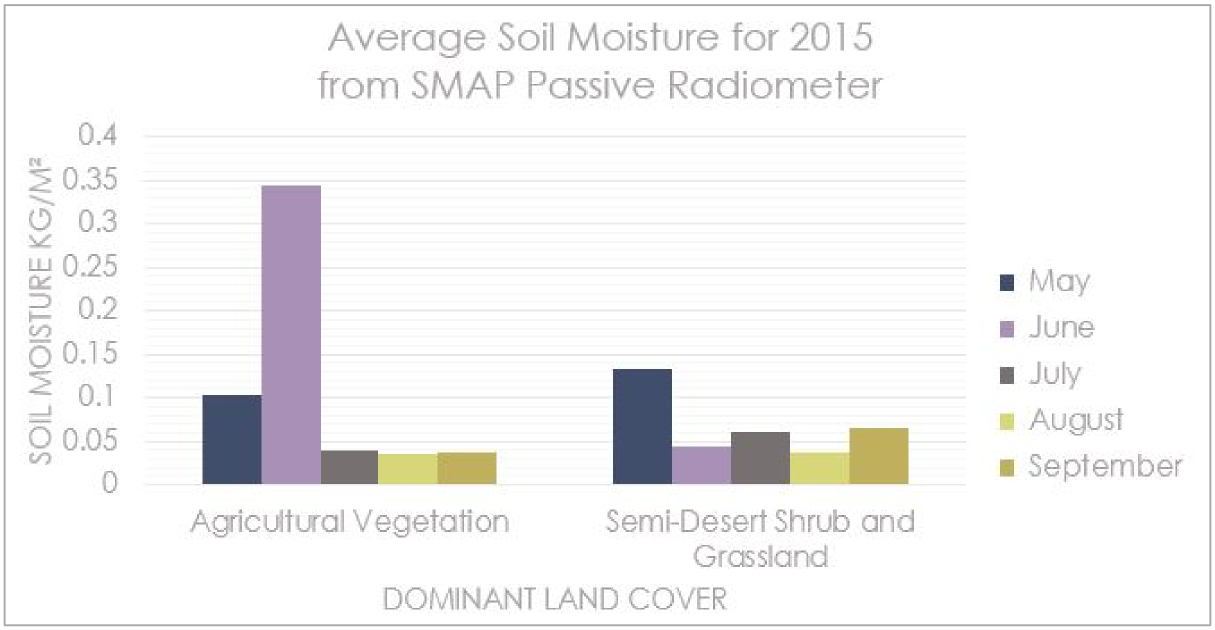

Figure 2 – Histogram displaying soil moisture measurement based on dominant land cover.

considered when looking at root zone soil wetness and may also be useful in identify areas of bare ground using a combination of leaf area index and bare soil evaporation analysis.

Juniper Encroachment Data

Due to the large amount of bare ground in this area spectral mixing introduced error due between vegetation classes. Denoting spectral signatures of junipers were also difficult due to the similarities between juniper and agricultural reflectance. The depth of the Landsat archive is advantageous when looking to analyze landscape changes but due to the slow growth rate of juniper an even longer temporal analysis may be beneficial in trying to characters where junipers are moving.

The overall classifications for the CTAs improved in the early years of the study period. This is most likely due to the fact that the classification points used to train the CTAs were created off imagery that was more reprehensive of the landscape at that time (Appendix D). Classification error could also have been introduced when removing classification points based on historical fire data. It is not known if the vegetation actually burned nor if they were able to reestablish by the time they were reintroduced into the classification sample. Adding in-situ data for training and validation sites could result in greater accuracy for the CTAs. Future work related to this study would want to address the lack of class homogeneity within 30-meter Landsat pixels as well as quantifying the abundance of “bare ground” in each pixel.

Juniper Prediction Model

Further exploration into the LCM is needed but still may be a useful tool when analyzing the changes from juniper into sagebrush regions. The introduction of multiple classification years in a prediction model may be able to analyze past change and thus predict future changes with greater certainty.

V. Conclusions

Understanding historical juniper movement is possible utilizing remotely sensed data. The depth of the Landsat missions make it possible to analyze changes on the environment over a long period of time. Predicting where this species will move in the future proved to be challenging and the addition of other characterizing information such as soil type into a change model is needed.

Determining dominant land cover type in correlation with soil moisture data on large land cover classes is possible using SMAP passive radiometer data if the land cover type is clearly dominate. This is advantageous in further understanding why vegetation is departing from its native habitat and help with vegetation conservation efforts.

The results from the juniper encroachment analysis will be useful for land managers in fire prevention planning and allocation of resources used for juniper reduction that will help to reduce wildfire severity and intensity by reducing heavy fuel loads. Overall these results relate directly to improving understanding of wildfire susceptibility and as wildfires continue to grow understanding of how remote sensing can be used to provide different types of information on a larger spatial scale is beneficial for our land managers in many different aspects of planning, fuels management, and land restoration.

VI. Acknowledgments

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VII. References

April Sahara, E., Sarr, D. A., Van Kirk, R. W., & Jules, E. S. (2015). Quantifying habitat loss: Assessing tree encroachment into a serpentine savanna using dendroecology and remote sensing. *Forest Ecology and Management*, 340, 9–21.

Ansley, R. J., & Wiedemann, H. T. (2008). Reversing the woodland steady state: vegetation responses during restoration of Juniperus-dominated grasslands with chaining and fire. In *Western North American Juniperus Communities* (pp. 272-290). Springer New York.

Balch, J. K., Bradley, B. A., D'Antonio, C. M., & Gómez-Dans, J. (2013). Introduced annual grass increases regional fire activity across the arid western USA (1980–2009). *Global Change Biology*, 19(1), 173-183

Barney, M. A., & Frischknecht, N. C. (1974). Vegetation changes following fire in the pinyon-juniper type of west-central Utah. *Journal of Range Management*, 91-96.

Bradley, B. A., & Fleishman, E. (2008). Relationships between expanding pinyon–juniper cover and topography in the central Great Basin, Nevada. *Journal of Biogeography*, *35*(5), 951-964.

Campbell, J. L., Kennedy, R. E., Cohen, W. B., & Miller, R. F. (2012). Assessing the carbon consequences of western juniper (Juniperus occidentalis) encroachment across Oregon, USA. *Rangeland Ecology & Management*, *65*(3), 223-231.

Caratti, J. F., et al. (2006). Line Intercept (LI). *FIREMON: Fire Effects Monitoring and Inventory System. Rocky Mountain Research Station, Natural Resources Research Center, Fort.*

Chen, F., Weber, K. T., Anderson, J., & Gokhal, B. (2011). Assessing the susceptibility of semiarid rangelands to wildfires using Terra MODIS and Landsat Thematic Mapper data. *International Journal of Wildland Fire*, 20(5), 690-701.

Cline, J. F., Uresk, D. W., & Rickard, W. H. (1977). Comparison of soil water used by a sagebrush-bunchgrass and a cheatgrass community. *Journal of Range Management*, 199-201.

Davies, K., Petersen, S., Johnson, D., Davis, D., Madsen, M., Zuirzdin, D., & Bates, J. (2010). Estimating Juniper Cover From national Agriculture Imagery program (NAIP) Imagery and Evaluating Relationships Between Potential Cover and Environmental Variables. *Rangeland Ecology & Management,* 63(6), 630-637.

Dennison, P. E., Brewer, S. C., Arnold, J. D., & Moritz, M. A. (2014). Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters*, *41*(8), 2928-2933.

Davies, K., Petersen, S., Johnson, D., Davis, D., Madsen, M., Zuirzdin, D., & Bates, J. (2010). Estimating Juniper Cover From national Agriculture Imagery program (NAIP) Imagery and Evaluating Relationships Between Potential Cover and Environmental Variables. *Rangeland Ecology & Management,* 63(6), 630-637.

Dudley, K. L., Dennison, P. E., Roth, K. L., Roberts, D. A., & Coates, A. R. (2015). A multi-temporal spectral library approach for mapping vegetation species across spatial and temporal phenological gradients. *Remote Sensing of Environment*, 167, 121-134

Everitt, J. H., Yang, C., Racher, B. J., Britton, C. M., & Davis, M. R. (2001). Remote sensing of redberry juniper in the Texas rolling plains. *Journal of Range Management*, 254-259.

Link, C., Entekhabi, B.D., Njoku, E. G., Neill, P.E.O., Kellogg, K.H., Crow, W.T., Zyl, J. (2016). The Soil Moisture Active Passive (SMAP) Mission.

Lupton, D. M. (2008). Remote Sensing of Wooded Species Remediation, 1–17.

Harris, G. A. (1977). Root phenology as a factor of competition among grass seedlings. *Journal of Range Management*, 30(3), 172-177.

Huang, C., Wylie, B., Yang, L., Homer, C., & Zylstra, G. (2002). Derivation of a tasselled cap transformation based on Landsat 7 at-satellite reflectance. *International Journal of Remote Sensing*, *23*(8), 1741-1748.

Laycock, W. A. (1991). Stable states and thresholds of range condition on North American rangelands: a viewpoint. *Journal of Range Management*, 427-433.(p. 430)

Melgoza, G., & Nowak, R. S. (1991). Competition between cheatgrass and two native species after fire: implications from observations and measurements of root distribution. *Journal of Range Management*, 27-33.

Miller, R. F., & Tausch, R. J. (2001). The role of fire in juniper and pinyon woodlands: a descriptive analysis. *Fire Conference 2000: The First National Congress on Fire Ecology, Prevention and Management.*

Miller, R. F. (2005). *Biology, ecology, and management of western juniper (Juniperus occidentalis)*. Corvallis, Or.: Agricultural Experiment Station, Oregon State University

Miller, R.F. (2009). Historical and modern disturbance regimes, stand structures, and landscape dynamics in pinon-juniper vegetation of the western United States. *Rangeland Ecology & Management, 62* (3), 203.

Miller, R., & Wigand, P. (1994). Holocene Changes in Semiarid Pinyon-Juniper Woodlands. *Bioscience*, 44(7), 465-474.

Mollnau, C., Newton, M., & Stringham, T. (2014). Soil water dynamics and water use in a western juniper (Juniperus occidentalis) woodland. *Journal of Arid Environments*, *102*, 117–126. http://doi.org/10.1016/j.jaridenv.2013.11.015

Morris, C., Morris, L., Leffler, A., Collins, C. H., Forman, A., Weltz, M., & Kitchen, S. (2013). Using long-term datasets to study exotic plant invasions on rangelands in the western United States. *Journal of Arid Environments, 95*, 65-74.

Noson, A. C., Schmitz, R. A., & Miller, R. F. (2006). Influence of fire and juniper encroachment on birds in high-elevation sagebrush steppe. *Western North American Naturalist*, *66*(3), 343-353.

Noone, M., Kagan, J. S., & Nielsen, E. (2013). *Western Juniper (Juniperus occidentalis) and invasive annual grass mapping in Eastern Oregon*. Institute for Natural Resources.

Roundy, D. B. (2015). Estimating Pinyon and Juniper Cover Across Utah Using NAIP Imagery. Retrieved from http://scholarsarchive.byu.edu/etd/5575/.

O'Neill, P. E., S. Chan, E. G. Njoku, T. Jackson, and R. Bindlish. 2015. *SMAP L3 Radiometer Global Daily 36 km EASE-Grid Soil Moisture, Version 2*. [L3_SM_P]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi:http://dx.doi.org/10.5067/7EW92T1NI4M4.

Oppenheimer, J. (2012). Fire in Idaho Lessons for Community Safety and Forest Restoration: An Analysis of Idaho's 2012 Fire Season. Retrieved June 3, 2015.

Pellant, M. (1996). Cheatgrass: The Invader That Won the West. Retrieved June 2, 2015.

Pellant, M., Abbey, B., & Karl, S. (2004). Restoring the Great Basin Desert, U.S.A.: Integrating science, management, and people. *Environmental Monitoring and Assessment*, 99(1-3), 169–179.

Platt, K. and E. R. Jackman. 1946. The cheatgrass problem in Oregon. Bull. 668. Oregon Agricultural Experiment Station. Corvallis, OR. 48 p.

Sankey, T. T., Glenn, N., Ehinger, S., Boehm, A., & Hardegree, S. (2010). Characterizing western juniper expansion via a fusion of Landsat 5 Thematic Mapper and LIDAR data. *Rangeland ecology & management*, *63*(5), 514-523.

Stewart, G. and A. C. Hull, Jr. 1949. Cheatgrass (Bromus tectorum L.) - an ecological intruder in southern Idaho. *Ecology* 30:58-74.

Wang, L., et al. (2007). Soil moisture estimation using MODIS and ground measurements in eastern China. *International Journal of Remote Sensing* 28(6), 1413-1418.

Whisenant, S. G. (1990). Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. Ogden (UT) US Department of Agriculture Forest Service, Intermountain Research Station.

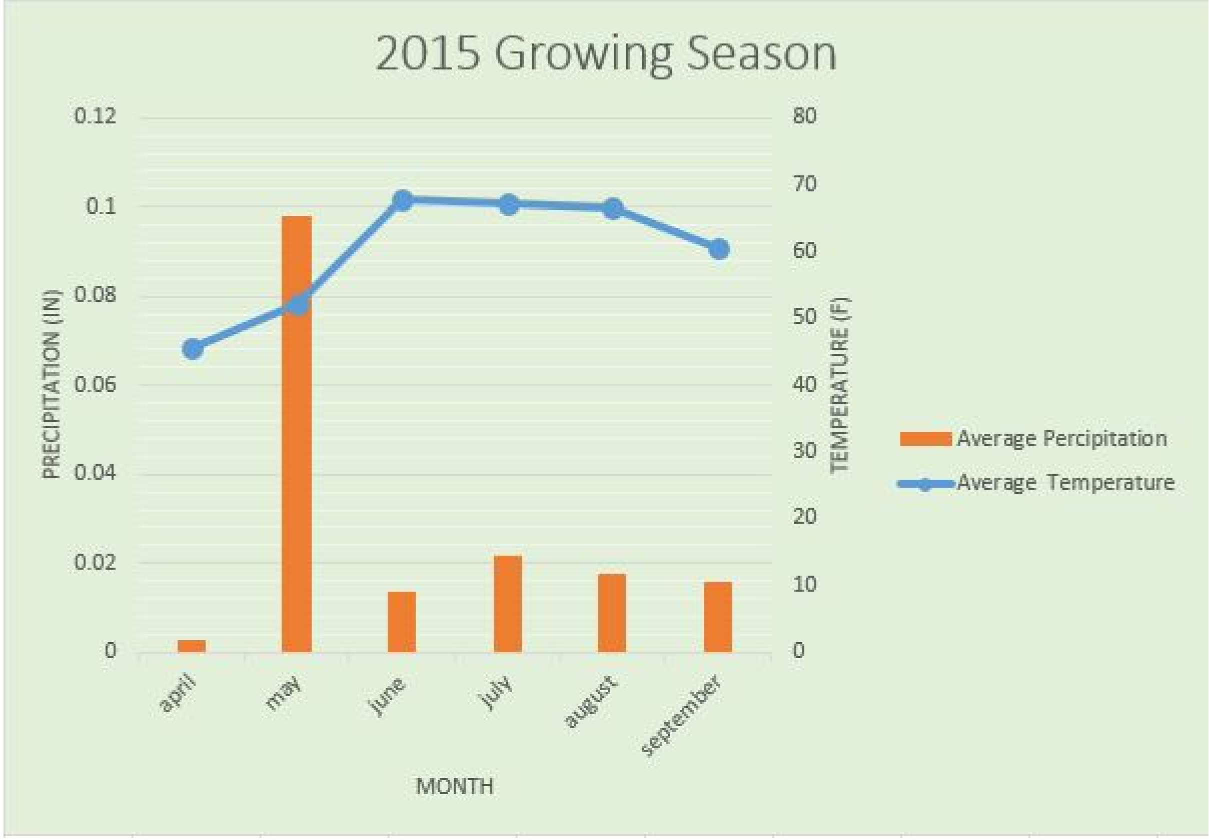
Williams, C. J., Pierson, F. B., Al-Hamdan, O. Z., Kormos, P. R., Hardegree, S. P., & Clark, P. E. (2014). Can wildfire serve as an ecohydrologic threshold-reversal mechanism on juniper-encroached shrublands. *Ecohydrology*, *7*(2), 453-477.

VIII. Content Innovation

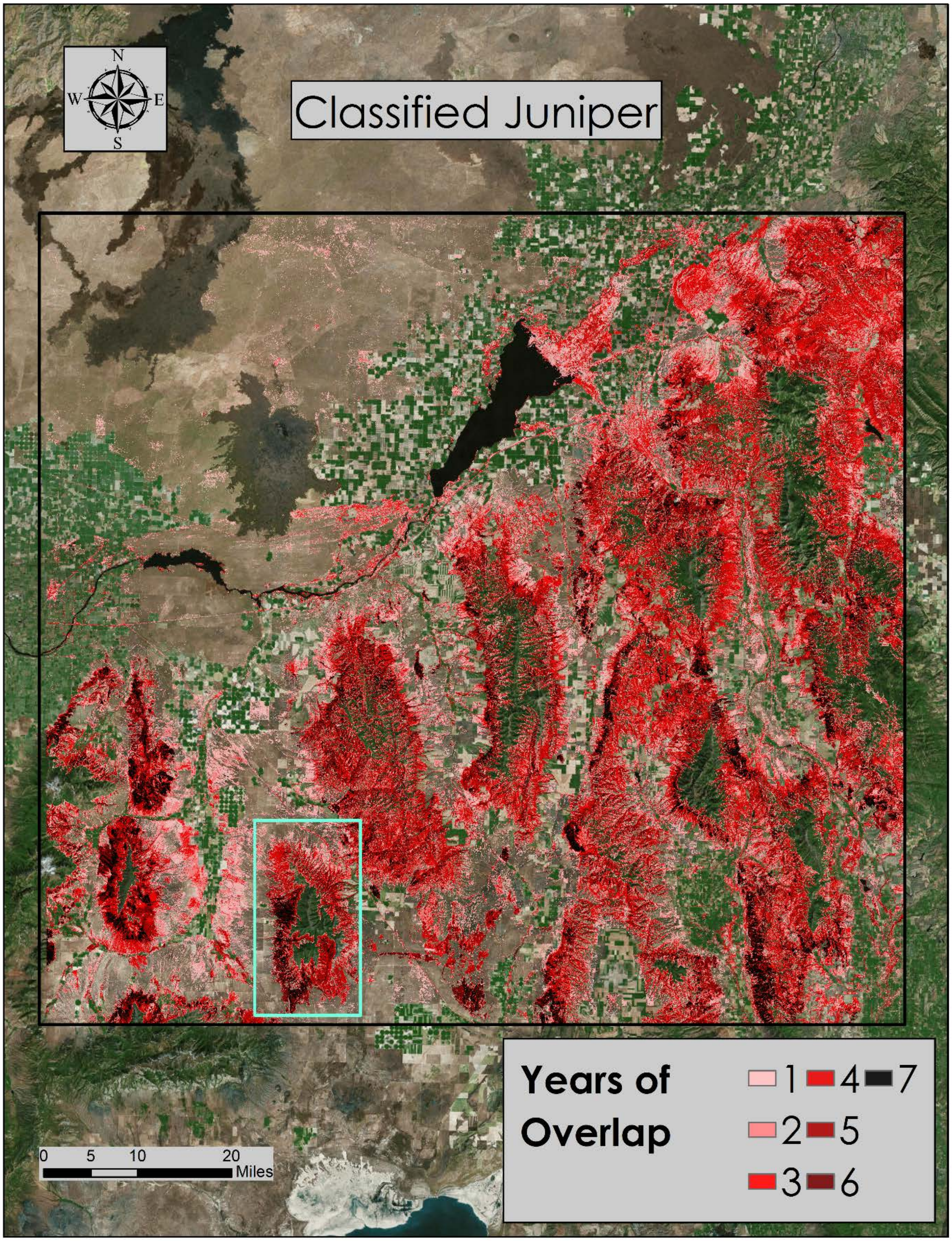
1. VPS Earthzine video entitled: Where have all the juniper gone?
2. Audio Slides
3. Inline supplementary material

IV. Appendices

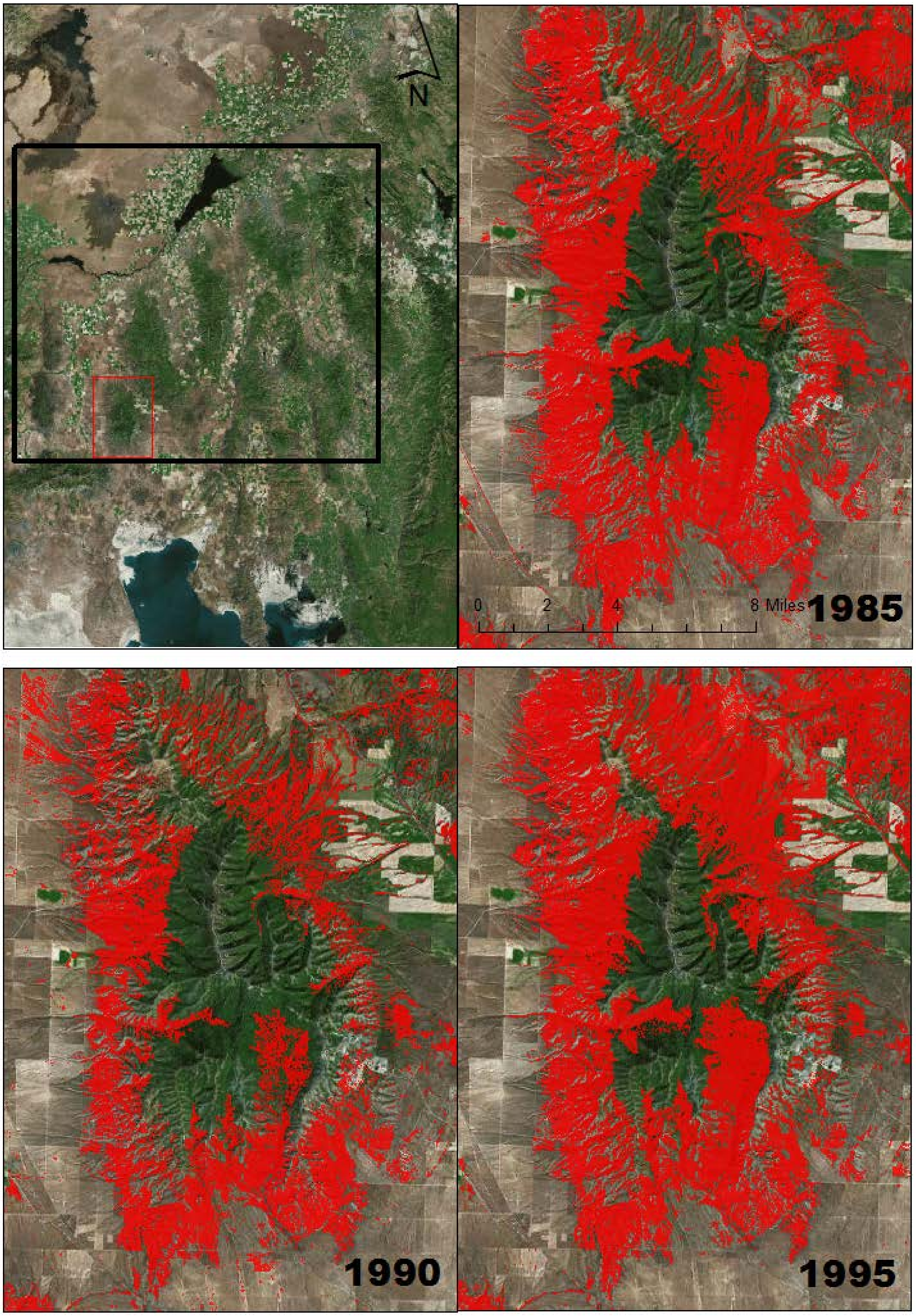
Appendix A- Averages precipitation and daily air temperature from Arigmet Weather station data.

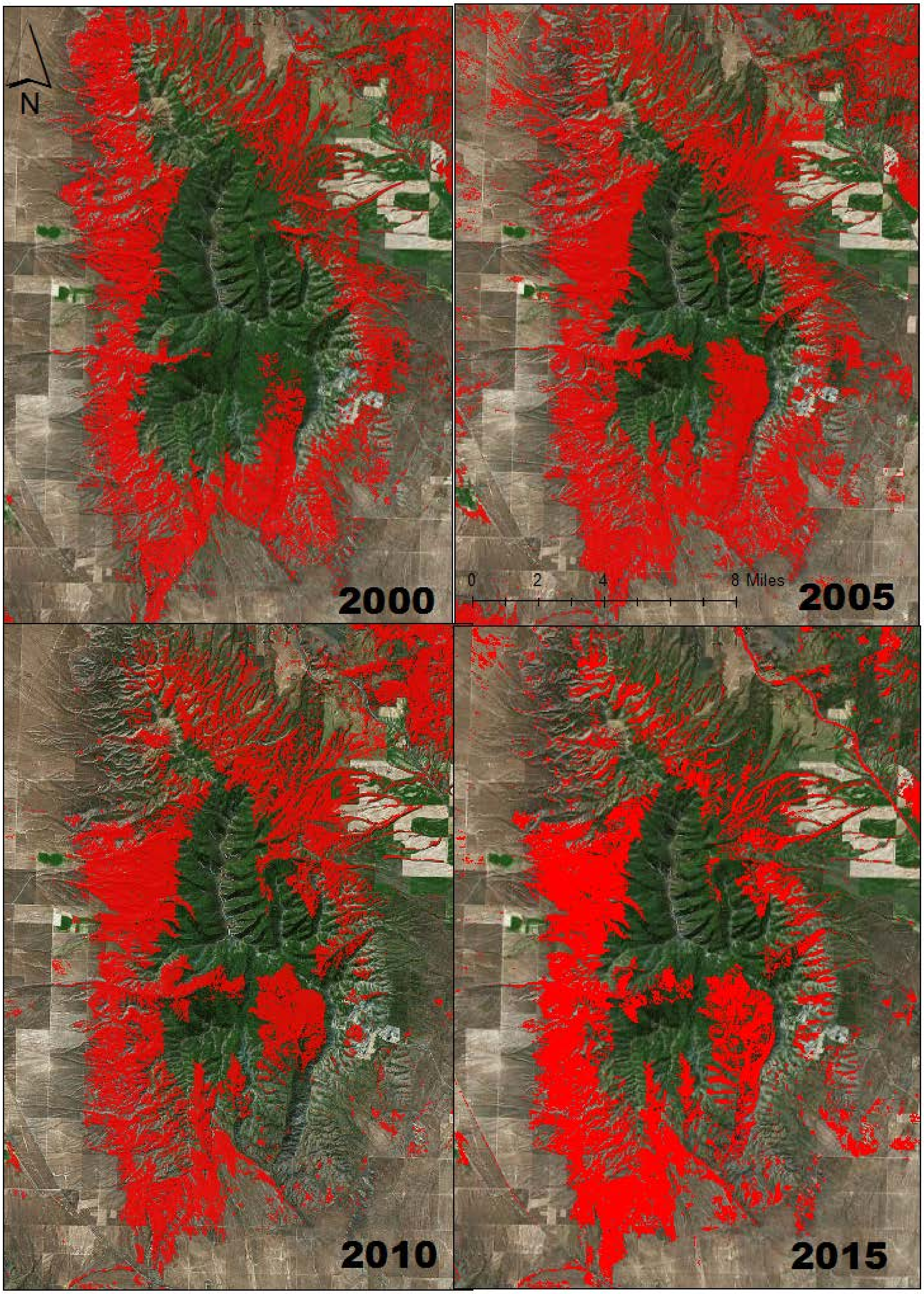


Appendix B – Combined CTA results for classified juniper stands over the years.



Appendix C – Depicting juniper CTA results over the years. These results were added together to create appendix b.

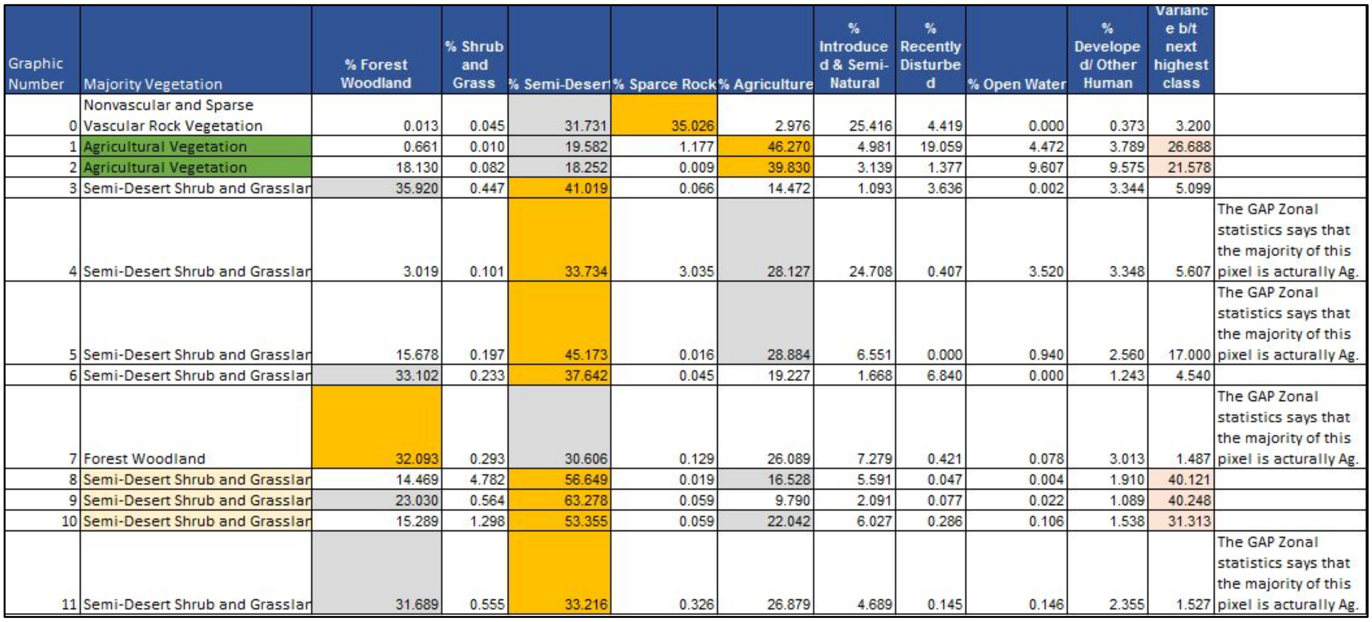



N
2000
0
2
4
8 Miles
2005
2010
2015

Appendix D – Overall Kappa's for CTAs

CTA Year	Overall Kappa
1985	0.70
1990	0.69
1995	0.68
2000	0.68
2005	0.76
2010	0.78
2015	0.78

Appendix E – Percent cover based upon zonal statistics of GAP data to determine dominant vegetation in a given SMAP pixel



Graphic Number	Majority Vegetation	% Forest Woodland	% Shrub and Grass	% Semi-Deser	% Sparce Rock	% Agriculture	% Introduced & Semi-Natural	% Recently Disturbed	% Open Water	% Developed/ Other Human	Variance b/t next highest class	
0	Nonvascular and Sparse Vascular Rock Vegetation	0.013	0.045	31.731	35.026	2.976	25.416	4.419	0.000	0.373	3.200	
1	Agricultural Vegetation	0.661	0.010	19.582	1.177	46.270	4.981	19.059	4.472	3.789	26.688	
2	Agricultural Vegetation	18.130	0.082	18.252	0.009	39.830	3.139	1.377	9.607	9.575	21.578	
3	Semi-Desert Shrub and Grasslar	35.920	0.447	41.019	0.066	14.472	1.093	3.636	0.002	3.344	5.099	
4	Semi-Desert Shrub and Grasslar	3.019	0.101	33.734	3.035	28.127	24.708	0.407	3.520	3.348	5.607	The GAP Zonal statistics says that the majority of this pixel is acturally Ag.
5	Semi-Desert Shrub and Grasslar	15.678	0.197	45.173	0.016	28.884	6.551	0.000	0.940	2.560	17.000	The GAP Zonal statistics says that the majority of this pixel is acturally Ag.
6	Semi-Desert Shrub and Grasslar	33.102	0.233	37.642	0.045	19.227	1.668	6.840	0.000	1.243	4.540	
7	Forest Woodland	32.093	0.293	30.606	0.129	26.089	7.279	0.421	0.078	3.013	1.487	The GAP Zonal statistics says that the majority of this pixel is acturally Ag.
8	Semi-Desert Shrub and Grasslar	14.469	4.782	56.649	0.019	16.528	5.591	0.047	0.004	1.910	40.121	
9	Semi-Desert Shrub and Grasslar	23.030	0.564	63.278	0.059	9.790	2.091	0.077	0.022	1.089	40.248	
10	Semi-Desert Shrub and Grasslar	15.289	1.298	53.355	0.059	22.042	6.027	0.286	0.106	1.538	31.313	
11	Semi-Desert Shrub and Grasslar	31.689	0.555	33.216	0.326	26.879	4.689	0.145	0.146	2.355	1.527	The GAP Zonal statistics says that the majority of this pixel is acturally Ag.