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Title: Ecohydrologic Connections in Semiarid Rangeland Ecosystems in Oregon.

Abstract approved:

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Carlos G. Ochoa

An improved understanding of the ecohydrologic relationships in semiarid rangelands is imperative for the development of effective rehabilitation and land management practices. This thesis addresses the ecohydrologic relationships of two significant issues concerning semiarid rangeland ecosystems: western juniper encroachment and increasing stream temperatures.

This thesis is divided into two chapters; each chapter is a manuscript reflecting a separate research site and project. The first chapter compares the use of ground and UAV-based measurements to assess vegetation and juniper characteristics in a juniper-dominated ecosystem. The second chapter describes the results of a preliminary investigation into stream temperature relationships of a semiarid riparian system in northcentral Oregon. Both manuscripts are currently being prepared for journal submission.

Western juniper encroachment is a concern across many areas of the western United States and is associated with ecohydrological changes such as increased erosion and reduced intercanopy vegetation. The first research study took place at the Camp Creek Paired Watershed Study (CCPWS), as part of a long-term research project into the ecohydrological impacts of juniper encroachment and removal. The study sought to assess differences in vegetation cover between two watersheds with different densities of western juniper and to examine the accuracy of data collected

using low-altitude Unmanned Aerial Vehicles (UAVs) to characterize canopy cover and vegetation cover.

Based on ground-based measurements, some significant differences in vegetation cover were found between the two watersheds. Shrub cover was higher in the treated watershed than in the untreated watershed, although bare ground was similar. Herbage production in the treated watershed was also significantly greater in the treated watershed.

Canopy cover estimates using UAV-based data were similar to ground estimates when multispectral vegetation indices were used. Additionally, supervised classification that utilized multispectral imagery and Normalized Difference Vegetation Index (NDVI) values yielded more accurate indications of overall vegetation cover than using multispectral imagery alone, but was only successful at differentiating between juniper from other vegetation when fall imagery was used.

The second chapter of this thesis addresses stream temperature, a concern in many regions of the world because of its impact on cold-water species and biochemical processes. However, published research regarding stream temperature dynamics in arid or semiarid rangeland systems is limited. The research for the second manuscript took place in a semiarid rangeland system in northcentral Oregon along Fifteenmile Creek, which has been found to exceed suggested maximum stream temperatures. This study took place between 2014 and 2017, and examined stream temperature relationships associated with riparian shade, groundwater inflows, and ambient conditions.

Stream temperatures generally followed the longitudinal gradient, with higher stream temperatures corresponding to lower elevations. During the summer, a difference of up to 5°C in the 7-day moving average stream temperature was observed between the highest and lowest elevation sites, while stream temperatures during the fall and winter seasons were more similar between sites. Air temperature was shown to be highly correlated to both shaded ($r=0.960$) and non-shaded ($r=0.961$) stream temperatures. In general, no significant difference was found between areas with riparian shading and non-shaded areas.

Shallow groundwater temperatures showed less variability than stream temperatures. Groundwater was also generally cooler in the summer and warmer in the winter when compared to surface flow conditions. Differences between shallow groundwater temperatures and stream temperatures of up to 8°C in the summer and 10°C in the winter were observed, indicating that shallow groundwater inputs may have a moderating input on stream temperatures.

Ecohydrologic connectivity, particularly concerning the relationship of vegetation and hydrologic characteristics, was an important consideration in both research studies. While additional research is necessary, this research provides insight into an improved understanding of how these connections can influence semiarid rangeland ecosystems.

Ecohydrologic Connections in Semiarid Rangeland Ecosystems in Oregon

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Nicole Durfee, Author

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CONTRIBUTION OF AUTHORS

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INTRODUCTION

The connections between ecological characteristics (e.g., vegetation) and hydrologic processes (e.g., infiltration) have been established in multiple research studies [1]. These relationships are key to understanding how ecological and hydrological processes can change under shifting disturbance regimes, anthropogenic impacts, or other environmental pressures. Semiarid rangeland ecosystems in particular face a number of management challenges; this thesis explores the ecohydrologic relationships related to two issues of concern in rangeland management: western juniper encroachment and stream temperature.

This thesis is divided into two chapters; each chapter is a separate manuscript addressing a different research study. Both chapters examine an aspect of ecohydrology in a semiarid rangeland ecosystem: the first manuscript compares the use of ground and unmanned aerial vehicle (UAV) based measurements to assess vegetation characteristics after juniper removal and the second examines stream temperature relationships in a riparian system. Both manuscripts are currently being prepared for journal submission.

The first chapter of this thesis builds on previous research into ecohydrologic connections and vegetation characteristics following juniper removal. Western juniper has expanded in both range and density over the past century and can be found across 3.6 million ha of the intermountain west [2]. The encroachment of juniper has been associated with a number of factors, such as overgrazing, suppressed fire, and favorable climate conditions [3]. Decreased intercanopy vegetation associated with juniper encroachment is linked to increased runoff, erosion, and decreased infiltration [4]. Therefore, monitoring vegetation cover and the reestablishment of juniper after removal can improve our understanding of the effectiveness of treatment techniques and determine how frequently treatment should occur.

Research for the first chapter took place as part of a long-term study into the ecohydrologic impacts of juniper in a semiarid system. Two watersheds make up the study site: Jensen WS (overstory dominated by juniper) and Mays WS (majority of juniper have been removed). Specific objectives of this study were to: 1) evaluate overstory and understory vegetative features (i.e., age structure, density, and composition) of both watersheds and 2) assess the effectiveness of using low altitude UAV-based imagery to measure tree density and canopy cover.

Increasing stream temperatures are a concern in many regions across the world [5], and are linked to a number of negative ecological impacts, to include increased salmonid mortality [6]. However, published research regarding stream temperature and riparian vegetation in semiarid landscapes has been limited [7]. The second chapter of this thesis examined stream temperature dynamics in a semiarid riparian system in northcentral Oregon. Stream temperatures, and related characteristics such as reduced water flows related to irrigation withdrawals, have been a major source of concern in this region. Fifteenmile Creek, the location for this research study, was chosen in part because it exceeds recommended maximum stream temperature in some reaches. This study examined the relationship between riparian shading, elevation, riparian air temperature, and shallow groundwater on stream temperatures. Specific objectives of this research were: 1) determine if seasonal vegetation shading is correlated to stream temperature differences, 2) evaluate subsurface water flow influence in stream temperature, and 3) describe stream temperature trends across the length of Fifteenmile Creek over seasonal and annual timeframes.

Effective land-use management and rehabilitation efforts require an understanding of the ecohydrologic relationships of a landscape. While each chapter of this thesis profiled a different research site, both addressed ecohydrologic relationships associated with significant concerns in rangeland management. The results of this thesis provide further insight into the ecohydrologic connections in semiarid rangeland ecosystems.

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A Comparison of UAV-Based Data and Ground-Based Information to Assess Western Juniper Reestablishment 12 Years After Tree Removal

Abstract

Monitoring vegetation characteristics and ground cover in western juniper dominated ecosystems is crucial to determine appropriate management techniques. While remote sensing techniques have been used to study woody plant encroachment in various research efforts, few studies have applied these techniques using Unmanned Aerial Vehicles (UAVs) specifically to juniper dominated systems. This study used ground-based data collection techniques in conjunction with low-altitude UAVs imagery to assess vegetation and ground cover characteristics in a paired watershed study, comprised of a treated watershed (most juniper removed) and an untreated watershed (juniper not removed). Specific objectives of this research were to 1) evaluate overstory and understory vegetative features (i.e., cover, age structure, density, and composition) in both watersheds and 2) assess the effectiveness of using low altitude UAV-based imagery to measure juniper sapling density and canopy cover. Ground-based measurements were used to assess vegetation characteristics of each watershed and as a means to verify analysis from aerial imagery. Vegetation indices calculated from multispectral imagery and from visual imagery were used to estimate tree canopy cover. Supervised classification was applied to multispectral imagery in the treated watershed to assess juniper sapling density and vegetative ground cover. Greater shrub cover and herbage production were found in the treated watershed, although perennial grass cover and bare ground were similar in both watersheds. Vegetation indices that incorporated near-infrared reflectance values estimated canopy cover within 1.9 and 4.1% of ground-based calculations. Supervised classification applied to fall imagery using multispectral bands and NDVI provided the best estimates of juniper sapling density and overall vegetation cover compared to imagery taken in the summer or using multispectral imagery alone. The results of this study suggest that multispectral imagery obtained from small, low-altitude UAVs can be effectively used to assess juniper density and vegetation cover in areas of juniper encroachment.

Keywords: Juniper; Ecohydrology; Remote sensing, Unmanned Aerial Vehicles

1. Introduction

The range and density of woody plant species, such as western juniper (*Juniperus occidentalis*), have substantially increased in the western United States over the last 150 years. Estimates of pinyon-juniper (*Pinus edulis* and *Juniperus* spp.) expansion across the Great Basin range from 125% to 625% [1], and western juniper alone can be found across 3.6 million ha in the intermountain west [2]. The expansion of juniper in particular has arisen in two primary forms: through the encroachment of juniper into areas previously dominated by sagebrush (*Artemisia tridentata* and similar species) and increases in the density of juniper in areas where it was previously relatively sparse [3]. Historically juniper was largely found in areas with lower fire risk [4]. However, intensive grazing, reduced fire occurrence, and favorable wetter climate conditions have all been cited as reasons for its expansion in the late 19th and early 20th century [3,5].

Juniper encroachment is a concern in many rangeland areas as it may lead to reduced water availability for other types of vegetation. The ecological and hydrological impacts associated with juniper expansion have been addressed by several research studies [6–9], and include increased erosion and runoff [10–12] and decreased soil moisture [7]. These changes are largely associated with shifts in vegetation cover [2,10,13], particularly increased bare ground in the intercanopy [14]. Reduced infiltration rates associated with litter cover [14], needle drop [7], or roots [15] also result in reduced soil moisture and vegetation cover. Higher rates of evapotranspiration and shortened summer flows have also been found in juniper-dominated sites compared to sagebrush-dominated sites [16] and transpiration by juniper may account for a high percentage of precipitation uptake in water-stressed environments [17]. In addition to interception by juniper canopy [18,19], these ecohydrological shifts can lead to reduced springflow [18] and soil moisture availability [8], further enabling juniper to outcompete other vegetation.

Increased juniper canopy cover has been associated with increased bare ground and decreased shrub, forb, and grass cover [6] and reductions in vegetation production and diversity [20]. Conversely, increases in vegetation biomass and diversity have been associated with juniper removal [21]; although vegetation responses may be delayed for several years depending on pre-treatment site conditions [22] and may vary with the type of treatment employed [23]. Longer-term (10 to 20 years) significant increases in herbaceous production have been found in sites where juniper was removed compared to juniper-dominated sites [24], although the rate of recovery for sagebrush in particular may depend on densities prior to treatment [25]. However, the removal of juniper in areas with severely reduced vegetation and the presence of invasive annual grasses such as cheatgrass (*Bromus tectorum*), can allow for continued spread of these invasive grasses [2,26].

Monitoring woody vegetation encroachment over time and at large scales can be difficult due to the large range occupied by juniper and pinyon-juniper woodlands, as traditional ground-based measurements alone may not be adequate to track vegetation changes. In conjunction with ground-based techniques, remote sensing offers the ability to assess these ecosystems over larger temporal and spatial scales. Satellite-based remote sensing has been used successfully to identify areas of juniper encroachment [27], assess shrub cover characteristics in encroached sagebrush steppe ecosystems [28], calculate canopy cover in juniper woodlands [29,30] and characterize ground cover following treatment [31]. Additionally, the use of multispectral imagery (particularly near-infrared reflectance) has improved the ability to assess changes in vegetation [32].

Vegetation indices derived from imagery can be particularly useful for vegetation identification and classification as they provide information about vegetation characteristics by analyzing specific band reflectance properties. This relationship between different spectral bands can be used to distinguish between areas of vegetation and bare soil or rock. Vegetation indices developed from remote sensing data have been used to determine gross primary production in pinyon-juniper woodlands, although the accuracy of these calculations may vary with disturbance levels [33].

There is a range of vegetation indices used to assess vegetation characteristics. Reflectance characteristics from multispectral imagery, particularly the near-infrared and red-edge spectral regions, have been successfully used to assess vegetation growth [34] and species identification [35,36], among other applications. A commonly used vegetation index, the Normalized Difference Vegetation Index (NDVI), is calculated from the reflectance characteristics of the near-infrared and red bands, and indicates photosynthetic activity. NDVI has also been found to be closely related to ground-based canopy cover calculations [37]. The Optimized Soil Adjusted Vegetation Index (OSAVI) has a similar formula to that of NDVI but is used to minimize the influence of soil reflectance [38], a concern in many arid and semiarid regions with high amounts of bare soil. Another example of an index potentially useful in studying western juniper is the Total Ration Vegetation Index (TRVI) [39], which was developed to address the different vegetation characteristics in arid and semiarid areas (to include juniper forests).

In addition to the use of vegetation indices, remote sensing (whether satellite, aircraft, or UAV-based) offers tools that can improve our ability to study juniper removal and recovery. The use of low altitude-UAVs to study juniper removal and recovery specifically has been limited. However, UAVs have been used for relevant applications that could be applied to juniper research including species classification [36], soil erosion monitoring [40], and measurements of tree canopy [41,42]. This study sought to build upon these UAV-based techniques in conjunction with ground-based data collection. Specifically, the objectives of this study were to 1) evaluate overstory and understory vegetative features (i.e., age structure, density, and composition) in one treated (juniper removed) and one untreated watershed in central Oregon and 2) assess the effectiveness of using low altitude UAV-based imagery to measure tree density and canopy cover in one watershed dominated by juvenile juniper stands and in one watershed dominated by mature juniper.

2.Methods

2.1 Site Description

This study occurred at the Camp Creek Paired Watershed Study (CCPWS) in central Oregon, 27 km northeast of the town of Brothers. The CCPWS was established in 1993 to study long-term ecohydrological relationships in western juniper dominated landscapes [18,43,44]. The study site (400 ha) includes two watersheds: Jensen WS (96 hectares) and Mays WS (116 hectares) (Figure 1). During 2005 to 2006, western juniper less than 140 years old were removed from the Mays WS using chainsaws. The boles were removed and tree limbs were scattered [43].

Climate in central Oregon is semiarid and precipitation falls largely during the fall and winter months. Average annual precipitation (2009-2017) at the study site is 358 mm $year^{-1}$ [18]. The vegetation-growing season begins in mid-March and continues until early June. Soils at the two watersheds are primarily Westbutte, Madeline, and Simaton, with the first two soil types accounting for approximately 80% of the watersheds [44]. Elevation at the study site is between 1350-1500 m.

The orientation of the Mays WS is primarily north by northwest while Jensen WS is largely oriented toward the north [44]. The average slope of the Jensen WS is 25% and 24% at the Mays WS [44]. The Jensen WS consists of 36% north-facing, 31% east-facing, 23% west-facing, and 5% south-facing aspects, while the Mays WS is comprised of 33% north-facing, 17% east-facing, 26% west-facing, and 11% south-facing aspects [44].

Overstory vegetation at Mays WS is dominated by big sagebrush (*Artemisia tridentata*, sp. *vaseyana*) while juniper is the dominant species at Jensen WS. Understory vegetation in both watersheds is dominated by perennial grasses, primarily bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), Indian ricegrass (*Achnatherum hymenoides*), Sandberg bluegrass (*Poa secunda*), and Thurber’s needlegrass (*Achnatherum thurberianum*) and some annual grasses, such as cheatgrass (*Bromus tectorum*) [44,45]. Prior to juniper removal from Mays WS, overstory and understory vegetation was similar at both watersheds with nearly 30% juniper canopy cover [44]. A study conducted by Ray [45] in 2015 showed that juniper canopy cover at Jensen WS is approximately 31% but less than 1% at Mays WS.

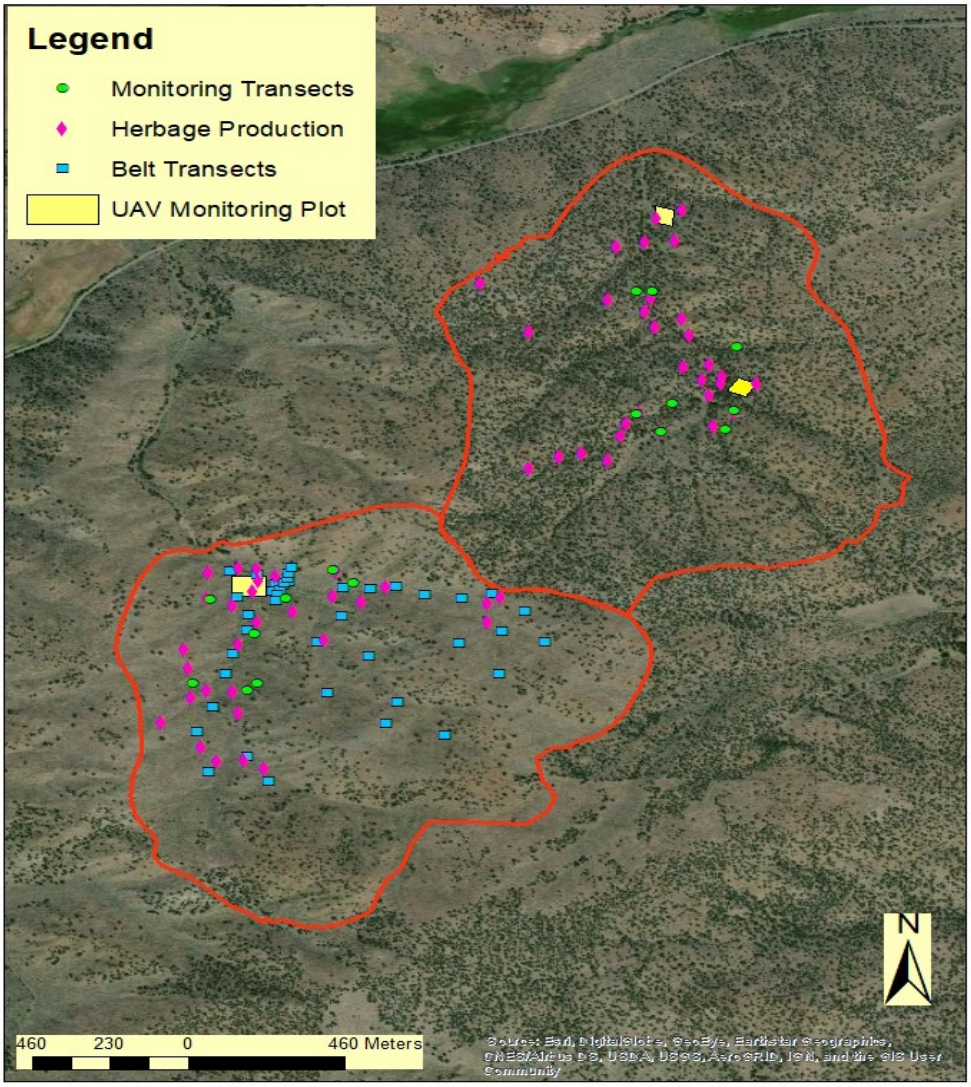

Figure 1. Location of Monitoring Sites. Jensen WS (untreated) is located in the northeast region of the image and Mays WS (treated) is located in the southwest portion.

Following juniper removal from the Mays WS, differences in vegetation cover characteristics were noted between the two watersheds. Two years after treatment, research found significant differences in tree cover ($p \leq 0.05$), perennial ($p \leq 0.05$) and annual forb cover ($p \leq 0.1$), and annual grass cover ($p \leq 0.05$) [43]. A study conducted in 2015 found a greater amount of shrub cover, annual grasses, and perennial grasses and a lower amount of bare ground at Mays WS (treated) compared to Jensen WS (untreated) [45].

2.2 Data Collection

2.2.1 Vegetation Data Sampling

Ground-based data collection regarding tree canopy cover, tree density, tree age structure, species richness, and herbage production at each watershed occurred in May through July of 2018 (Figure 1). These ground-based measurements served as both a means of improving our understanding of the characteristics of each watershed and to verify analysis from aerial imagery.

In order to analyze canopy cover, stem density, and age structure of juniper saplings forty-one belt transects (30-m by 3-m) were measured in the Mays WS (Figure 1). Belt transects were installed to represent varying aspect and slope characteristics present in Mays WS. Using techniques modified from Bonham [46], the location of juniper saplings along each transect was recorded along with the width at the base, middle, and top of each tree. Stem density was determined by counting the number of juniper saplings across all transects. In order to calculate canopy cover in each transect, the largest width measurement from each juniper was totaled. This was used as an indicator of tree diameter, assuming a generally circular shape. Total canopy cover for all juniper within a transect was then divided by the area (90 m^2) for each transect. An average was taken for the total canopy cover for each transect to provide an estimate of canopy cover across Mays WS.

In order to estimate juniper sapling age in the Mays WS (treated) the tree rings of eighteen juniper saplings of varying height and width characteristics were analyzed. These tree-ring samples were sanded and tree rings were counted to provide an indication of tree age, similar to techniques described by Phipps [47].

Herbage production was assessed using thirty 0.1 m^2 (0.2 m by 0.5 m) sampling frames within each watershed, similar to techniques described by Herrick et al. [48]. Sampling locations were chosen to represent varying characteristics of slope and aspect within each watershed. Within each sampling frame, herbaceous vegetation was cut at ground level. Samples were dried at 60 °C for 24 hours and weighed. The weight of each functional type (annual grass, perennial grass, and forb) and total vegetation weight were determined for each watershed.

Species richness and ground and vegetation cover data were obtained using eight long-term line intercept transects (30 m in length) installed in 1995 in each watershed. Data regarding functional vegetation type (grass, forb, shrub, or tree) and ground cover (bare soil, litter, dead vegetation) were collected at 1 m intervals using the line intercept method [48]. Data was collected for understory (on the ground) and overstory (vegetation immediately above the survey point).

Three monitoring plots were installed to compare UAV-based versus ground-based data. Two 2000 m^2 plots were established in the Jensen WS (untreated): one in a valley near the outlet of the watershed ("Jensen WS valley") and one located upstream 650 m on a hillslope ("Jensen WS upslope"). One 5400 m^2 monitoring plot was used in Mays WS (treated) ("Mays WS"). All sapling and mature juniper trees were physically counted on the ground in both monitoring plots in Jensen WS. In Mays WS, the density of juniper saplings was estimated based on the belt transects. At the Juniper WS, canopy cover was measured using a spherical concave densiometer (model A) (Forestry Suppliers; Jackson, MS) at 5 m increments facing each cardinal direction across five, 40 m parallel transects in both Jensen WS monitoring plots. A subset of juniper saplings was identified in the Mays WS plot using belt transects, ground identification, and visual identification from UAV imagery.

2.2.2 UAV-based imagery and analysis

The majority of UAVs flights were conducted in the spring and summer of 2018. In order to minimize shadows, flights occurred around noon and early afternoon. Additionally, one flight was conducted in November of 2017 in order to compare multispectral data across seasons at Mays WS. Three quadcopter UAVs (Table 1) were used to collect imagery. Multispectral imagery was captured using a RedEdge camera (MicaSense, Inc.; Seattle, WA), which collects imagery across five bands: blue (475 +/- 20 nm), green (560 +/- 20 nm), red (668 +/- 10 nm), red-edge (717 +/- 10 nm), and near infrared (840 +/- 40 nm). The RedEdge camera was attached to a Matrice 100 (DJI; Shenzhen, China) and Solo (3D Robotics, Inc.; Berkeley, CA) UAV for image collection. Visual imagery (red, green, and blue wavelengths) was collected using a DJI Phantom 3 Professional camera (DJI; Shenzhen, China). Flight plans were created and conducted using the Pix4Dcapture (Pix4D; Lausanne, Switzerland) mobile application or flown manually. Relatively low flight altitudes (40 to 50 m above ground level for imagery collected in July, November imagery was collected at 60 m) were conducted to assess the ability of the UAV-imagery to detect relatively short vegetation (e.g., juniper saplings). The ground sampling distance of source images created at 40 to 60 m using the RedEdge camera is 2.7 to 4.1 cm pixel^{-1}. The Phantom 3 Professional camera ground sampling distance for 40 to 50 m (highest flight altitude for visual capture was 50m) is 1.7 to 2.6 cm pixel^{-1}.

Table 1. UAVs used for data collection. Multispectral (red, green, blue, near-infrared, and red-edge bands) imagery was captured by attaching the RedEdge camera to the Solo and Matrice 100. Visual imagery (red, green, and blue bands) was collected using the Phantom 3 Professional camera.

UAV Platform	Manufacturer	Image type
Solo	3D Robotics, Inc.; Berkeley, CA	Multispectral (RedEdge)
Matrice 100	DJI; Shenzhen, China	Multispectral (RedEdge)
Phantom 3 Professional	DJI; Shenzhen, China	Visual

Image processing, to include the creation of Digital Elevation Models (DEMs) and orthomosaics, was conducted using PhotoScan professional (Agisoft LLC; St Petersburg, Russia). Image analysis was conducted using ArcGIS (version 10.6; Redlands, CA). Georectification of images was conducted in ArcGIS using landscape features (gully intersection points, etc.) and selected ground control reference markers that could be easily identified in imagery.

Four vegetation indices were selected to assess vegetation and ground cover characteristics of the study plots (Table 2). As visual imagery (red, green, and blue wavelengths) is often more accessible, we assessed the effectiveness of using visual imagery for measuring canopy cover and ground cover characteristics. In order to accomplish this, the Triangular Greenness Index (TGI) [49], which indicates chlorophyll content, was applied to the visual imagery to calculate canopy cover. Additionally, three vegetation indices (NDVI, OSAVI, and TRVI) which utilize multispectral imagery were used in the calculation of canopy. Vegetation indices were calculated using the Raster Calculator function in ArcGIS, which created a raster of one band with these values.

Supervised classification in the Mays WS monitoring plot was accomplished using multispectral imagery and NDVI values. Supervised classification utilizes user-specified pixel characteristics (training sites) to create different classes. These training sites are used to separate the pixels in an image into different classes based on common characteristics, such as reflectance values, within a certain threshold. The number of classification groups is specified by the user.

Table 2. Vegetation Indices. Names refer to reflectance values for each band. The TGI uses the wavelength (ʎ) for the red, green, and blue bands in the calculation. NIR refers to near-infrared.

Method	**Formula**
Triangular Greenness Index (TGI)[49]	-0.5[(ʎred - ʎblue)(Red-Green)-(ʎred - ʎgreen)(Red-Blue)]
Optimized Soil Adjusted Vegetation Index (OSAVI)[38]	(NIR-Red)/(NIR + Red + 0.16)
Normalized Difference Vegetation Index (NDVI)[50]	(NIR-Red)/(NIR + Red)
Total Ratio Vegetation Index (TRVI)[39]	4((NIR-Red)/(NIR+Red+Green+Blue))

2.3 Comparative Analysis

As an initial measure to determine the potential for using UAV imagery to detect juniper, visual UAV imagery from the monitoring plots in the Jensen WS (untreated) was compared to ground-based vegetation data and to lower-resolution satellite imagery using Google Earth®. Within each untreated monitoring plot in Jensen WS, the total number of juniper of all age classes and sizes was physically counted. This was then compared to the number of juniper found by visual inspection of the UAV-imagery and in Google Earth® satellite imagery for the monitoring plots.

As hand-counting vegetation within imagery is a time-consuming process, and not practical over large scales, a pixel-based analysis was also conducted to assess juniper density and total vegetation cover. By determining the number of pixels which correspond to vegetation compared to all other types of ground cover, the percentage of vegetation and canopy cover can be estimated within an area. For the indices selected in this research, higher values (above 0) correspond to greater photosynthetic activity or chlorophyll depending on the index applied. For instance, values for NDVI can range from -1 to 1, with areas of bare soil corresponding to values of approximately 0.025 or less, grasslands and shrub vegetation corresponding to values of around 0.09, and areas of dense vegetation corresponding to values of 0.4 or greater [51]. These values can vary depending on study site characteristics, vegetation type, season, and weather conditions [52]. Based on visual inspection of the imagery, threshold values were established for each index to separate vegetation from all other ground cover. The number of pixels with values greater than the threshold were divided by the total number of pixels in order calculate the percent of canopy cover or area covered by vegetation, similar to methods described by Wu [37].

The use of pixel-based classification offers a more expedient alternative to visual inspection for identifying land cover to evaluate juniper density and ground cover characteristics. For two dates (November 2017 and July 2018), supervised classification was applied to the multispectral rasters (red, green, blue, NIR, and red-edge bands) and rasters with multispectral bands and NDVI values at Mays WS.

The general supervised classification procedure used in this research is shown in Figure 2. Using the Training Sample Manager within ArcGIS, polygons were drawn around representative samples of each of the following classes: juniper, large shrubs, other vegetation (divided initially into smaller groups), bare soil, and woody debris. Training sites were selected from different areas of the image to represent different reflectance characteristics. A minimum of 2000 pixels was used for each class. Vegetation training sites were initially divided into separate groups (sagebrush, other shrubs, grasses, etc.) and then combined after classification. An initial image was created using the Interactive Supervised Classification function in order to determine how well the land cover was represented and to determine if more training samples were needed. Once each class could be differentiated, the Maximum Likelihood classifier was applied in ArcGIS to assign pixels to each class. In order to minimize noise within the image, and remove small isolated clusters of pixels, the Majority Filter was then applied. Following this step, the number of pixels classified as juniper, vegetation, or non-vegetated ground cover was tabulated. Similar to calculations made for canopy cover in the untreated plots, the number of pixels represented by each class was divided by the total number of pixels to determine a percent cover of juniper. This was then compared to estimates of juniper sapling density and vegetated ground cover calculated using the belt and line intercept transects.

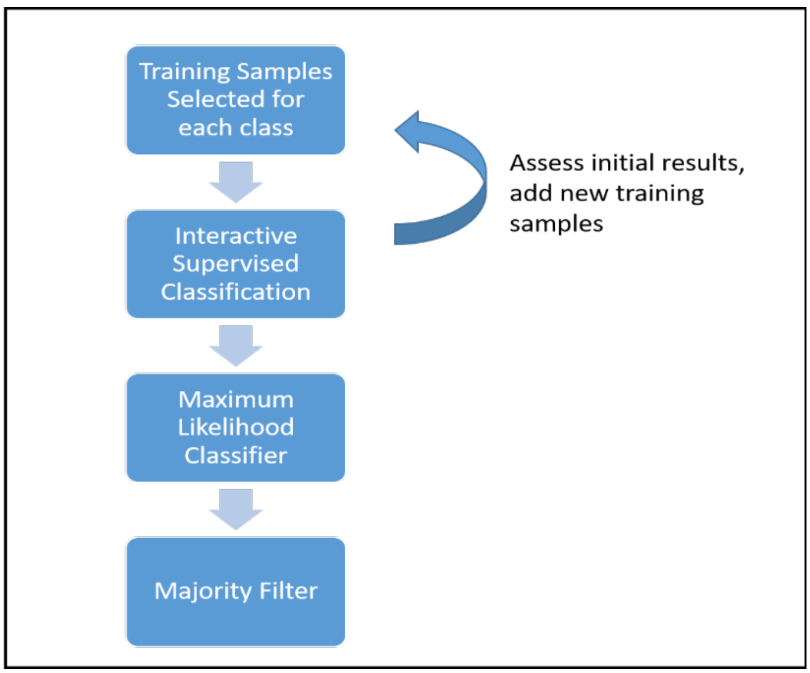

Figure 2. Supervised classification procedure performed in ArcMap.

To assess the accuracy of the supervised classification approach, twenty-nine juniper saplings that were identified within the Mays WS monitoring plot were used. The supervised classification results were then examined to see if these juniper saplings were correctly placed in the juniper class (positive identification). To be considered a positive identification, at least half of the pixels corresponding to a tree must be classified as juniper. In order to determine if vegetation other than juniper were incorrectly classified as juniper (false positive), 25-pixel clusters classified as juniper in each of the four supervised images were examined to see if the clusters corresponded to juniper or other ground cover. A minimum size of 20 pixels was used for each cluster analyzed.

2.4 Data Analysis

Two-sample *t-tests* were used to compare the difference in herbage production between both watersheds and to compare difference in ground cover characteristics observed from line intercept transects at both watersheds. SigmaPlot (version 13.0, Systat Software, Inc. San Jose, CA) was used for all statistical analysis.

3. Results

3.1 Herbage Production

A significant difference in herbage production was found between the two watersheds ($p \leq 0.001$). Prior to drying, herbaceous vegetation was determined to be 620 kg ha^{-1} at Mays WS (treated) and 433 kg ha^{-1} at Jensen WS (untreated) site. Total dried herbaceous vegetation was 208 kg ha^{-1} at Jensen and 291 kg ha^{-1} at Mays WS. At both sites, perennial grasses made up the majority of the herbaceous vegetation (80.1% at Mays WS and 84.6% at Jensen WS). At Mays WS, annual grasses made up 9.4% of herbaceous vegetation and forbs made up 10.6%. Annual grasses accounted for 8.2%, and forbs accounted for 7.2% of herbaceous vegetation at Jensen WS.

3.2 Stem Density

A greater density of juniper was indicated at the untreated site than at the treated site. Juniper density at Mays WS was determined to be 313 stems ha^{-1}. Based on ground measurements from the monitoring plots at Jensen WS, juniper density was calculated to be 797 stems ha^{-1}. This is similar to research conducted by Fisher in 2004 [44], which previously estimated the tree density of 743 trees ha^{-1} in Jensen WS.

3.3 Juniper Sapling Age Structure

A total of 113 juniper saplings were measured in Mays WS (an average of 2.8 trees per transect). The mean tree height was 75 cm and the mean width was 45 cm. The height of juniper saplings surveyed ranged from 9 to 208 cm. Width ranged from 0.9 cm to 140 cm. The average age of the 18 juniper core samples analyzed was 9 years old (juniper removal occurred 12 years ago), ranging from less than one year to 15 years old . The mean height of these samples was 89 cm with a mean width of 36 cm. Based on these samples, growth of sapling height was estimated at 10 cm per year and width was estimated at 4 cm per year.

3.4 Vegetation Cover

No significant difference (at $p \leq 0.05$) in bare ground, forb, or perennial grass cover was observed between the two watersheds (Table 3). A significant difference was found between shrub cover between the two watersheds ($p \leq 0.001$).

Table 3. Comparison of selected vegetation characteristics of the Mays WS (treated) and Jensen WS (untreated). All measurements are based on 2018 data collection. Ground cover calculations are based on the line intercept transects conducted in each watershed. A significant difference in values between watersheds ($p \leq 0.05$) is denoted with an asterisk.

Location	**% Ground Cover**			
	Perennial Grass	Forb	Shrub*	Bare
Mays WS	16.8	5.2	18.5	42.7
Jensen WS	21.1	4.3	1.7	44.4

Several differences were noted between the results of the line intercept transects conducted for this research and those of a study conducted eleven years earlier. A significant difference ($p \leq 0.05$) was found between 2007 and 2018 in perennial grass cover at both Mays WS (7.7% to 16.8%) and Jensen WS (12.2% to 21.1%). A significant difference in shrub cover was also found at Mays WS (5.7% to 18.5%). In 2018, shrubs accounted for 1.7% of ground cover at Jensen WS while shrub cover at Jensen WS was 5.3% in 2007 [43]. Annual grasses were not found at any of the Jensen WS line intercept transects during this study but accounted for 1.7% of the understory at Mays WS. (However, annual grasses were found at Jensen WS in the herbage production analysis.) In 2007, annual grasses accounted for less than 0.2% of ground cover at Jensen WS and 1.4% of ground cover at Mays WS. In 2018, pine needles accounted for 15.5% of the ground cover at the untreated site, largely near or in the undercanopy of mature juniper but were not specifically addressed by the 2007 study. The 2007 study [43] estimated bare soil at Jensen WS to be 50.1%, while this research estimated bare soil to be 44.4%. Bare ground at May WS was more similar between the study in 2007 (44.9%) and this study (42.7%).

3.5 Canopy Cover

Based on the densiometer measurements, canopy cover at Jensen WS was determined to be 30.4% in the valley area and 28.0% in the upslope area, similar to results found in an earlier study conducted at this site [45]. The canopy cover at Mays WS was estimated to be 0.7%, which is also similar to calculations made in previous research [45]. This does not account for the canopy cover provided by the few old growth juniper trees that remain in Mays WS.

Canopy cover estimates using the UAV-based imagery at both Jensen WS monitoring plots varied between vegetation indices that used visual or multispectral data (Table 4). For NDVI and OSAVI, the threshold value to determine vegetation was 0.05, while 0.1 was used for TRVI and 0 was used for TGI calculations. All pixels valued at and below that threshold were considered to be non-vegetated areas. At the Jensen WS upslope plot, NDVI, OSAVI and TRVI based-methods estimated canopy cover to be 26.1% to 27.3% (0.7% to 1.9% less than ground observations) while canopy cover measurements using TGI indicated 22.8% canopy cover (5.2% less than ground calculations). At the Jensen WS valley site, canopy cover estimates using NDVI, OSAVI, and TRVI were 33.7% to 34.5 % (3.3% to 4.1% greater than ground measurements) (Figure 3). Canopy cover estimates using TGI at the

JensenWS valley site showed the largest difference from ground-based measurements at 21.2% (9.2% lower than ground estimates).

Table 4. Canopy cover at the untreated study plots. Method refers to the vegetation index used to calculate the canopy cover. TGI is calculated using reflectance values from the visual imagery. NDVI, OSAVI, and TRVI are calculated using reflectance values from the multispectral imagery. Values above the threshold value are considered vegetation.

Location	Method	CC (%)	Threshold
Jensen WS Upslope	TGI	22.8	0
	NDVI	26.1	0.05
	OSAVI	26.7	0.05
	TRVI	27.3	0.1
	Ground	28.0	N/A
Jensen WS Valley	TGI	21.2	0
	NDVI	33.7	0.05
	OSAVI	33.7	0.05
	TRVI	34.5	0.1
	Ground	30.4	N/A

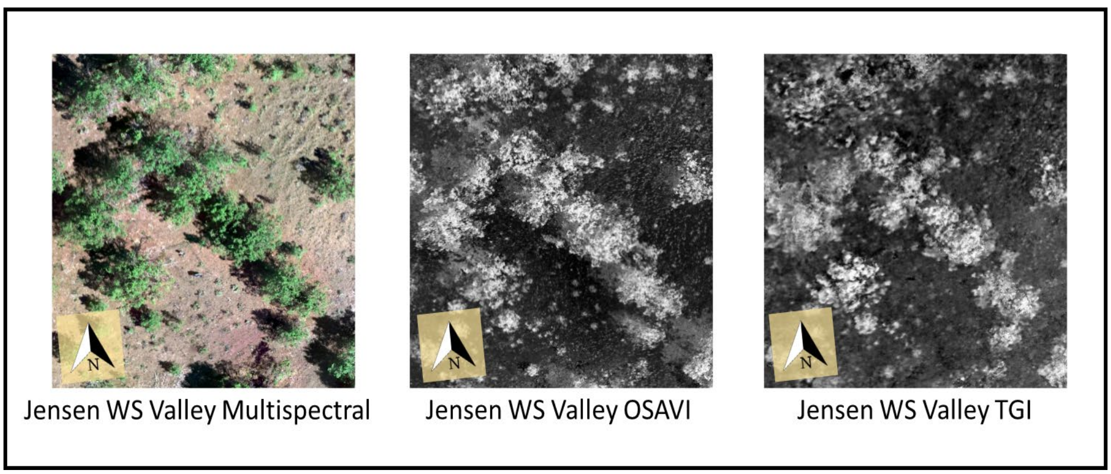

Figure 3. Jensen WS valley canopy cover. Darker shades correspond to lower vegetation index values and lighter shades correspond to higher values. NDVI, TRVI, and OSAVI values were similar therefore only OSAVI is shown for comparison. Differences can be seen in the characterization of canopy cover and in the shadows under the canopy between the OSAVI and TGI images.

3.6 Identification of Juniper and Ground Cover

Of the methods using UAV-data to assess land cover characteristics, visual inspection of the imagery was the least effective. Visual inspection of UAV imagery and Google Earth® imagery was largely unable to identify non-mature juniper within the Jensen WS monitoring plots. While some large shrubs could be discerned from the imagery, species identification was not possible and difficulty was encountered positively distinguishing small juniper trees from other vegetation. At the Jensen WS valley monitoring plot, 133 juniper (of all age classes) were physically counted using ground inventories while 186 were counted at the Jensen WS upslope plot. Twenty-nine juniper were positively identified within the Jensen WS valley plot from Google Earth® satellite imagery while 59 were identified from the UAV visual imagery. Within the Jensen WS upslope plot, 43 juniper were positively identified by visual inspection using the satellite imagery and 82 juniper were identified from UAV imagery. Additionally, as many of the mature juniper are grouped together, it was difficult to distinguish between the canopies of multiple trees in both the UAV and satellite-based imagery at both Jensen WS monitoring plots.

As multispectral imagery was shown to be most effective at delineating canopy cover, this was selected to assess vegetation cover and juniper density at Mays WS. The effectiveness of supervised classification for identifying land cover at the Mays WS varied with the type of raster used (multispectral data only compared to the multispectral raster with NDVI values) and the season the imagery was collected (Fall 2017 compared to Summer 2018). Notable differences were found between methods in the amount of ground cover classified as non-vegetated land cover (to include bare ground, woody debris, and litter), juniper, or other vegetation (Table 5).

Table 5. Characterization of ground cover by pixel-based analysis from supervised classification. Multispectral information from November 2017 and July 2018 was used for classification. Multispectral data ("MS only") uses reflectance values from the red, green, blue, near-infrared, and red-edge wavelengths. Multispectral with NDVI ("MS+NDVI") used the multispectral bands with the addition of NDVI values for classification. Non-vegetated ground cover refers to all other types of ground cover, to include: bare ground, woody debris, and plant litter. Ground-based information was obtained using belt-transects and line-intercept transects.

	Juniper density (%)	**Vegetation Cover (%)**	**Non-vegetated cover (%)**
November: MS only	3.2	16.8	83.2
November: MS +NDVI	0.7	58.2	41.8
July: MS only	15.2	35.5	64.5
July: MS +NDVI	9.4	50.4	49.6
Ground-based measurements	0.7	43.1	56.9

When supervised classification was applied to multispectral imagery (rasters containing red, green, blue, near-infrared and red-edge bands) collected in July, we were largely unable to distinguish juniper from the majority of other vegetation even after multiple attempts and multiple training sets. Combining all vegetation classes together, total vegetation cover was estimated to be 35.5% based on this classification approach, while the line intercept transects for Mays WS estimated vegetated ground cover to be 43.1%. Based on visual inspection and analysis of test sites (Tables 6 and 7), it was determined that the juniper class was not an accurate representation of ground conditions. Visual inspection of the classified imagery also indicated that shadows were sometimes falsely classified as vegetation, indicating overlap between vegetation and non-vegetation classes.

Table 6. Identified sample juniper. For each classification approach (by time of collection and data type), the percentage of juniper correctly identified for 29 trees is shown. "Identified" refers to a true positive in which the tree was correctly classified, while "not-identified" indicates that the tree was incorrectly classified.

	Identified (%)	Not Identified (%)
November: MS only	93.1	6.9
November: MS +NDVI	100.0	0.0
July: MS only	55.2	44.8
July: MS +NDVI	62.1	37.9

Table 7. Juniper identification by pixel cluster. True positive indicates the pixels classified as juniper correctly identified juniper, false positive indicates pixels classified as juniper were associated with another type of ground cover. "Unknown" refers to situations in which the vegetation type could not be determined.

	True Positive (%)	False Positive (%)	Unknown (%)
November: MS only	44.0	8.0	48.0
November: MS +NDVI	52.0	12.0	36.0
July: MS only	36.0	48.0	16.0
July: MS +NDVI	48.0	28.0	24.0

The use of supervised classification on composite rasters using multispectral imagery with NDVI values from July 2018 improved the identification of juniper (Table 6), but considerable overlap of classes between juniper and other vegetation types was still observed (Table 7, Figure 4). The use of NDVI in addition to the multispectral data resulted in estimates of vegetated ground cover (50.4%) that were greater than that calculated using the line intercept transects (43.1%).

Seasonal differences were apparent in the use of supervised classification to assess land cover. When supervised classification was applied to the multispectral raster without NDVI values from November 2017, juniper was more easily distinguished from surrounding vegetation than in imagery from July 2018 (Figure 5) but false positives (pixels falsely classified as juniper) were still found (Table 7). Using multispectral imagery from November, estimated juniper cover was 3.2%, which is greater than canopy cover calculated from the belt transect measurements (0.7%) and from line intercept transects in Mays WS (0.9% for overstory).

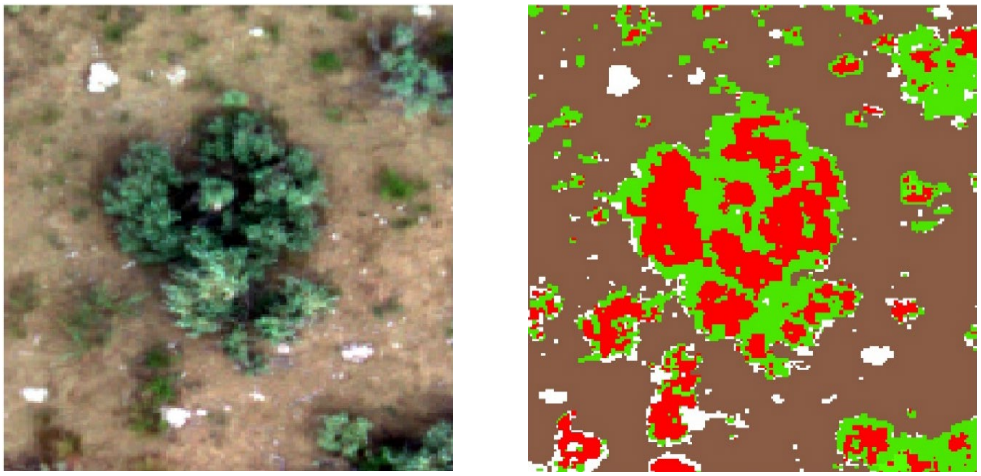

Figure 4. Example of falsely classified pixels. Image on left is a multispectral image taken in July; image on right is same image with supervised classification applied using the multispectral bands and NDVI values. Pixels classified as juniper are shaded red. Pixels shaded as green represent a combination of other vegetation classes. Shrub in center of image is a sagebrush, but has been falsely classified as sagebrush and juniper.

Estimated vegetation cover for November imagery using only multispectral data was considerably lower than expected at 16.8%, while non-vegetated ground cover was estimated to be 83%. Based on the line intercept transects for Mays WS, all non-vegetation ground cover combined (woody debris and dead vegetation, bare ground, and other litter) was estimated to be 57% (Table 5). This could be associated with the training data not identifying all vegetation as well as seasonal differences (line intercept transects were conducted during the summer months and this imagery was collected in the fall). Additionally, the image from the fall is notably darker than the image of the same area taken in the summer and there is a notable difference in the appearance in much of the shrub cover between the images (Figure 5). The classification using multispectral imagery from November also did not identify all juniper (Table 7) and there was some overlap with other vegetation (Figure 5).

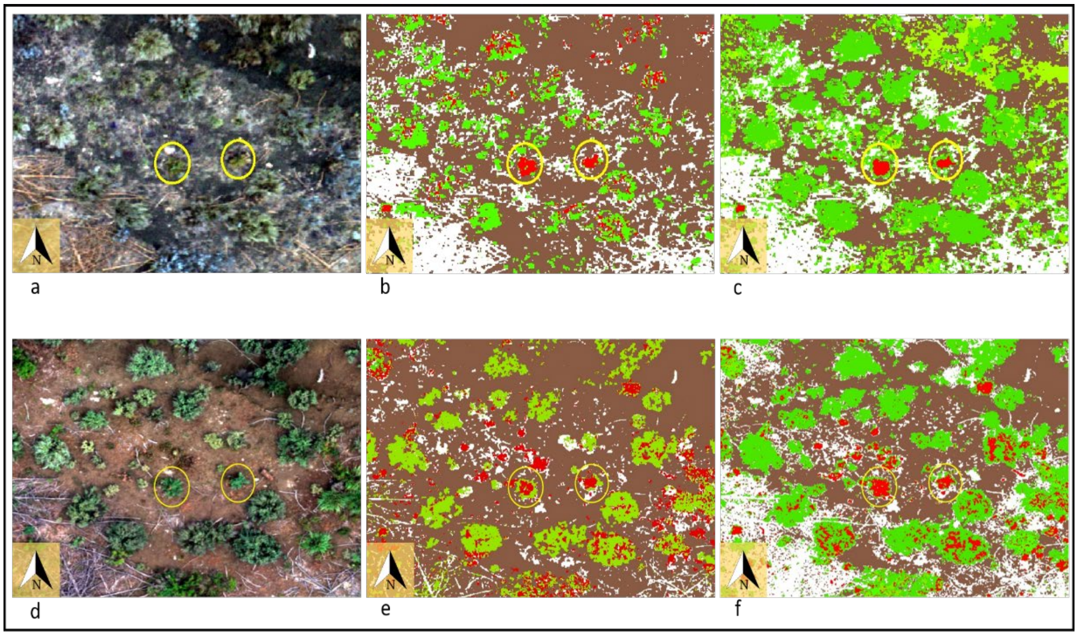

Figure 5. Subset of Mays WS imagery. Two selected juniper are circled in yellow. For scale: juniper on left is 0.9 m by 1.0 m. Pixels shaded as red are classified as juniper, pixels shaded white are classified as woody debris, and pixels shaded as green are classified as non-juniper vegetation. Results from November 2017 are displayed on the top row: a) Multispectral composite image; b) Supervised classification using multispectral imagery; c) Supervised classification using multispectral imagery with NDVI values. Results from July 2018 are displayed on the bottom row: d) Multispectral composite image; e) Supervised classification using multispectral imagery; f) Supervised classification using multispectral imagery with NDVI values. Overall, the classification using November multispectral data and NDVI values (c), identified juniper better than other methods with less overlap between classes.

Estimates of ground cover more closely aligned with data from the line intercept transects and belt transects when supervised classification was applied to the fall composite imagery with the multispectral bands and NDVI values. Using this method, juniper cover was estimated to be 0.7% and total vegetation cover was estimated to be 58.2% (by the line intercept method, vegetation cover was 43.1% across Mays WS). Non-vegetated ground cover was estimated to be 41.8% based on the UAV measurements using multispectral imagery with NDVI. Additionally, differences between ground and UAV-based measurements could be associated with the location of the UAV monitoring plot and may not represent differing vegetation characteristics across the topography of the watershed.

The classification using multispectral imagery and NDVI from November performed better than the other approaches at identifying the 29 juniper samples locations within the plot (Table 6). This classification approach identified all sample locations while the classification using multispectral imagery alone identified 93.1%. Supervised classification applied to July imagery with only multispectral data positively identified 55.2% of these juniper while 62.1% were identified when NDVI values were included.

The use of multispectral values without NDVI resulted in a greater amount of ground cover being falsely classified as juniper (Table 7). Additionally, between 16 and 48% of the pixel clusters analyzed for all methods could not be positively identified as juniper or another type of vegetation. Of the 25 pixel clusters selected for analysis in the November imagery using multispectral data only, 44% correctly identified juniper, 8% were false positives (another type of land cover was classified as juniper), and 48% could not be determined to be either juniper or another vegetation type. November imagery with multispectral imagery and NDVI correctly identified juniper in 52% of the cases, 12% were false positives, and 36% could not be determined. For July data, the use of multispectral and NDVI improved juniper identification slightly: 48% correctly identified juniper, 28% were false positives, and 24% could not be determined. The use of July multispectral data alone correctly identified juniper in 36% of cases, demonstrated false positives in 48% of cases while 16% of pixel clusters could not be positively identified.

4. Discussion

This research examined the use of ground and UAV-based techniques to assess vegetation characteristics in two watersheds, one dominated by juniper and one with the majority of juniper removed. Similar to past research studies [6,13,14], this study found that removal of juniper is associated with shifts in vegetation cover. Results of this study suggest these vegetation characteristics can be effectively evaluated using multispectral imagery collected from low-altitude UAVs.

Key differences in vegetation characteristics were found between the two watersheds. A difference in herbage production was noted, potentially indicating reduced forage biomass available for grazing. An increase in shrub cover was found at Mays WS (treated) compared to studies conducted in 2007, and a decrease in shrub cover was indicated at Jensen WS (untreated). While vegetation cover was divided into functional plant groups, and did not identify sagebrush specifically, increased shrub cover may be an indication of an ecosystem shift at the treated watershed. Other studies have found a significant negative correlation between juniper density and vegetation diversity and cover [6], while the amount of total vegetation cover and bare ground calculated in this research was similar at both watersheds. This suggests that other site-specific watershed characteristics should be considered and that the influence of juniper encroachment and removal may vary.

The density of juniper in the Mays WS is less than half of the tree density in Jensen WS, although juniper cover at both watersheds was similar prior to removal. In combination with age structure and growth rates of juniper saplings, information regarding juniper recovery rates can improve our ability to assess re-establishment rates and determine effective treatment timing of treatments. Seasonal and interannual precipitation and weather characteristics will also influence juniper growth rates along with topographical differences. Future research focused on assessing these differences could further improve the ability to refine management practices.

Previous research found increased presence of invasive annual grasses, such as cheatgrass, following juniper removal at other sites [13]. This research however found only a slight increase in annual grasses (from 1.4% to 1.7% of ground cover) at Mays WS (treated) in the last eleven years. This suggests that, for this research site, while the establishment of invasive annual grasses should be monitored, there has not been a rapid expansion following treatment.

Satellite-based remote sensing techniques have been previously used in research studying western juniper encroachment [31,32], although limited research has taken place utilizing these techniques with UAVs in juniper-dominated environments. The results of this study suggest that high-resolution, multispectral data from UAV-based imagery can be used to determine juniper canopy cover and ground cover characteristics in these environments.

In this study, vegetation indices calculated from multispectral imagery provided reasonable estimates of canopy cover. The use of visual imagery alone (red, green, blue bands) was not as effective at determining canopy cover, indicating the use of near-infrared information is important for assessing vegetation. The TGI was the only index used based on visual data alone and similar assessments using different vegetation indices may yield different results. The discrepancy in canopy cover calculation between TGI and other methods may be associated with several factors. While three of the four flights were conducted on the same day and around the same time of day, cloud cover differences could have influenced the amount of shade and the reflectance of the vegetation. The flight used to calculate TGI at the valley site was flown two weeks earlier, although under similar conditions. Additionally, while the two study plots are only 750 m apart, the topographical differences between the two study sites could have influenced shade and reflectance values.

Consideration should also be given to the threshold value used to separate vegetation from non-vegetation. As the distribution of all vegetation index values in this ecosystem largely centered around zero, small differences in the threshold value could significantly influence the canopy cover estimate.

The accuracy of juniper detection in the Mays WS monitoring plot varied with the season imagery was collected. Visible differences in vegetation were apparent in the imagery collected in the fall compared to the summer, and much of the non-juniper vegetation was brown or displayed reduced vigor compared to the July imagery. While more research is necessary, these results suggest that the vegetation phenology should be considered when determining optimum data collection regimes.

Calculations of total vegetated ground cover at the Mays WS monitoring plot varied widely between seasons (Fall versus Summer) and method (multispectral raster versus multispectral raster with NDVI). Vegetated ground cover calculated using multispectral data and NDVI values from July was more similar to ground calculations than other approaches, although timing of ground-based data collection should also be considered. As NDVI is an indication of photosynthetic activity, the addition of this index improved our ability to distinguish vegetation from non-vegetated areas.

By using small monitoring plots we were able to compare ground measurements more directly to UAV analysis to determine accuracy. However, there are some distinct disadvantages associated with the use of small plots. For example, a larger study area could encompass more topographical features of the watershed allowing us to compare results by aspect and slope. Using a small study plot limits the number of ground samples (such as juniper) that can be used to develop training samples for classification and to assess accuracy. The vegetation type (juniper or non-juniper) also could not be confirmed for a number of the pixel clusters analyzed due to the small size. Additional ground-based information (such as a larger number of sample sites feature juniper of multiple age classes) used for verifying accuracy could improve this methodology for future use.

The UAV-based data collection and analysis techniques used in this study are easy to replicate and can be applied to larger study areas. Initial supervised classification results using fall imagery with NDVI values are promising, but may be improved with the use of more training data (more juniper data) across a larger study area and more seasonal information. It should be noted that different flight altitudes were used to collect data in July and November at Mays WS. While this results in a slight difference in ground sampling distance (~ 1 cm) and image resolution, consideration should be given to the myriad of factors outside of vegetation that can influence image analysis such as flight regimes, cloud cover, and sun angle. Additionally, while the pixel-based analysis used in this research is simple to perform, incorporating object-based analysis or using unsupervised classification prior to supervised classification could improve the accuracy of detecting juniper saplings.

5. Conclusions

As the results of this research and past studies indicate, juniper encroachment can result in shifts in vegetation density and composition. However, given the large scale of juniper encroachment, the use of UAVs offers the advantage of more efficient data collection compared to using ground-based techniques alone (depending on image processing requirements). In contrast to satellite-based techniques, UAVs offer a high-resolution, flexible platform which can be used to target specific study sites and objectives. The results of this study suggest that UAVs can be effectively used to assess vegetation characteristics and tree density in juniper systems when multispectral imagery is used in analysis. For our objectives, data collected using UAVs did not replace the need for ground-based measurements. However, when used in conjunction with ground-based measurements UAVs can improve our understanding of the effects of juniper removal and inform future management decisions.

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Stream Temperature Dynamics in a Semiarid Riparian System in Northcentral Oregon

Abstract: A number of factors can influence stream temperature to include riparian vegetation, land use practices, and shallow groundwater flows. This study examined the relationship between riparian vegetation shading, elevation, air temperature, and shallow groundwater on stream temperatures in a semiarid riparian system in northcentral Oregon. Data collection occurred at four observation sites in the Fifteenmile Creek watershed. Air and stream temperature measurements were recorded at all sites. Intensive data collection was conducted along a 0.8-km riparian corridor of Fifteenmile Creek. Along this corridor, riparian vegetation composition and cover was analyzed using field surveys and shallow monitoring wells were used to characterize subsurface flow temperature from an intermittent tributary stream. Stream temperature data was collected using standalone sensors beginning in the spring of 2014 through October 2015, and using Distributed Temperature Sensing (DTS) technology in the summer of 2015. A comparison of stream temperature data from standalone sensors and DTS showed both to be in close agreement. No significant differences in stream temperature were found between sensors located in shaded and non-shaded areas along the stream ($p \leq 0.05$). Fluctuations in stream temperature followed those observed in ambient temperature. Shallow groundwater temperature values in the intermittent stream were cooler than main stem stream temperatures in the summer and warmer during winter months, indicating the tributary may have a moderating effect on stream temperature. The results of this research indicate that factors in addition to riparian shading, such as groundwater inputs and stream velocity, may influence stream temperature in this study area.

Keywords: stream temperature, Distributed Temperature Sensing technology, intermittent stream, riparian, shallow groundwater

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1. Introduction

Across the United States increasing stream temperatures have become a concern for a number of ecological reasons [1], to include negative impacts on water quality, reduced dissolved oxygen concentrations and reduced species richness and diversity in stream ecosystems [2]. Increased stream temperatures are also associated with lethal and sub-lethal effects in cold-water fish species such as salmonids [3,4], a species of particular concern in the Pacific Northwest of the United States and Canada. Additionally, stream temperature influences primary production and nutrient uptake [5] which can further exacerbate water quality challenges. In order to better address the effects of stream temperature, there is a call for more research that examines the multiple factors which can influence stream temperature [6,7].

Riparian vegetation in particular has been the focus of multiple studies into stream temperature dynamics and water quality [8–12]. The removal of riparian vegetation has been associated with increases in both maximum and mean stream temperature [13–25] and a reduction in undercanopy diurnal temperature ranges [13,25]. Minor increases in riparian vegetation in some agricultural areas have led to improvements in water quality, to include decreased stream temperature [14]. Additionally, research indicates that riparian vegetation may also have the potential to mitigate stream temperature increases associated with a changing climate [26]. A recent study in the Oregon Coast Range also found that when harvesting practices maintained riparian vegetation no increase in the 7-day moving average or daily mean temperature was experienced, although the 7-day maximum temperature did increase [27]. However, concern regarding the regional differences in riparian characteristics [10,28] has also emphasized the need for more research into stream temperature dynamics in semiarid and arid areas specifically.

In addition to riparian vegetation, multiple biophysical characteristics influence stream temperature. While solar radiation is one of the key factors influencing stream temperature, other physical processes such as evaporation, convection, conduction, longwave radiation, and groundwater flows all contribute to the heat budget within a stream. It is important to note that while riparian canopy reduces the amount of solar radiation that reaches the water [15,16], it does not cool the water directly [28]. The primary drivers of stream temperature vary with regional, climatic (e.g., arid compared to temperate climates), and stream size characteristics [29]. Geomorphological characteristics, such as elevation, can also play a strong role in influencing stream temperature [30] in addition to stream discharge [31], shallow groundwater inflows [32] and substrate [33]. The degree of influence of biophysical factors can also vary throughout the extent of a stream, as stream temperature is often more strongly related to groundwater near the headwaters but more correlated to climatic characteristics in downstream reaches [7]. The influence of these characteristics varies between seasons and research has found that stream temperature may be more influenced by air temperature during cooler seasons than in warmer times of the year [34], although this could vary greatly between regions. An improved understanding of the collective influence of these biophysical characteristics of a watershed on stream temperature may lead to management decisions that are beneficial to producers while protecting stream ecosystems.

In order to better assess the biophysical characteristics associated with stream temperature, this research utilized various measurement techniques. This included the use of individual measurement devices that provide discrete, point-specific records of temperature and the use of DTS. DTS systems are based upon the movement of light over the length of the fiber optic cable, providing a continuous longitudinal temperature profile with high spatial resolution [35]. DTS accuracy is 0.02 °C. Research has shown that DTS can be used to accurately collect and verify stream temperature measurements [21,36], in addition to other applications such as monitoring groundwater discharge [38,39] and shade estimation [35]. The use of DTS in this research provides both high-accuracy temperature data and a means of validating results from the standalone stream temperature sensors.

Much of the research into riparian vegetation and stream temperature relationships conducted in the Pacific Northwest has focused on temperate climates. This study aimed to improve the understanding of the multiple biotic and abiotic relationships affecting stream temperature in a semiarid riparian system in northcentral Oregon. In particular, this study was interested in characterizing the influence of vegetation shade and subsurface flows as potential modifiers of stream water temperature. We hypothesized that areas of with greater riparian shade would have lower mean and maximum stream temperatures and shallow groundwater temperatures would demonstrate a moderating effect on stream temperature over small areas. Specific objectives of this study were to 1) determine if seasonal vegetation shading is associated with stream temperature differences, 2) evaluate subsurface water flow influence on stream temperature, and 3) describe stream temperature trends across the length of Fifteenmile Creek over seasonal and annual timeframes.

2. Methods

2.1 *Site Description*

This study was conducted at four different locations in the Fifteenmile Creek watershed in Wasco County, in northcentral OR. Fifteenmile Creek (15-MC) is the main stream within the watershed. It extends 88 km from its headwaters near Lookout Mountain, at 1950 meters above sea level (mASL), to its convergence with the Columbia River at 24 mASL (Figure 1). The 15-MC watershed is approximately 96,700 hectares and has five main tributaries[40,41] (Figure 1). 15-MC is of particular interest because stream temperatures have been found to exceed suggested temperatures for salmonid habitat [42].

Human-related activities, such as agriculture, have influenced the 15-MC watershed. Eighty-five percent of the watershed is privately owned and a large portion of the lower-elevation areas of the watershed is used for agricultural purposes [40]. Because sections of 15-MC near Dufur city were channelized following a flood in 1964, there is little sinuosity in these areas [43]. Riparian and instream areas have also been altered through road building and other land-use activities [44]. Water usage in the region is primarily for irrigation, although summer flows are often insufficient to meet the amount of water appropriated [41].

The 15-MC watershed is located within the Dalles Ecological Province, in a region between the Cascade Mountain range to the west and grasslands of the Columbia Basin to the east [45]. The region is largely semiarid although precipitation varies considerably with elevation from 300 mm in the eastern portions (the focus of our study) of the watershed to 2500 mm in the western areas near the stream's origin [41]. Most precipitation (62%) in the region falls between October and February, with 30% falling during the dryland growing season from March to June [45]. The 15-MC is largely snowmelt-fed and approximately 22 percent of stream length in the basin is classified as perennial [41]. Vegetation in the region shifts from fir and pine forests at higher altitudes to oak, grasses, forbs and agricultural land in lower lying areas [41]. Riparian vegetation is primarily hardwoods, grasses and forbs, including some invasive species such as reed canary grass (*Phalaris arundinacea*).

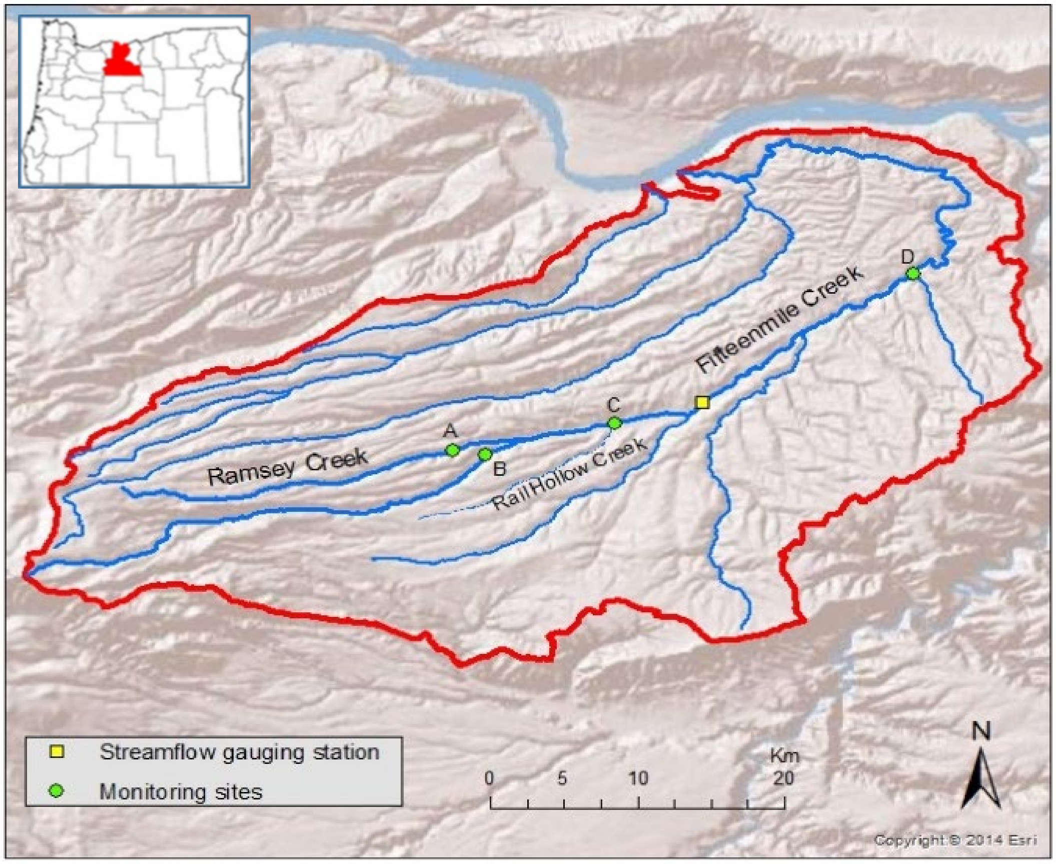

Figure 1. Study area map. Wasco County is highlighted in the Oregon county map in the upper left corner of the image. Monitoring sites are labeled as follows: Ramsey Creek (A), 15-MC upstream (B), 15-MC valley site (C), and 15-MC downstream site (D). The Oregon Water Resources Department streamflow monitoring gauge outside of Dufur, OR is labeled as "Streamflow gauging station."

In order to characterize stream temperature trends along the longitudinal gradient, three monitoring sites were located along 15-MC, and one monitoring site was located along Ramsey Creek, a tributary of 15-MC. In addition to vegetation and topographic differences, sites were selected based on access provided by private landowners. Following the elevation gradient profile, the Ramsey Creek monitoring site has an elevation of 558 m, the 15-MC upstream site has an elevation of 512 m, the 15-MC valley site has an elevation of 426 m, and the 15-MC downstream site has an elevation of 282 m (Figure 2).

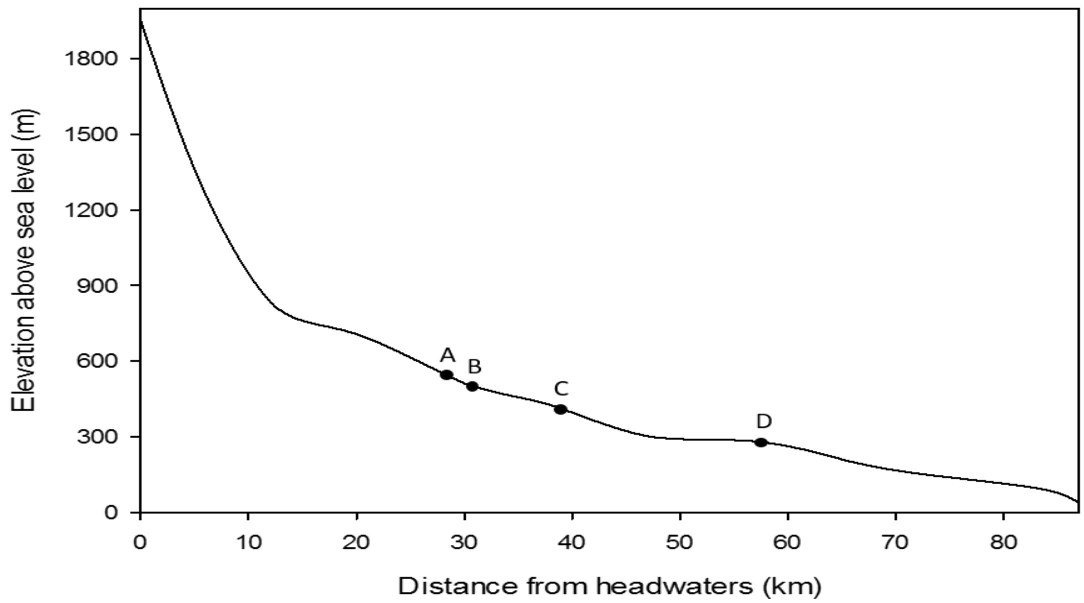

Figure 2. Approximate elevation of 15-MC and monitoring sites. The Ramsey Creek valley site (A) has an elevation of 558 m, the 15-MC upstream site (B) has an elevation of 512 m, the 15-MC valley site (C) has an elevation of 426 m, and the 15-MC downstream (D) has an elevation of 282 m.

A significant portion of the field data collection effort was conducted along an 800 m corridor of 15-MC (the 15-MC valley monitoring site), in order to assess differences in stream temperature between shaded and non-shaded areas and to characterize the temperature of surface and subsurface flows from an intermittent tributary. Riparian shading was measured using a spherical crown densiometer (Forestry Suppliers, Jackson, MS). Riparian vegetation cover at the 15-MC valley site ranged from 4% to 95%, with an average canopy cover of 70%.

Approximately 5 to 12 m of the riparian area on either side of the creek is fenced off at the 15-MC valley site in accordance with the Conservation Reserve Enhancement Program (CREP) [46]. Alder (*Alnus* spp.) represents 88% of overstory vegetation cover and reed canary grass accounts for 87% of the understory at this site [47]. Willow (*Salix* spp.), sedges (*Carex* spp.), and various woody species are also present in the riparian area. Alfalfa (*Medicago sativa*) and grass (various spp.) are grown on the irrigated fields adjacent to the CREP fenced area. These fields are irrigated using sprinkler systems fed by water pumped out of the creek during high flow season and/or from a deep groundwater well located in the property near the stream. Livestock grazing occurs during late spring and early summer in the grass-dominated fields.

Relative narrow valleys are spread on alluvial deposits overlying basalt deposits typical of the region [44]. The riparian soils are formed of volcanic materials, loess, and sedimentary rock deposited by alluvial processes. Depth to the water table is approximately 0.6 to 0.9 m near the riparian areas although the depth to water table is greater than 2 m in the upland regions [40]. There are various soil types present upslope of the riparian areas to include silt loam on steeper slopes stony or cobbly loam. Coarse-silty soil types are more predominant in the downstream areas, while loamy soils of either coarse or fine particle size are more dominant at the Ramsey valley, 15-MC valley and upstream study sites [48].

2.2 *Data Collection*

2.2.1 Stream and Air Temperature

In the summer of 2014, the four monitoring sites were instrumented to collect stream and air temperature data. At each site, three temperature sensors (Tibdit, Onset Computer Corp., Bourne, MA) were installed in non-shaded (2) and shaded (1) areas within a 100 m section along the creek. Data was collected throughout the summer and into the fall to account for shaded vs. non-shaded condition effects on stream temperature. All but one upstream (site A) and one downstream (site D) sensors were retrieved prior to the winter season in that year. Ambient (air) temperature conditions were recorded using a similar sensor installed along the creek side in each monitoring site. One pair of sensors (one in air, one in water) were re-installed in the spring of 2015 at each site and remained through the end of the study period to capture seasonal temperature variability. Throughout the study (2014 to 2017), a total of 17 stream temperature sensors were placed in shaded and non-shaded locations along the 800-m reach of the 15-MC valley site. Additional instrumentation was installed in the spring and summer of 2015 at the 15-MC valley monitoring site to characterize air, stream, and subsurface flow temperature relationships (Figure 3). Stream and air temperature sensors were set to record on an hourly basis.

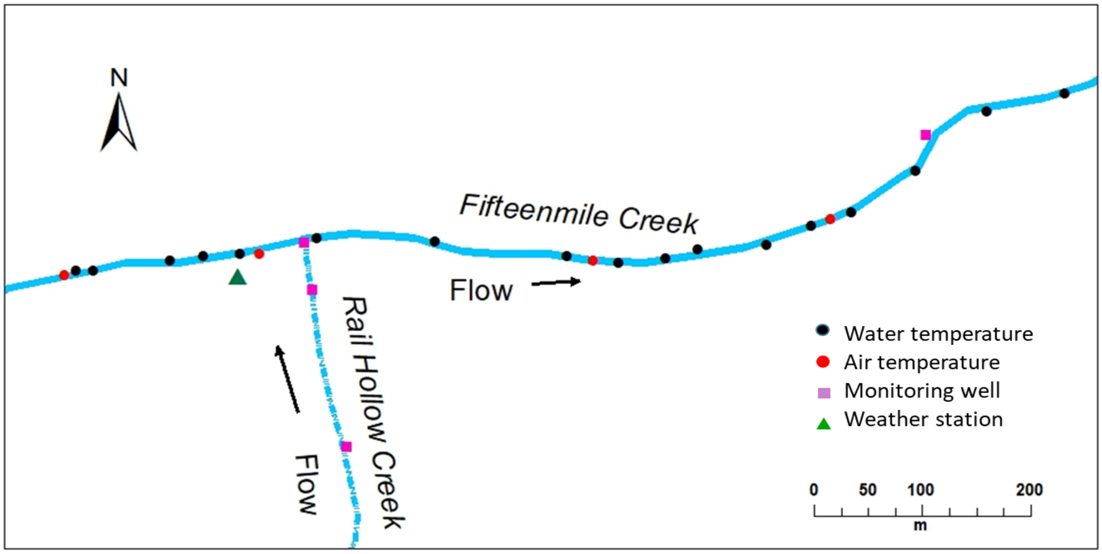

Figure 3. Map of the 15-MC valley site illustrating the location of instrumentation installed. A total of 17 stream temperature sensors, four shallow groundwater wells, four air temperature sensors, and one weather station were used over the course of the study at this the 15-MC valley site.

Over the course of this research, several stream temperature sensors and one air temperature sensor were lost. An air temperature sensor at the 15-MC downstream monitoring site was lost and later replaced, resulting in gaps in data. Although some stream sensors were lost in the 15-MC valley monitoring site, there were a sufficient number of sensors present to allow for analysis of shaded and non-shaded areas.

2.2.2 Subsurface Flow

In order to characterize subsurface flow water temperature, we installed four driving point wells that were equipped with automated water level and temperature loggers (model U20-L, Onset Computer Corp., Bourne, MA). Two of the wells (SW-1 and SW-2) were installed 500 m apart of each other along 15-MC. Two wells were also installed in an intermittent tributary (Rail Hollow Creek), at 20 m (TW-1) and 110 m (TW-2) upstream of the confluence with 15-MC. All wells were installed in the streambed and were pounded in until they reached bedrock, typically at less than 1.5 m depth (Figure 3). The wells consisted of 32 mm diameter by 1.2 m screen section in the bottom and a solid galvanized pipe riser. Groundwater sensors were set to record data hourly.

2.2.3 Distributed Temperature Sensing

An Oryx OX4-SR distributed temperature sensing system (Sensornet, Hertfordshire, UK) was installed in the summer of 2015 along a 0.72 km section of the 15-MC valley site. The two km cable was installed along the left and ride stream banks to assess for temperature differences associated with riparian shading, shallow groundwater inputs, and/or surface water inputs from the intermittent tributary. RBR and standalone data loggers were used to calibrate the DTS. The RBR and standalone sensors were installed along the length of the cable to validate the data. Stream temperature was recorded every 15 minutes at a spatial resolution of one meter.

2.2.4 Streamflow

Streamflow data were collected at selected dates in 2015 and 2016. We used a current velocity meter (Global Water FP311, Geotech Environmental Equipment Inc., Denver, CO) and the 0.6 tenth method [49] to estimate streamflow conditions at upstream and downstream locations along the 800 m reach of the 15-MC valley site. Data were also compared against streamflow data reported from a gauging station (OWRD, St. 14104190) 5 km downstream from our study site.

2.3 Data Analysis

Data analysis was conducted using SigmaPlot (Version 13, Systat Software, Inc., San Jose, CA) for all data, excluding DTS results which were evaluated using SAS software (Version 9.4, SAS Institute, Inc., Cary, NC). Hourly temperature data were used to calculate mean daily temperature values for stream and air temperature and the 7-day moving average stream temperature. Box plots and descriptive statistics were created for initial analysis of mean stream, mean air, and mean shallow groundwater temperature. Comparison of mean and maximum stream temperature values from standalone sensors were conducted using the Mann-Whitney Rank Sum test in order to determine if there were differences between shaded and non-shaded stream sites. A Kruskal-Wallis one way analysis of variance (ANOVA) on ranks test was used to analyze the mean daily stream temperatures at the Ramsey, 15-MC upstream, 15-MC valley, and 15-MC downstream sites. A comparison between DTS and standalone sensor data was conducted using a two-sample *t-test* in order to determine if there any differences between stream temperature measurements taken by the two methods. A Pearson Correlation was conducted to determine the correlation between mean air temperature and mean stream temperature.

3. Results

3.1 Air Temperature

The downstream site (the lowest elevation site) had the highest mean temperature in the summer of 2014 and the Ramsey Creek site experienced the lowest mean daily temperature from 2 July 2014 through 1 October 2014, although the difference between all sites was generally less than 2°C (Table 1). The 15-MC upstream site experienced the highest maximum daily average temperature while the 15-MC valley site experienced the lowest during this summer. A similar pattern in mean daily air temperatures was observed from 2 July 2014 through 15 January 2015, with mean daily temperatures at all sites generally being within 3°C of one another (Figure 4).

Across a period of one year (22 October 2015 to 21 October 2016), there was less than a 2°C difference in mean air temperature between the Ramsey site, 15-MC upstream Site, and 15-MC valley. No data for the downstream sensor is available for this time period as a downstream air temperature sensor was lost and later replaced, resulting in a data gap.

Table 1. Air temperature for 2 July 2014 through 1 October 14. All measurements are based on averaged daily temperature.

Location	Mean (°C)	SE (°C)	Max (°C)	Min (°C)
Ramsey Creek	18.2	0.4	25.8	9.2
15-MC Upstream	20.0	0.4	28.8	11.7
15-MC Valley	19.2	0.4	25.4	11.4
15-MC Downstream	20.1	0.4	27.2	11.7

Table 2. Air temperature for 22 October 2015 through 21 October 2016. All measurements are based on averaged daily temperature. A downstream air sensor was not in place during this time period.

Location	Mean (°C)	SE (°C)	Max (°C)	Min (°C)
Ramsey Creek	8.9	0.4	22.6	-8.2
15-MC Upstream	7.4	0.4	24.7	-8.3
15-MC Valley	9.7	0.4	24.3	-6.9

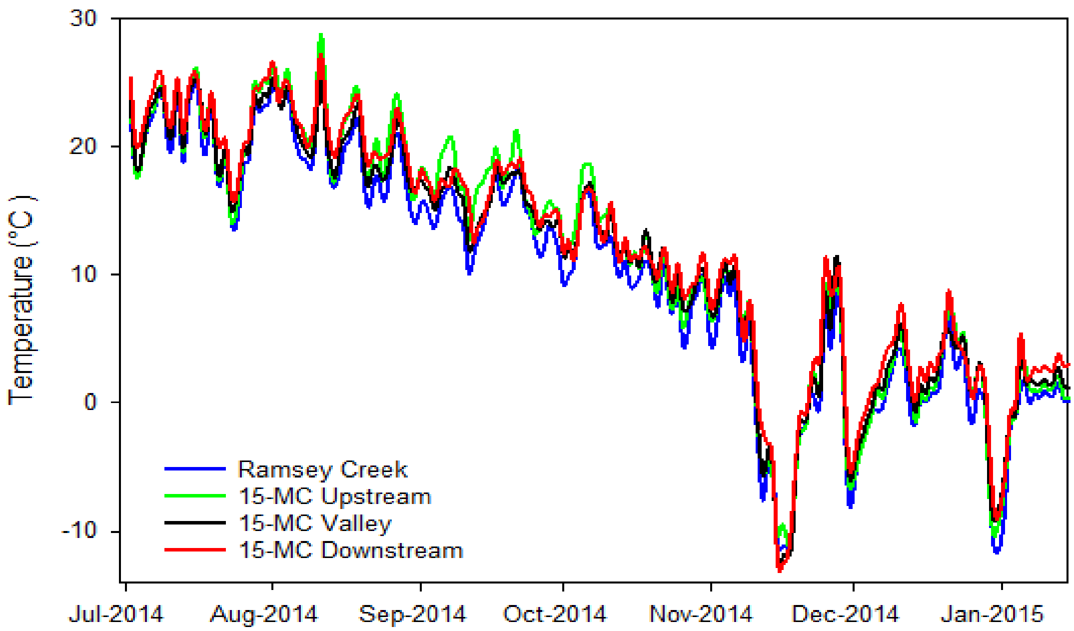

Figure 4. Mean daily air temperature at all monitoring sites from 2 July 2014 through 15 January 2015.

3.2 Stream Temperature

3.2.1 Stream Longitudinal Profile

In general, higher stream temperature values were observed in lower elevation sites (i.e., 15-MC Valley and 15-MC Downstream) compared to sites at higher elevations. Differences in temperature between study sites were greatest during the summer months (Figure 5). A difference in the 7-day moving average of up to 5°C was observed between the highest elevation site (Ramsey) and the 15-MC Downstream site. Lower temperature variability among study sites was observed during late fall and winter.

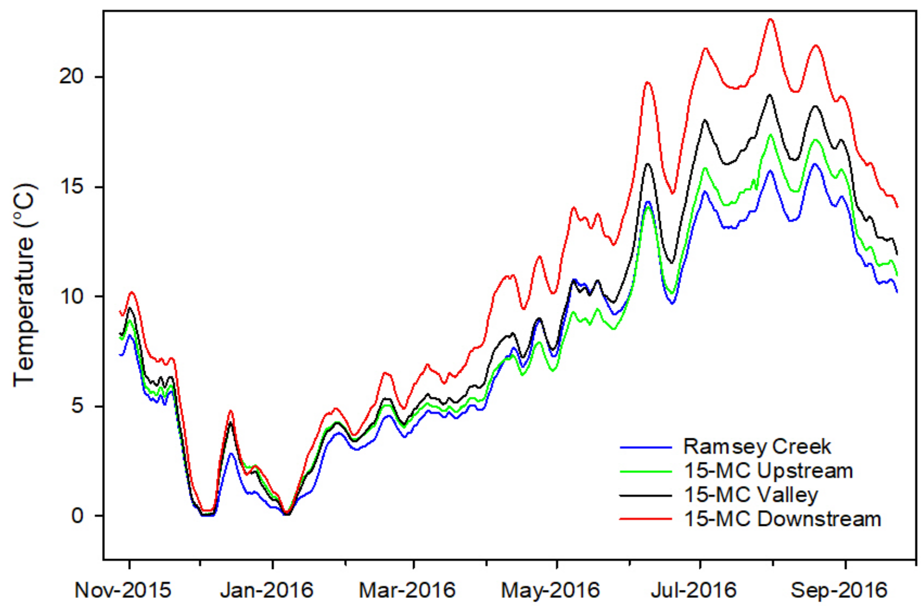

Figure 5. 7-day running average mean stream temperature at the four monitoring sites from 21 October 2015 to 23 September 2016.

Maximum and mean stream temperatures were highest at the downstream site location: 24.0°C and 10.8°C (Table 3). The lowest maximum and mean daily stream temperatures were observed at the site located at the Ramsey tributary site (17.0°C and 7.7°C), which also experienced the least fluctuation in stream temperature across an annual timeframe.

The 7-day moving average temperatures of the downstream site exceeded the recommended maximum temperatures for salmonid and other cold-water fish rearing (16°C) and for migration (18°C) during the summer (Figure 5). The maximum daily average temperature reached from 21 October 2015 to 23 September 2016 at the 15-MC upstream, 15-MC valley, and 15-MC also exceeded this recommendation (Table 3).

As expected, stream temperature followed the general seasonal trend of air temperature, although the range of air temperatures was greater than that of stream temperatures. Figure 6 shows daily-averaged stream and air temperature data for the 15-MC valley site during year 2015 to 2016. Air temperature was significantly higher (up to 8°C) than stream temperature during spring and summer. Peak maximum temperatures for air (24°C) and stream (17°C) occurred in August (Figure 6). Based on the Pearson correlation analysis, air temperature was shown to be highly correlated to both shaded (r = 0.960, $p \leq 0.001$) and non-shaded (r = 0.961, $p \leq 0.001$) stream temperatures.

Table 3. Comparison of mean daily stream temperatures at all study sites from 21 October 2015 to 23 September 2016.

Location	Elevation (m)	Mean (°C)	SE (°C)	Max (°C)	Min (°C)
Ramsey Creek	558	7.7	0.3	17.0	0.0
15-MC Upstream	512	8.2	0.4	21.6	0.1
15-MC Valley	426	8.9	0.3	20.6	0.1
15-MC Downstream	282	10.8	0.3	24.0	0.1

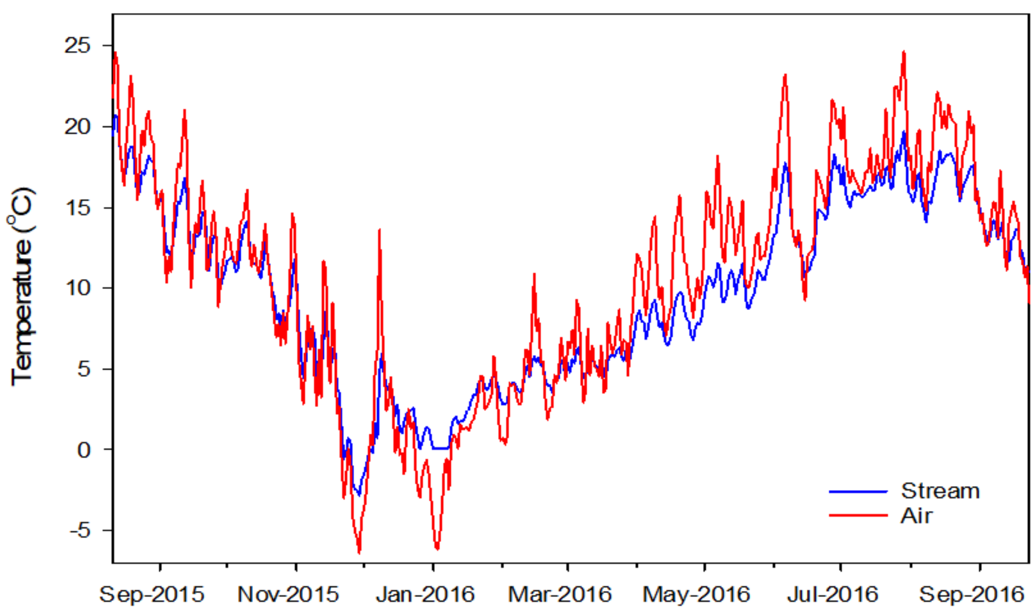

Figure 6. Daily average stream and air temperature in the 15-MC valley site riparian area from 11 August 2015 to 23 September 2016.

3.2.2 Shaded and Non-shaded

In general, no significant difference was found between stream temperature measurements (DTS or standalone sensors) in shaded and non-shaded sections. An analysis of a shaded and non-shaded standalone sensors from 2 July 2014 to 20 January 2015 indicated there was a significant difference in daily maximum temperatures ($p = 0.01$). However, when compared across an annual timeframe (3 August 2015 to 22 September 2016) no significant difference in maximum daily temperature was noted between the shaded and non-shaded sensors ($p = 0.962$). An analysis of maximum daily temperatures over one summer (1 June 2015 through 30 September 2015) also indicated no significant difference (at $p \leq 0.05$).

Data analysis of the multiple sensor locations in the 15-MC valley site showed that minimum, maximum, and mean temperatures of shaded and non-shaded sites were similar across observations made over summer and annual timeframes. A comparison of all shaded and non-shaded sensors for the full duration of the study also yielded no significant differences ($p = 0.519$). Figure 7 displays the mean stream temperature for all shaded and non-shaded sensors at the 15-MC valley site for one year.

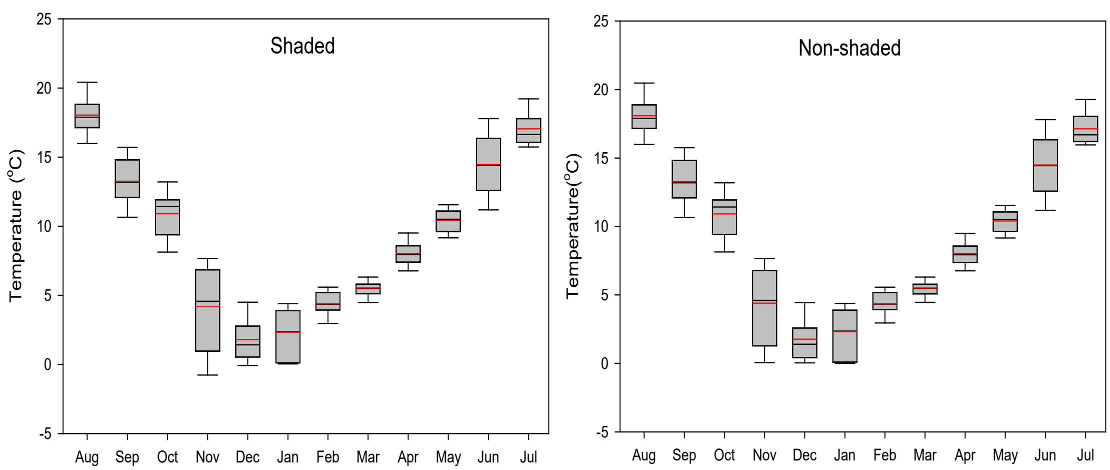

Figure 7. Box diagram showing mean daily temperature per month for all non-shaded and all shaded stream temperature sensors at the 15-MC valley site from August 2015 to July 2016. Each box shows the mean (red line) and median (black line). The upper and lower ends of the boxes represent the 25th and 75th percentiles. Lower and upper error bars represent the 10th and 90th percentiles.

In order to assess if any significant temperature differences occurred over small stretches of the cable, a 120 m reach with roughly equivalent portions of shaded and non-shaded areas was analyzed. The mean and maximum stream temperatures recorded using DTS along this 120 m reach were assessed for 1700 (to reflect the warmest time of the day) for five days during August 2015. Using the ambient temperature for the 15-MC valley site, the warmest day of each week in August was used. In addition to the DTS cable, four standalone sensors (two shaded, two non-shaded) were located along this reach of cable and were used for comparison.

A comparison of average daily stream temperature between the standalone sensors and DTS fiber optic measurements yielded no significant differences overall for July, August, and September of 2015 (at $p \leq 0.05$). Significant differences were indicated between the fiber optic measurements and stand-alone measurements for recordings made at 1500 and 1600 during these months. This difference may be attributed to the location of the cable and standalone sensor within the vertical stream profile. However, trends in stream temperature along the length of the cable were relatively similar across the 15-MC valley site.

The DTS results indicated that stream temperatures were generally greatest between 1500 and 1800 during the summer (Figure 8). In order to assess potential trends over short distances during the warmest times of the year, a 120 m reach of DTS cable was analyzed for five selected days in August for temperature at 1700. No significant difference was found in mean and maximum temperature between the selected shaded and non-shaded portions of the cables nor between standalone sensor measurements and DTS cable for these portions. The mean temperatures of the DTS cable tended to be slightly less than those of the standalone sensors (Table 4).

Table 4. Mean stream temperatures at 1700 on four selected dates in August 2015. DTS results refer to the mean shaded and non-shaded stream temperature across a 120 m portion of fiber optic cable. Standalone results are the averaged results for two shaded and two non-shaded stream temperature located along the same reach.

	Standalone		**DTS**	
	shaded	non-shaded	shaded	non-shaded
1 Aug 15	24.2	24.2	23.5	23.6
11 Aug 15	22.3	22.3	21.3	21.3
19 Aug 15	21.8	21.8	21.4	21.4
20 Aug 15	20.7	20.7	20.6	20.6
27 Aug 15	20.6	20.5	20.1	20.1

No significant difference ($p \leq 0.05$) was found between 15-MC valley stream temperature at standalone sensors before and after the confluence (regardless of shading). The DTS cable indicated significant differences in stream temperature between areas 100 m upstream and 100 m downstream on four (1 August, 11 August, 19 August, and 27 August) of the selected days at 1700. However, no significant difference was found in mean daily temperatures at any other time from the DTS upstream and downstream of the confluence A mixture of partial shade and non-shaded areas are present both immediately upstream and downstream of the confluence.

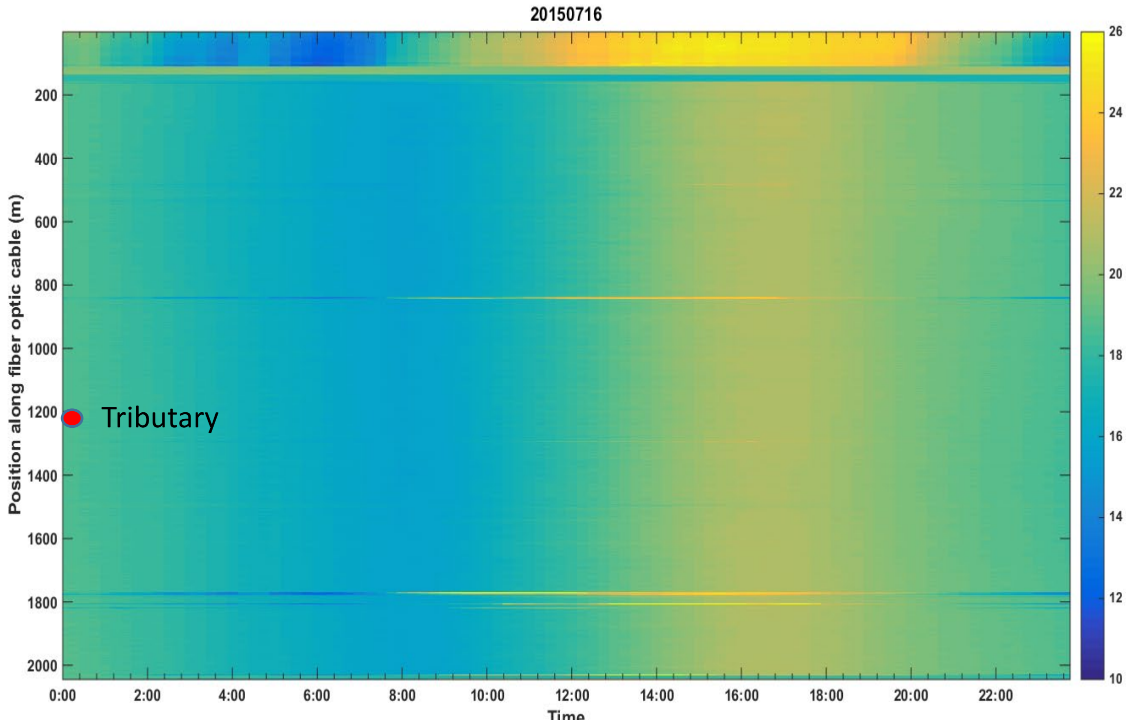

Figure 8. DTS results for 16 July 2015. Stream temperature trends throughout the day where similar at all sites along the cable. No significant differences in stream temperature were observed between shaded and non-shaded areas or between locations prior to and after the confluence. Approximate location of tributary is shown.

3.3 Subsurface Flow

Subsurface flow locations at the 15-MC valley site reflect shallow groundwater (< 1.5m) conditions in 15-MC (SW-1 and SW-2) and in the Rail Hollow Creek intermittent stream (TW-1 and TW-2) that drains into the creek. The intermittent stream has active surface streamflow during the early part of the snowmelt runoff season (January through early March). Subsurface flow is the primary contributor for the rest of the year. Shallow groundwater temperature in the subsurface wells showed less variability in temperature than stream temperature (Figure 9). Groundwater was generally cooler in the summer and warmer in the winter when compared to surface flow conditions. Differences of up to 8°C in the summer and 10°C in the winter were observed between stream temperatures and shallow groundwater temperatures in the tributary. From 1 May 2016 to 30 April 2017 an increase in mean daily shallow groundwater temperatures across the reach of the 15-MC valley site was noted between SW-1 (9.4°C) and the downstream well, SW-2 (10.4°C) (Table 5). The tributary well furthest away from the confluence (TW-2) had a higher mean daily groundwater temperature (10.0°C) compared to that of the more downstream tributary well (TW-1, 9.4°C) for this same time period.

Table 5. Mean daily temperature at four wells in the 15-MC valley monitoring site from 1 May 2016 to 4 Apr 2017. SW-1 is located along 15-MC just prior to the confluence with the tributary, SW-2 is located 500 m downstream of SW-1. TW-1 is located along the tributary (Rail Hollow Creek), 15 m from the confluence with 15-MC. TW-2 is located 95 m upstream of TW-1 along the tributary.

Well	Mean	SE	Max	Range
SW-1	9.4	0.2	14.1	10.6
SW-2	10.4	0.2	14.0	8.6
TW-1	9.4	0.2	12.6	10.2
TW-2	10.0	0.2	12.8	7.3

From 1 May 2016 to 30 April 2017, a statistically significant ($p \leq 0.05$) difference was noted in the mean daily temperature between the wells along 15-MC wells (SW-1 and SW-2), between the tributary wells (TW-1 and TW-2), between SW-2 and TW-1, and between SW-2 and TW-2. A comparison of the average of 15-MC wells (SW-1 and SW-2) mean daily temperatures to that of the tributary wells (TW-1 and TW-2) also indicated a significant difference.

A seasonal trend in shallow groundwater temperature response was observed in all wells. One of the wells (TW-2) in the tributary showed the lowest temperature values in the summer and also the largest decrease in temperature during the snowmelt runoff season (Figure 9). We attributed this response to the location of the well farther upstream (110 m) from the confluence with the main creek, which may have prevented the moderating temperature effect exerted by streamflow in the creek. The range of mean daily shallow groundwater temperatures was much less than that of the riparian air temperature.

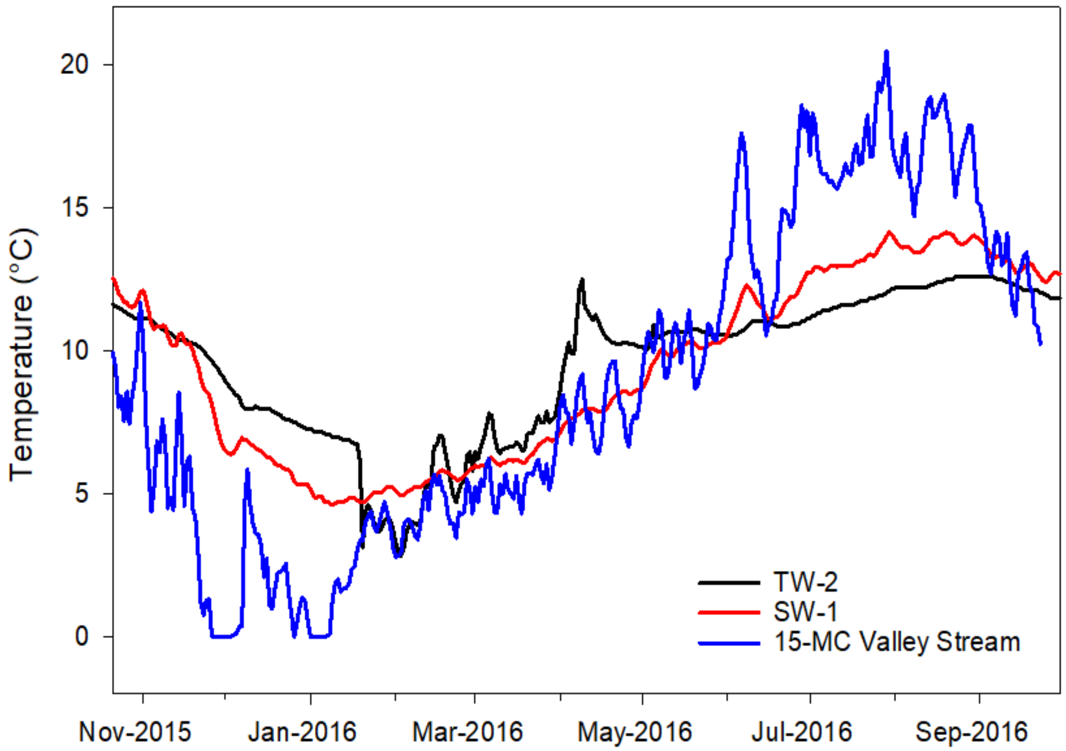

Figure 9. Shallow groundwater temperature fluctuations in two monitoring wells at the 15-MC valley site from 21 October 2015 to 30 September 2016. SW-1 is a shallow groundwater well located along 15-MC prior to the confluence with Rail Hollow Creek. TW-2 is a shallow groundwater well located along Rail Hollow Creek approximately 110 meters prior to the confluence.

An analysis of mean daily temperatures during one summer (1 June 2016 to 30 September 2016) found significant differences in mean daily temperature between wells. Statistically significant differences (at $p \leq 0.05$) were found between SW-1 and TW-2, SW-1 and TW-1, SW-2 and TW-2, TW-1 and SW-2, and TW-1 and TW-2. No statistically significant differences were found for this summer for SW-1 and SW-2 (p= 0.912). A comparison of the average of 15-MC wells (SW-1 and SW-2) mean daily temperatures to that of the tributary wells (TW-1 and TW-2) for this summer timeframe also indicated a statistically significant difference.

3.4 Streamflow

Streamflow measurements were taken on four separate dates at the 15-MC valley site in 2015 and 2016 (Figure 10) and once at the Ramsey valley location (Table 6). Highest measured streamflow levels were observed on 7 April 2016 at about two cubic meters per second (cms), while lowest streamflow levels were observed on 11 August 2015 (0.1 to 0.2 cms). Comparisons of streamflow discharge at upstream and downstream locations in the 15-MC valley site did not indicate significant gains or losses in discharge over the 800-m reach. A comparison of mean daily streamflow measurements from the Oregon Water Resources Department [50] indicated that streamflow was greater in 2017 than in 2014 to 2016 (Figure 10).

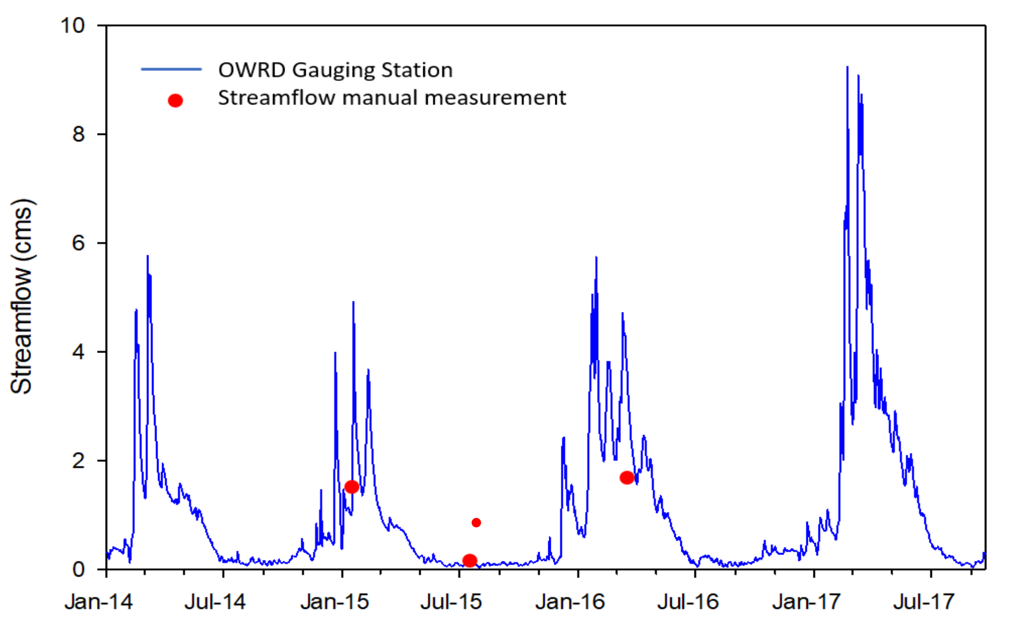

Figure 10. Streamflow data from Oregon Water Resources gauging station 1410419 located outside of Dufur, OR and manual measurements taken at the 15-MC valley site on selected dates.

Table 6.Comparison of streamflow discharge. Designations of “upstream” or “downstream” refer to relative position of measurements made at the 15-MC Valley monitoring site.

Date	Location	Streamflow (cms)
28 Feb 2015	Ramsey valley	0.4
28 Feb 2015	15-MC valley (upstream)	1.1
11 Aug 2015	15-MC valley (upstream)	0.1
11 Aug 2015	15-MC valley (downstream)	0.1
31 Aug 2015	15-MC valley (upstream)	0.2
31 Aug 2015	15-MC valley (downstream)	0.2
7 Apr 2016	15-MC valley (upstream)	2.0
7 Apr 2016	15-MC valley (downstream)	1.9

4. Discussion

This study illustrates the importance of using an integrated, systems-based approach to characterize the multiple factors that influence stream temperature in semiarid riparian ecosystems. This research sought to characterize several aspects associated with stream temperature in a semiarid watershed and the results indicate that multiple factors influence stream temperature. Stream temperature was associated with elevation, air temperature, season, and potentially shallow groundwater interactions, although the latter was only analyzed at one monitoring site. In general, no significant differences were found between stream temperature sensors placed in shaded versus non-shaded locations at the 15-MC valley monitoring site, Ramsey site, or at the 15-MC upstream site. These results emphasize that consideration should be given to the collective influence of environmental characteristics, including riparian vegetation, shallow groundwater inflows and intermittent streams, on stream temperature.

Study results show that several factors other than riparian shading can affect stream temperature dynamics in snowmelt-runoff dominated systems such as the one described here. It should also be noted that the characteristics of riparian vegetation (density, species, and age characteristics) influence the degree of shading provided. This study does not negate the importance of the role of riparian vegetation on stream temperature but suggests that a myriad of factors should be considered, particularly in streams that do not meet stream temperature requirements.

While this study did not address the relationship between the percentage of riparian shading (other than to classify areas as shaded or non-shaded), this is an important aspect for future research. This could improve our ability to determine not only if shading is impacting stream temperatures, but also what amount of shading may or may not be influential. During this study, riparian vegetation was not actively grazed or removed in these study sites. However, as many of the areas adjacent to the riparian areas are used for cattle grazing, future research may also focus on potential differences in stream temperature between grazed and non-grazed areas.

It should be noted that the importance of riparian vegetation in stream ecosystems extends beyond its potential influence on stream temperature. Riparian vegetation can also provide a source of allochthonous inputs into the stream system in addition to influencing nutrient cycling and concentrations and other ecological processes [10]. Riparian buffers can also play an important role in preventing erosion and maintaining stability.

Additional research is needed to evaluate how riparian characteristics over larger spatial scales may influence stream temperature. Although the results of this study did not indicate a difference between stream temperature in shaded and non-shaded areas of the stream, upstream riparian shading characteristics are also an important consideration. The presence of vegetation may prevent stream temperature warming by providing reducing direct sunlight, but this alone may not be sufficient to reduce stream temperature particularly if riparian vegetation upstream is limited. The proximity of stream temperature sensors in shaded and non-shaded locations to one another may be another factor in why temperature differences were not seen, so future research may address not only the type and density of riparian vegetation but also the width and length along the stream.

Similar to previous research [23], this study indicated that cold groundwater can influence stream temperature. Subsurface-flow temperature values in the intermittent stream at the 15-MC valley site were substantially lower than those observed in the main creek during summer months, suggesting that subsurface flows may serve as a modulating influence into the main stream system and potentially produce cold water habitat at the confluence.

While daily average stream temperatures did not indicate significant differences between areas immediately before and after the confluence with the tributary, some significant differences were found during the hottest times of the day. Additionally, mean daily shallow groundwater temperatures just prior to the confluence with the intermittent tributary were lower than those downstream. This suggests that the influence of the groundwater inflows may be localized. Additionally, these discrepancies may be associated with inherent differences between the standalone sensors, which takes a measurement at one point in space, and the DTS cable, which integrates the temperature over a portion of the cable.

The limited differences between individual standalone sensors (regardless of shading) may also be influenced by stream velocity and discharge. Steep gradients help move water through the landscape relatively rapidly during the snowmelt runoff season. As a result, movement through shaded or non-shaded areas may be less influential than at lower velocities. For instance, likely due to higher elevation conditions, stream temperature values at Ramsey Creek were consistently lower than those observed at the other lower elevation locations regardless of riparian vegetation in 15-MC. The lowest shallow groundwater temperatures during the year were associated with higher rates of stream discharge in 15-MC during the spring snowmelt but not the lowest annual stream temperatures, reemphasizing the importance of ambient conditions. A comparison of stream temperature at different stream discharge levels was beyond the scope of this research, but this aspect may provide further insight into the relationship between stream temperature, shallow groundwater, and streamflow characteristics.

Ambient air temperatures were highly correlated to stream temperatures. This relationship was found regardless of whether the area was shaded or non-shaded. While many management approaches have focused on riparian vegetation, this suggests the relationship between interannual and intra-annual weather patterns (to include ambient temperatures) and stream temperature should be taken into consideration.

The research study encountered several challenges in data recording and implementing instrumentation. Over the course of the study, several sensors were lost. During adverse weather conditions or in high stream velocity, stream temperature sensors could not be located and collected. Additionally, the remote locations presented issues with data recording as all data must be manually collected in the field. As a result, there are some gaps in data collected from the weather station at the 15-MC valley monitoring site and for air temperature at the 15-MC downstream site. While we were not able to use all standalone sensors for the comparison, sufficient sensors remained to assess shaded and non-shaded areas <.

The use of DTS provided valuable information regarding stream temperature across the 15-MC valley reach and an opportunity to compare results to the standalone sensors. However, conditions at the 15-MC Valley monitoring site posed challenges to implementation of the cable. Cable placement was further complicated due to the high stream velocity at the time of observation. Additionally, instream structures resulted in the displacement of the cable, so temperature measurements in some areas were not the same distance from the streambank. The data collected was deemed sufficient for inclusion in this study as comparisons were made at specific sites along the cable.

The monitoring sites selected for this study were chosen to represent different areas along the longitudinal gradient and were also based on landowner participation. As a result, analysis of riparian vegetation immediately upstream of the 15-MC valley site or other sites was limited to what could be characterized using remote sensing techniques. Additionally, land use practices such as irrigation (whether at the study sites or other areas) were outside the scope of this research. However, as irrigation can influence groundwater discharge to stream and stream temperature [51], this may be an important factor to consider in future research.

5. Conclusions

This study did not find stream temperature differences between areas of different riparian shading. While concerns regarding stream temperatures, particularly the effects they may have on salmonid species, are reflected in many management policies, the focus is often placed on riparian vegetation. Programs such as the Conservation Reserve Enhancement Program (CREP) [52] aim to improve stream temperature regimes by providing incentives to producers to protect environmentally sensitive areas, to include fencing off riparian areas in order to provide more shading for stream ecosystems. However, in addition to riparian vegetation, this research suggests that management of stream temperature in semiarid ecosystems should also consider subsurface flow from intermittent and perennial streams, as well as other factors.

Based on the results of previous studies, we anticipated that areas with higher degrees of riparian shading would have lower stream temperatures than areas with greater sun exposure. However, this study found that stream temperature patterns were most likely the result of a combination of factors to include ambient temperature and groundwater inflows. While previous studies indicate that riparian shading is associated with lower stream temperatures, further research is necessary to understand how riparian shading may influence stream temperatures in semiarid and arid environments specifically. By utilizing systems based research, the individual and cumulative influence of ecohydrological connections can be better understood. A more comprehensive approach can lead to an improved understanding of the collective influence of the biophysical factors discussed and can better inform management and policy decisions.

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GENERAL CONCLUSIONS

This thesis examined ecohydrologic connections in two separate semiarid rangeland systems in Oregon. While both projects had separate specific objectives, each study sought to improve our understanding of an aspect of the relationship between ecological characteristics and hydrological processes in a semiarid rangeland system.

The first chapter of this compared data collection techniques (ground and UAV-based) and assessed vegetation characteristics of one treated watershed (most juniper removed) and one untreated watershed (juniper is dominant overstory vegetation) in central Oregon. Data was collected regarding vegetation ground cover, juniper density, herbage production, and canopy cover. Shrub cover has increased since the removal of juniper from the Mays WS (treated) and decreased at Jensen WS (untreated), which is similar to trends seen in past research. Additionally, while the percent of bare ground was similar between the watersheds, the herbage production in Mays WS was significantly greater than that of Jensen WS. As both watersheds are used for grazing, reduced herbage production could have ramifications if it results in reduced forage availability for livestock.

The results of the first study also suggest that UAVs can be used to improve data collection in juniper-dominated ecosystems, provided that data type (multispectral versus visual bands) and plant phenology are considered. When vegetation indices using near-infrared were used to calculate canopy cover, the results were similar (1.9% to 4.1%) to those results found using ground-based measurements. However, when a vegetation index using visual imagery (using red, green, and blue wavelengths) was used to estimate canopy cover the results were more varied (5.2% to 9.2%). The use of supervised classification to determine juniper density and characterize ground cover yielded mixed results. When multispectral imagery and NDVI were both used for classification, the overall estimate of vegetated ground cover was more similar to that of ground estimates. However, when summer multispectral data was used (with or without the addition of NDVI) the classification was largely unable to successfully distinguish juniper from other vegetation. When supervised classification was applied to November multispectral imagery with NDVI, juniper identification improved accuracy substantially. I attributed this largely to plant phenology as juniper in the November image appeared to have more vigor than much of the other vegetation. This contrast in plant vigor was not apparent in the July imagery. As NDVI is an indication of photosynthetic activity, this method may be most effective at identifying at juniper when differences in transpiration between juniper and other vegetation are most apparent.

Vegetation characteristics will change across seasons and years, depending on annual rainfall and temperature patterns. As such, applying the UAV measurement techniques used here across seasonal and annual timeframes can improve our understanding of changes in vegetation cover across longer timeframes. Additionally, more intensive ground-based seasonal data collection could further refine these techniques. The use of additional ground data could improve our ability to determine if very small juniper, particularly those which are immediately near shrubs, are accurately detected by our methods.

While utilizing fall data and NDVI improved our ability to identify juniper, these techniques could also be used to other vegetation species of interest. Both watersheds in the first study experienced a shift in sagebrush density since 2007. Expanding UAV-based identification to monitor sagebrush could also enable us to address correlations between juniper density and sagebrush density on a watershed scale.

The second chapter of this thesis sought to characterize stream temperature relationships in a semiarid rangeland ecosystem in northcentral Oregon. While stream temperature generally followed the elevation gradient, no differences were found between shaded and non-shaded areas at any of the study sites. Stream temperatures and air temperatures were strongly correlated.

Results of the second study indicate that shallow groundwater inputs from intermittent tributary streams may influence stream temperature, although further research is needed to analyze temperatures at the confluence over seasonal and annual timeframes. While no difference was found in mean daily stream temperatures upstream and downstream of the confluence, more targeted analysis could indicate whether cold-water habitat is created as a result of shallow groundwater inflows from the tributary.

This study suggests that multiple factors in addition to riparian shading can influence stream temperature, and that the cumulative influence of these characteristics should be taken into consideration when studying stream temperature. Although patterns across the watershed should also be considered, the results of this study highlight potential limitations to solely focusing on riparian vegetation to address stream temperature. Additionally, by expanding this research to address watershed-scale riparian vegetation patterns we can better determine both how scale and vegetation density may influence riparian vegetation.

In order to address concerns over increasing stream temperatures, it is also necessary to consider climate. Given that research often focuses on stream temperature in more mesic environments, this research highlights the need to also focus on semiarid and arid regions. Just as vegetation and precipitation will be different in semiarid climates, streamflow and groundwater relationships may also differ. However, while no difference was found between shaded and non-shaded areas of 15-MC in this study, this does not negate the importance of riparian vegetation in potentially preventing further stream temperature increases. It does however emphasize the need to use a systems-based approach towards understanding stream temperatures.

Both studies highlight different approaches to ecohydrologic monitoring. In the first study, UAVs offer high-resolution spatial information that can be used to augment ground-based data collection. While UAVs do not replace the need for in-situ data research, they can improve our understanding of juniper encroachment on a watershed scale. In the second study, DTS and standalone sensors provided similar results regarding stream temperature. While standalone sensors offer the advantage of easier installation and lower cost, DTS offers high-spatial resolution and accuracy. The methods discussed in both studies offer advantages and disadvantages, and the most effective use will depend on research objectives.

While continued research is needed in both studies, this research provides further insight into the ecohydrological relationships in semiarid rangeland environments. An improved understanding of ecohydrological connections can lead to improved land use practices and more effective management strategies to address woody encroachment or rising stream temperatures in these environments.

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