WITH TREES AS MY WITNESS:

The Use of Historical Survey Records in Understanding Contact-Era Forest Structure in The Upper Middle Fork Willamette River Watershed

by

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This research examined the use and limitations of United States General Land Office surveys for reconstructing historical landscape patterns. We reconstructed forest structure for three townships surveyed in 1869 and 1902 in the Upper Middle Fork Willamette watershed. Survey of the area was preceded by early Euro-American explorers, construction of the Oregon Central Military Wagon Road, and timber and grazing activity. We used historical survey notes to conduct an iterative fuzzy classification of section lines that assigned each line degree of membership to closed canopy forest. The final fuzzy classification relied on a composite index comprised of the number of witness and bearing trees recorded along each line and the average distance of each tree recorded from the line. This approach minimized research bias and mitigated the inherent limitations of historical data. Fuzzy membership was then compared with other variables derived from survey notes as well as a previously published reconstruction that uses discrete vegetation classes. Our findings show a positive relationship between survey line membership to degree of closed canopy forest and elevation. We conclude that fuzzy set theory is an appropriate method to work with GLO survey records. However, our investigation suggests that on their own, GLO survey data is insufficient in quality and reliability to confidently reconstruct historical forest structure at a spatial grain needed to inform management plans.

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Introduction

The forests in the western United States are challenged by a slew of factors that limit their resiliency: history of fire suppression, timber harvest, pestilence, and droughts and wildfires linked to climate change (Levine, et. al., 2017). In response to these stressors, forest managers are turning to resilience-based management plans that model conditions before Euro-American colonization. The forests before Euro-American colonization are thought to have been healthier and more resilient than contemporary forests and as such, should form the basis of current and future management plans. Research into General Land Surveys (GLOs) has been increasing in the past several decades to reconstruct those historical forests. The limitations and biases inherent in the survey data are widely acknowledged by researchers, but those factors do not act as a hindrance. The objective of this research is to evaluate the scientific reliability and validity of GLO data as a source to understand historical forest conditions. To address our objective, we applied fuzzy set classification to historical land survey notes dating from the period of Euro-American colonization (Contact Era) to reconstruct forest structure in a portion of the upper Middle Fork Willamette River watershed. We devoted significant time to data exploration and analysis to ensure minimal researcher subjectivity and maximum confidence in our methods. We used section lines as the unit of analysis and kept our classification general with degree of closed canopy forest, instead of extrapolating discrete vegetation type boundaries. The analysis conducted in this study consists only of data directly from the GLO surveys, we did not supplement the classification with other information. Our conclusions show that as a baseline, GLO surveys provide valuable insight; however, the reliability depends on the methodology and spatial grain of the investigation.

Public Land Survey System

In 1785 the U.S. government established the Public Land Survey System (PLSS) to map and divide land for sale and settlement across the entire United States (Whitney and Decant, 2001). From Ohio to the West Coast, a rectangular system, colloquially known as the township and range system, was used to conduct the land surveys. The General Land Office (GLO) was the lead department and contracted thousands of surveyors to carry out the work. Survey of Oregon began in 1851 with the establishment of the Willamette Meridian and the baseline; at the intersection of these lines is the initial point from which all surveys began (Stewart 1935).

While the purpose of the PLSS was to provide a systematic framework for surveying and dividing land as real property; the true work of surveyors was to assess the land quality and potential uses, and physically mark boundaries between sections linking the legal representation of land embodied in the paper map to the land (i.e., real property). The basis of their notation and marking system was the assignment of specific trees as “witness trees” for locating and re-locating section boundaries. As surveyors traveled along compass bearings, they selected and recorded trees to mark (or “witness”) the midpoint and beginning/end of each section line (i.e. section corners). At the midpoint, surveyors chose two trees, one for each section, to mark with the township, range, and section number. Section corners serve as both beginning and ends of lines, so surveyors preferably selected four trees, one for each section, and marked them accordingly. For each tree, surveyors noted the species, diameter in breast height (DBH), and direction and distance from the midpoint or corner. Surveyors were also required to record information like cultural features (roads, trails, burns), terrain, soil quality, and understory flora. Soil quality was rated on a scale 1-4 with 1 being high quality and 4 being poor quality.

This information was collected to assess the potential use and value of the land to Euro-American society; section lines that passed through low, flat, and mid to low grade soil were noted for potential settlement, while section lines rated for first rate soil were noted for potential agricultural use (White, 1926).

Background

The spatial extent of the study for our investigation is along the Middle Fork of the Willamette River in the Western Cascades at a point just upstream from Oakridge, Oregon. The study area is in the foothills of the southern end of the Willamette Valley: a rich and fertile region bounded by the Cascade, Coast, and Calapooya ranges. Because the townships are mountainous and were not considered an ideal place for settlement or other settler colonist activities of commerce or production, the area was not surveyed until almost two decades after survey of Oregon began.

The wealth of resources and diversity of life in the valley supported indigenous peoples for thousands of years before Euro-American arrival and colonization. A common misconception, that has by now hopefully been dispelled by research produced on the subject, was of the landscape as being pristine before Euro-American colonization. In truth, extensive scholarship has brought to light the dynamic relationship that existed between indigenous peoples of North America and their environment–a relationship that shaped the landscape that settler colonists first saw (Boag, 1992; Boyd, 1999). Indigenous fire use maintained the open prairies and savannas of the valleys which benefited the tribes by drawing game animals and increasing production of food crops (Kimmerer and Lake, 2001). It is these kinds of disturbance regimes and vegetation patterns that researchers seek to understand with GLO surveys. Presence of European fur trappers and explorers had been documented in the valley as early as the 1700s, and they brought disease with them that decimated indigenous populations before major westward expansion in the 1840s (Olson and Suski, 2021).

Timber production has been an important sector in the Pacific Northwest since the arrival of European settler colonists to the region; therefore, the study of forest management plans and policy is a justified and relevant topic for understanding the changes to the landscape. Management changes since the incorporation of what is now called the Willamette National Forest into the national forest system has shaped the land use history of our study area. One of the first models of forest management was sustained yield which was developed under Pinchot conservation: prioritization of use over preservation (Johnson and Swanson, 2009). Sustained yield was characterized by clear cutting, fire and pest suppression, and late successional harvesting to make way for young faster growing stands. Clear cutting was the prescribed method for the Middle Fork Willamette watershed which contributed to increased landslides in the area (Lyons and Beschta, 1983). This model valued forests and timber as a commodity and did not acknowledge their ecological value. An estimated 300 million board feet were produced in the Willamette National Forest alone from 1930 to the 1950s (Tonsfeldt, 1994). Timber harvest was concentrated in the Cascade foothills at sites like our study area where easy access was facilitated by roads like the Oregon Central Military Wagon Road. A significant shift in management came during the 1970s with the passage of the National Environmental Policy Act (1970), Endangered Species Act (1973), and National Forest Management Act (1976). Collectively, these pieces of legislature changed the approach from conservation to ecological forestry.

One of the most significant moments in forest management history was the Northwest Forest Plan (NWFP) of 1994 spurred by the controversy over the logging of old growth forest, primary habitat for the endangered northern spotted owl (*Strix occidentalis caurina*). The NWFP plan area was bounded by the range of the owl in the federal forest lands of Northern California, Oregon, and Washington. This plan was more ambitious in its goal to preserve forest lands and increase health of the various forest ecosystems to maintain diversity of native populations.

Within the Middle Fork NWFP project site, the plan prescribed thinning services, some for timber harvest and some not, to decrease fuel abundance and therefore reduce fire severity (Thomas, et. al., 2006). Restoration in the Middle Fork area continued use of thinning, bringing back meadow habitat, and repairing the riparian corridor (Franklin and Johnson, 2012). In the last two decades since its passage, the focus of the NWFP has shifted from conservation and restoration to the revival of historical forest disturbance regimes, namely low intensity fires (Spies et. al., 2019). Not long after, the Healthy Forest Restoration Act was passed in 2003, mostly in response to recent catastrophic wildfires and the growing realization of the role forest management played in them. According to Johnson and Swanson (2009), the act set two important precedents:

> i. The first statutory protection of old-growth forests, and
> ii. The first statutory call for the use of past ecological conditions in planning. (p. 15)

The second precedent keyed forest managers into the need to understand historical forest conditions; thus, the increased interest to use GLO records to inform management plans. Some concern over this law was that fuel reduction was a guise for timber companies to increase their access (Hanson, 2002); however, the evidence to substantiate the claim is unclear. Thoughtful and intentional management of forests is of increasing importance as wildfires become more severe, rural communities are put at risk, livelihoods are threatened, and natural habitat is shrinking. Researchers continue to develop ways in which data from GLOs can best be utilized to provide solutions.

History of GLO Survey Records in Research

Use of GLO surveys in research has a long history but wasn't widely employed in historical landscape reconstruction studies until the mid-20th century. The first documented use of GLO surveys in research was by naturalist Increase Lapham in 1855; Lapham used the survey notes to reconstruct locations of windfalls, prairies, and other features in Wisconsin to understand the effect of disturbance regimes on vegetation (Dorney, 1983). It was nearly three quarters of a century later in 1925 when ecologist Paul Sears used GLOs to define historical prairie boundaries and distribution of tree species across the state of Ohio (Sears, 1921; Sears, 1925). At the time of Sears' investigation, the survey of Ohio was not yet complete; therefore, as many future studies would do, he supplemented the land surveys with geological surveys and qualitative sources such as early explorers' journal entries. The methodologies Sears applied in his research were influential for many other researchers, namely those on the northeast coast (Stuckey, 2009). Use of GLOs was still slow to gain traction with ecologists and others in the academic circles until Bourdo's paper *A Review of the General Land Office Survey and of Its Use in Quantitative Studies of Former Forests* (1956) which encouraged the use of land surveys in ecological reconstruction work (Dorney, 1983).

Prior to the establishment of the rectangular system, land surveys on the east coast began as "colonial surveys" that recorded only acreage and vegetation type (i.e., woodland or meadow), and later transitioned to the metes and bounds system (Whitney and DeCant, 2001). Previous work also depended on qualitative sources like journal entries from early explorers which were often exaggerated and generally less reliable (Noss, 1985). As a semi-standardized source with both qualitative and quantitative data, ecologists and other researchers quickly took to incorporating GLO surveys into their work. A Google Scholar search (accessed May 15, 2023) shows that between 1920 and 1956 (the year Bourdo published his paper), there were just 75 records of "pre-settlement vegetation" papers; from 1956 and until 2000, the number of papers retrieved by the Google search was almost 7,000, and for the last two decades that number is more than double. With this increasing interest in reconstructing historical landscape conditions, it is of increasing importance to thoroughly understand and evaluate GLO surveys strengths and weaknesses as a reliable data source.

Reckoning with Biases and Limitations

Despite the widespread use of GLO surveys, many of the limitations and biases of the data are broadly acknowledged. Much of the uncertainty around GLO surveys as a dependable source stem from inconsistency of survey handbook rules and a few known cases of surveyor fraud. Survey rules were still being defined in the first several decades following the creation of the PLSS which created variation in survey documentation; for example, standards for selecting trees at quarter sections changed from trees at “adjacent sections” to merely “different sections” between 1831 and 1850 (Bourdo, 1956). The vague language and back and forth changes likely created confusion and jeopardized consistency within surveys. In addition, the level of detailed notation required by the surveyors changed throughout the decades. For instance, the enumeration of plant species was specified in 1843, and natural disturbances and water feature boundaries were required in 1850 (Whitney and DeCant, 2001). The rules were finally standardized in 1855 (White, 1984). Furthermore, the effect of instances of fraud on the data, although speculated to be uncommon and remedied by the surveyor generals, cannot be ruled out entirely. Glaring examples of fraud in which surveyors fictionalized accounts of survey lines were usually quickly discovered and the lines resurveyed; one such resurvey revealed missing corners and erroneous distances between the survey line and landmarks (Stewart, 1935). Nonetheless, researchers often acknowledge the difficult conditions of the surveyors’ work and commend the fact that most of the surveys were well done (Schulte and Mladenoff, 2001).

The uncertainty surrounding surveyor reliability and survey instructions bleeds into all areas of the data. One central concern is the ability of land surveys to support quantitative versus qualitative analysis. Researchers express caution against the use of land surveys for quantitative analysis because of low confidence in accurate survey methodology (Grimm,1984; Wang, 2005). This is also doubt over the extent to which any findings could be compared to modern forest inventories. Formulas have been created to account for surveyor bias in quadrant placement and bearing angle (Kronenfeld and Wang, 2007; Hanberry et. al., 2012), and tree density estimates (Pollard, 1971; Jost, 1993). Numerous methodologies have likewise been developed to extrapolate point data of bearing trees into continuous vegetation coverage (Brown, 1998; Manies and Mladenoff, 2000; Fagin and Hoagland, 2011). The many limitations and uncertainties regarding GLO survey data are well documented and addressed but do not impede their continued use.

“Pre-settlement” an Accurate Description?

As one of the few systematic historical records of landscape conditions, GLO surveys are most commonly used to understand vegetation patterns before Euro-American colonization. Without justification or reference, “pre-settlement” is the term most often used to describe that time period (Galatowitsch, 1990; Kronenfeld and Wang, 2007; Aube, 2008); however, this term may not be the most accurate description of historical landscape conditions. In many cases, there were pre-existing Euro-American settlements or extensive colonial commercial activities in areas that had yet to be surveyed (Horne, 2010). For example, commercial logging in Maine began in the 1650s, but the earliest survey records were not completed until 1793 (Lorimer, 1977). In addition, Freidman and Reich (2005) described 1880s Minnesota as pre-settlement even though population of Euro-American settlers in area boomed in the mid-1800s (Larsen, 1940). The term "pre-settlement" references the period prior to Euro-American colonization; therefore, to use this term would be inaccurate in many cases. The GLO survey notes are often the oldest systematic records of landscape conditions and therefore the closest proxy data for pre-settlement vegetation conditions. However, the term is rooted in the Eurocentric idea that prior to Euro-American arrival and colonialist activities, North American landscapes were "pristine," thereby neglecting any recognition that landscapes were shaped by thousands of years of indigenous inhabitation and stewardship (Williams, 2000; Kimmerer and Lake, 2001).

Euro-American presence in Oregon was limited to fur trappers and a few early settlers until an influx of people arrived via the Oregon Trail in 1843 (Boag, 1992). Settlers concentrated in the fertile lands of the northern Willamette Valley before spreading outward and down. Construction of the Oregon Central Military Road was one of the drivers for workers and their families to move south towards the mid-1850s (Beckham, 1981). Although the foothills of the Cascades were not conducive to settlement, there was substantial colonialist activity taking place. In our study area, research shows that commercial grazing was introduced around the time of survey in 1869 which likely impacted the environment observed by the surveyors (Hadley, 1999). Furthermore, settlers' desire to forge a trail south for settlement of the Klamath Basin had explorers scouting routes in the Western Cascades in the 1850s before land surveys in Oregon began (Beckham, 1981). Therefore, Contact Era is a more accurate description of the temporal setting of our research rather than "pre-settlement" which gives a false sense of historical human-landscape relationships.

Site Specificity

Considering the variable nature of surveyor instructions, known cases of fraud, and inconsistent settlement patterns, researchers must conduct thorough investigation into their study area. Indeed, independent studies have been dedicated to understanding the instructions of one’s state or region (Dodds, et. al., 1943). Depth of knowledge of any instruction inconsistencies or individual surveyor biases will help inform appropriate methodologies based on the unique limitations of one's study area (Manies, et. al., 2001). Areas surveyed using the metes and bounds system, which featured unevenly distributed survey sections, would necessitate a different approach (Aube, 2008). Methodologies to assess bias are likewise impacted by survey differences. Bourdo (1956) analyzed distances between bearing trees and wooden stakes used to mark section corners to evaluate tree selection bias; however, no such markers were used in Maine surveys, so Bourdo’s method cannot be applied to surveys from Maine (Lorimer, 1977). Much of the existing research takes into consideration how the unique characteristics of the study site impact data limitations.

Current Use of GLO Surveys

Over the decades, researchers have explored various methods and approaches to GLO data interpretation. GLO records have been used for large-scale vegetation reconstructions (Christy and Alverson, 2011; Powell, 2008), forest composition analyses (Friedman and Reich, 2005; Knight, et. al., 2020), and comparisons to modern day forests (Dryer, 2001; Hessburg, et. al., 2005). Some methodologies took a deductive approach to create a coding schema and pulled information from supplementary sources such as plat maps and soil surveys (Habeck, 1961; Christy and Alverson, 2011). While this approach maintained consistency within classifications, pre-defining classes may have obscured patterns that otherwise might have been seen. Other methodologies conducted analyses with a more complex statistical approach, for example estimation of forest density (Anderson, et. al., 2006; Hanberry, et. al., 2012; Levine, et. al., 2017), and fuzzy sets (Brown, 1998). Brown critiqued the assignment of discrete boundaries on vegetation types because that assumes that only one vegetation class can exist at a given location. Instead, Brown used fuzzy membership, which is the transformation of data along a common scale (usually 0 to 1) based on degree of membership to a set. This method allows a many-to-many relationship between section lines and degree of membership to closed canopy forest. Regardless of the approach taken, studies of GLO survey records continue to be published and discussed because, in most cases, they represent the only systematic record of historic forest conditions that exist (Schulte and Mladenoff, 2001).

Overall, scholars come to a shared conclusion that imperfection is not reason enough to reject a valuable data source on historic land cover. GLO survey data was collected for the specific reason to assess the potential value of land for settlement, farming, and timber harvest, so data must be carefully interpreted when used for other reasons. Based on settler activity in our study area, the difficulty of traversing mountainous terrain, and the other limitations we have listed above, we chose a methodology that embodies all the uncertainty of working with GLO data, but that is still founded on confident variable relationships: fuzzy set classification (Brown, 1998). Fuzzy set classification is an appropriate research approach to inform the reconstruction of historical forest structure from survey records because it accounts for some of the inherent limitations of the data.

Methods

Study Site

The project area consists of the upper Middle Fork Willamette River watershed located within Township 23 South Range 3 East, and Township 24 South Ranges 3 & 4 East (Figure 1). These sections were chosen because 1) the Forest Service is actively conducting restoration projects in the area, and 2) the Oregon Central Military Wagon Road runs through the area which resulted in a relatively early government survey by the General Land Office. The earliest surveys for the area were conducted in 1869 and 1902; thus, we selected these surveys to capture the landscape conditions as close to the Contact Era time frame as possible. Contact Era is defined as the time of first arrival by European settler colonists to land occupied by indigenous peoples; the Oregon trail facilitated the influx of colonists' arrival to Oregon in the 1840s. The arrival of European colonists through the Oregon trail accelerated changes to the landscape that were already set in motion by the forced removal of indigenous groups from the valley just a few decades prior.

Survey Note Transcription

Scans of original surveyor notes were downloaded from the Bureau of Land Management (BLM)[1] and organized by township and range, year, and surveyor. Survey pages were cataloged by section boundaries (North, South, East, West, or subdivision) which were then combined by township into one document (pdf file format) so that the surveys could be transcribed chronologically. We transcribed survey notes from the PDF files into an MS Excel spreadsheet so that data could be pulled out and analyzed. Although the 1902 notes had been transcribed and

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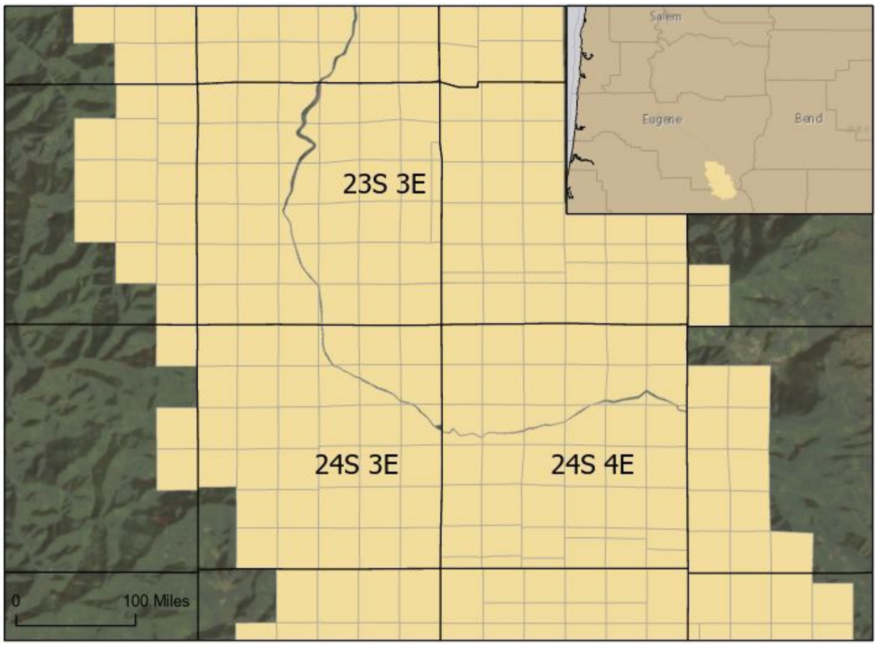
[1] https://www.blm.gov/or/landrecords/survey/ySrvy1.php accessed and downloaded 6 July 2022

typed some time prior to digital archiving, the notes from the 1869 surveys were scanned and archived by the BLM in their original form of handwritten script; therefore, data transcribed from these scans into MS Excel included a column for confidence level to account for the difficulty of reading handwritten notes. We took an iterative approach to transcription; as the handwriting of each surveyor became more familiar, we were able to return to areas of uncertainty and make updates and corrections.

Figure 1: Project area by township and range

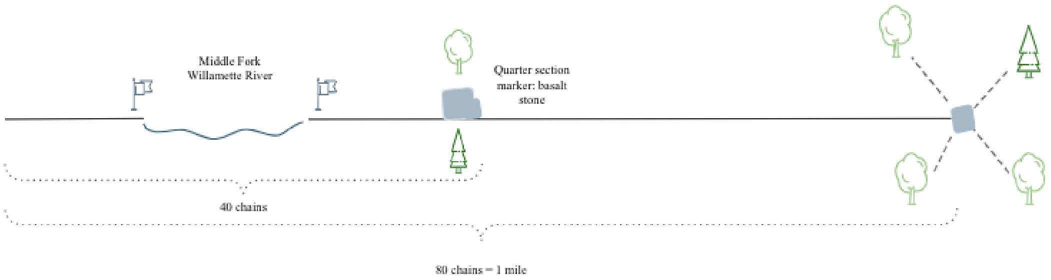


Note. Project area is shown in yellow color overlaid by the township and range grid.

Townships are divided into 36 sections of one-by-one mile squares. Surveyors completed a survey of a square section going line by line (e.g., 4 lines for each side of the square, unless one of the lines had already been surveyed for the previous section). Surveyors used a measurement system with units called chains and links to mark their course: a chain had 100 links and totaled 66 feet in length (Powell, 2008). A section line is 80 chains long (i.e., one mile). Figure 2 shows what a section line crossing the Middle Fork of the Willamette River may have looked like based on survey data.

For data entry, we set up a spreadsheet so that each row corresponded with a point on the section line (e.g., 40 chains from the start corner) at which a surveyor noted a tree, change of topography, or other point of interest. The surveyor also noted the distance to the feature from the line (e.g., 10 links), feature characteristics such as tree species, stream width, or rock type, and if it was a tree, the diameter at breast height (DBH). For each row, we also documented the township and range, the year, the direction the surveyor traveled on the line (e.g., East to West), and the name of the surveyor. We assigned a unique ID to each section line to more easily track which features belonged to which section lines. When surveyors reached the end of a section line, they often described the overall characteristics of the land: terrain, soil quality, stand structure, tree species, and undergrowth. In anticipation of later analysis, we calculated the average and maximum DBH and distance of bearing trees for one section line. To capture this information pertaining to the entire section line, we created a separate spreadsheet with the individual rows corresponding to entire section lines. We linked this data with the individual features along a line through the unique ID.

Figure 2: Schematic of a section line



Data Exploration

The variable types transcribed from survey records include ordinal (soil rating), categorical (tree species), continuous (measure of distance and DBH), and counts (number of bearing trees). Variable relationships were explored using histograms, bar graphs, box plots, and regression analyses. Terrain, soil description, and stand structure were ranked and assigned a value; in some cases, similar descriptors such as “stony” and “rocky” were combined into one category. If multiple soil ratings were recorded for a section line, we took the average. Understory and tree species were converted into a binary variable to represent presence or absence of specific species (or species families as specified in the notes). Because the surveys used in this project come from both 1869 and 1902 resulting in a 33 year gap between surveys, we decided to separate the data and explore the variables as two sets. During this process, we identified lines that were originally surveyed in 1869 and were resurveyed in 1902 for comparative analysis. Some standalone section corners that had been resurveyed were likewise identified. To assess differences in survey methodologies and forest changes between 1869 and 1902, we compared the number of witness trees, the DBHs, and tree species of the original and resurveyed lines. Resurveyed lines were excluded from the 1902 portion of the data set for forest structure analysis and maps in favor of representing the earlier, 1869 data.

Analyzing Forest Structure

Initially, at the start of this project, we considered adopting Christy and Alverson’s 2011 coding schema, but we found it to be a poor fit for the data from either of the surveys. Their methodology used distance to bearing tree and stand structure and undergrowth descriptors to categorize survey lines into crisp categories of forest, woodland, savanna, or prairie. For example, their schema dictated that a line be classified as “forest” if all bearing trees were present and within 100 links of the line, and if terms like “heavy”, “dense”, or “brushy” were used. We found it difficult to match lines to those ecosystem categories based on this coding schema. For instance, the range of BT distances we transcribed was 1.36 to 258 links, but only 2% of bearing tree distances had a value over 100 links; therefore, distance as a classification tool made little sense. A review of statistical comparisons to understand variation in surveyor performance suggests a preference for trees located closer to the line for reasons of time, pay, and the difficult nature of the work (Schulte and Mladenoff, 2001). This cast further doubt on the meaning and reliability of the distance metric as used in Christy and Alverson's coding schema. Furthermore, of the 136 lines that had stand structure descriptions, "heavy timber" made up 90% (122 lines). Under the Christy and Alverson schema, a section line with three bearing trees all under 100 links from the line and a descriptor of "heavy timber" fits all but the bearing tree requirement to be coded as "forest"; however, we felt that a line with this description is more likely to have had a more open structure than a closed one, rendering the "forest" designation misleading (Table 1). In addition, as noted below, Christy and Alverson apparently did not follow this scheme very closely in their reconstruction of our project area, but for undisclosed reasons privileged historical aerial photos.

Table 1: "Heavy timber" example survey lines

Section Line ID	Township and Range	Survey Line	Stand Structure	Tree Species	Understory Species	# BTs	Distance (links)	Comment
375	T23S_R03E_1902	E-W between S20-S29	heavy timber	fir, hemlock	vine maple, rhododendron	6	55, 46, 33, 28, 13, 10	NA
139	T24S_R04E_1869	W-E between S1-S12	heavy timber	not noted	not noted	3	14, 27, 30	NA
189	T23S_R04E_1902	S-N between T23SR3ES25 - T23SR4ES30	heavy timber	pine, larch & fir	salal & huckleberry	10	20, 89, 30, 13, 39, 76, 20, 24, 6, 16	mentions open prairie at 30 links

Note. None of these lines fit into the Christy and Alverson coding schema. We found their approach to be too rigid to explain something as dynamic and complex as forest structure.

Fuzzy Set Construction

A fuzzy set is a group (set) of objects that have varying degrees of membership to the set (Zadeh, 1965). Fuzzy set theory is useful when working with data that is imprecise and can accommodate both quantitative and qualitative data. We normalized data by scaling variables between 0-1 where 0 is full non-membership and 1 is full membership, and any value in between describes the degree to which an object is a member of that set. We used min-max normalization where the minimum and maximum were taken from the overall dataset; the min and max were kept the same to normalize data from both 1869 and 1902 survey years. We used the formula below shown in (1). Fuzzy membership is not to be misunderstood as simply the transformation of variables along a continuum, but a process based on thorough understanding of relationships and a sound knowledge base (Ragin, 2000). Our objective was to use the GLO survey data to construct a fuzzy set for closed canopy forest structure to help inform better understanding of Contact Era forest structure.

$$Xnorm = \frac{x - \min(x)}{\max(x) - \min(x)} \tag{1}$$

We identified the following variables for possible inclusion in the fuzzy set based on careful consideration of how they relate to forest canopy closure: the number of bearing trees per section line, the median, average, and maximum inverse distance of the bearing trees from the line, and the tree species and undergrowth communities. The number of bearing trees was a clear choice; we trust that there were no (or few living and of sufficiently robust size) trees present when the surveyor notes indicate so, and vice versa. Although we had difficulty using distance in parameters used by Christy and Alverson (2011), we felt that distance of the bearing trees from the line does contribute to our overall understanding of forest structure. We suggest that shorter distances between the line and the bearing tree would indicate a more closed canopy forest; however, since larger values on the 0-1 scale indicate higher degrees of closed canopy, we took the inverse value of distance (1-x) as a pre-processing step before normalization. Therefore, we chose to include the number of bearing trees and average inverse distance of the bearing trees from the line for both 1869 and 1902 as indicators of closed canopy forest. The minimum and maximum values found were 0 and 12 for number of BTs, and 0 and 258 for distance. The variables were normalized separately, then combined in three different ways to create three versions of the fuzzy index of closed canopy forest: 1) the fuzzy "and," the minimum of the input, 2) the fuzzy "or," the maximum of the input, and 3) the fuzzy "sum," the average of input (ArcGIS Pro). (See Appendix I)

We also analyzed tree and understory species for 1902 as indicators for degree of forest canopy closure. The *Field Guide to the Forested Plant Associations of the Westside Central Cascades of Northwest Oregon* from the United States Forest Service was used to attribute a percentage of canopy closure to each pairing of tree species and undergrowth (McCain, 2002). Since the surveyors only recorded tree species as "fir", "pine", "hemlock" and not the specific species, the grouping of tree and understory species for each line was matched as best as possible to the plant associations in the field guide. The guidebook mapped plots where each association was found; therefore, we gave priority to associations which had plots nearest to our project site. Additionally, we gave preference to associations with the highest presence percentage of the understory species. For lines that had several possible associations, we took the average percentage of canopy closure. Because of the high uncertainty, we ultimately excluded tree and understory species from the final fuzzy set (see Appendix II).

We gave priority to the oldest available survey; therefore, a section corner with no BTs recorded in 1869 was maintained as having zero BTs, even if a 1902 resurvey recorded four BTs. Surveys from 1869 had less data recorded; understory species were “not noted” for all but a few lines for which surveyors noted “some grass”, and there were no soil descriptions recorded. Some lines had no tree species recorded in their line summaries but had BTs; in this circumstance the BT species were substituted for their line summary. We felt that BT species were a reasonable proxy for these lines; however, it is important to note that tree species listed and the species of the BTs of the same line do not always correspond in the original survey notes. Furthermore, during preliminary iterations of visualizing the 1869 fuzzy set, we noted that lines along the Middle Fork of the Willamette River were coded as being more closed than open canopy. In addition, a survey line following the course of the river indicated that the riparian corridor was apparently characterized by a closed canopy forest. These data points skew the fuzzy value towards canopy closure for each line crossing the river. To account for this, we removed the BTs that were recorded within the riparian corridor from the fuzzy analysis.

Mapping the Fuzzy Sets

We mapped the fuzzy sets along the GLO survey lines in ArcGIS Pro 3.0.2. Degree of membership to closed canopy forest was symbolized using the unclassed method, and the 1869 data is distinguished from 1902 by solid and dotted lines, respectively. Unclassed colors symbology does not use discrete classes like graduated colors but rather evenly assigns colors across the input value range (ArcGIS Pro); we felt unclassed colors best represented the fuzzy index for closed canopy forest.

Results

The three fuzzy sets of closed canopy forest are shown below (Figures 3-5). The spatial distribution of section lines categorized by degree of membership to the closed canopy forest shows a gradient between less closed canopy lines and more closed canopy lines. Across the three methods— "or", "and", and "sum" (see Appendix I)—lower degrees of closed canopy forest are characterized by the lighter shades of orange as seen along the Middle Fork of the Willamette River course. The river course is situated at lower elevations and the topography is relatively level and more gently sloping. In comparison, the survey lines modeled as higher degree of membership to closed canopy (in the darker shades) are located at higher elevations in the mountainous terrain surrounding the river corridor, most of which were surveyed in 1902. Most lines produced using the "or" method show more closed canopy forest outside of the riparian area (Figure 3); "or" maximized the input fuzzy membership which tended to favor the fuzzy variable for distance of bearing trees from the line. Because shorter distances suggest a more closed canopy and the inverse distance was taken to transform the value along the 0-1 index, the fuzzy variable for distance produced higher index values. The map produced using the "and" method displays the most variability of degree of closed canopy (Figure 4), but still follows the overall pattern of less closed canopy forest along lower elevations and more closed canopy in the uplands, generally >3,600 meters in elevation. The "sum" method maintains some of that variation but overall shows higher degrees of closed canopy than the "and" method because it took the average of the fuzzy variables for distance and number of bearing trees (Figure 5).

Figure 3: Fuzzy “Or” Method

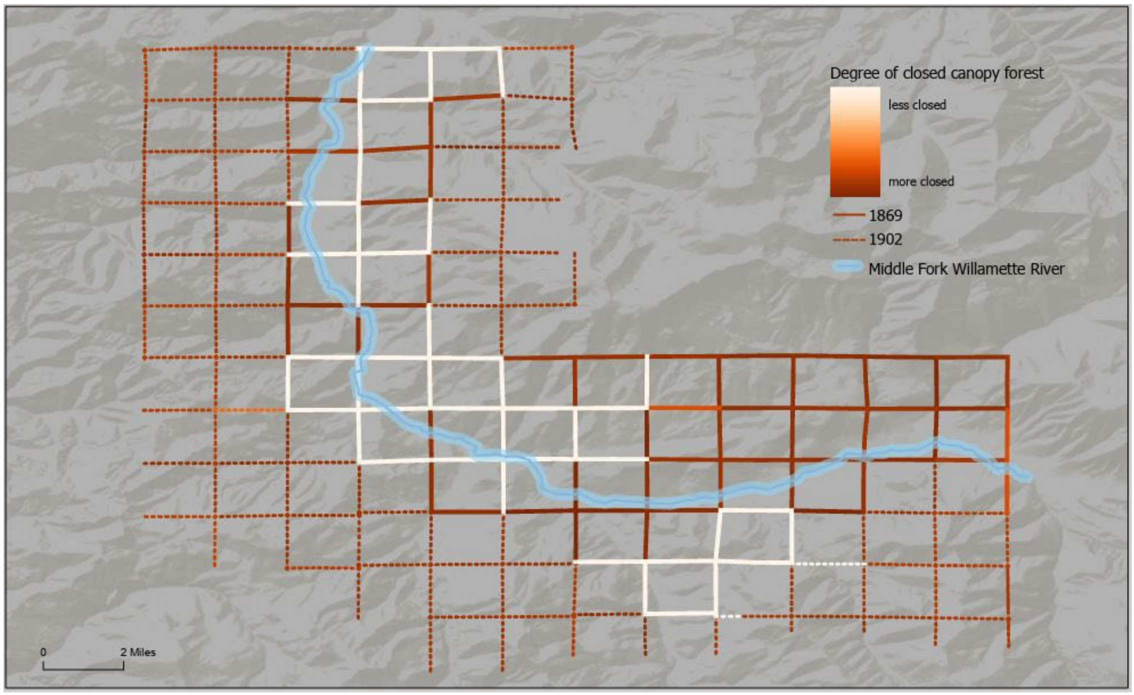


Figure 4: Fuzzy “And” Method

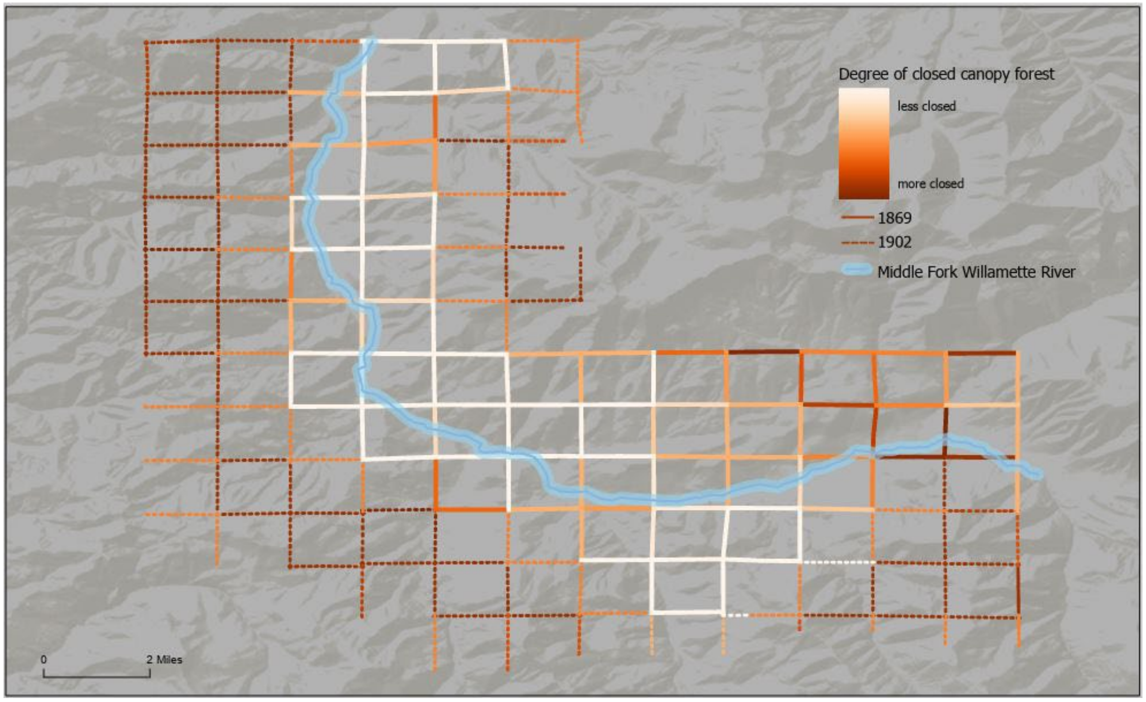
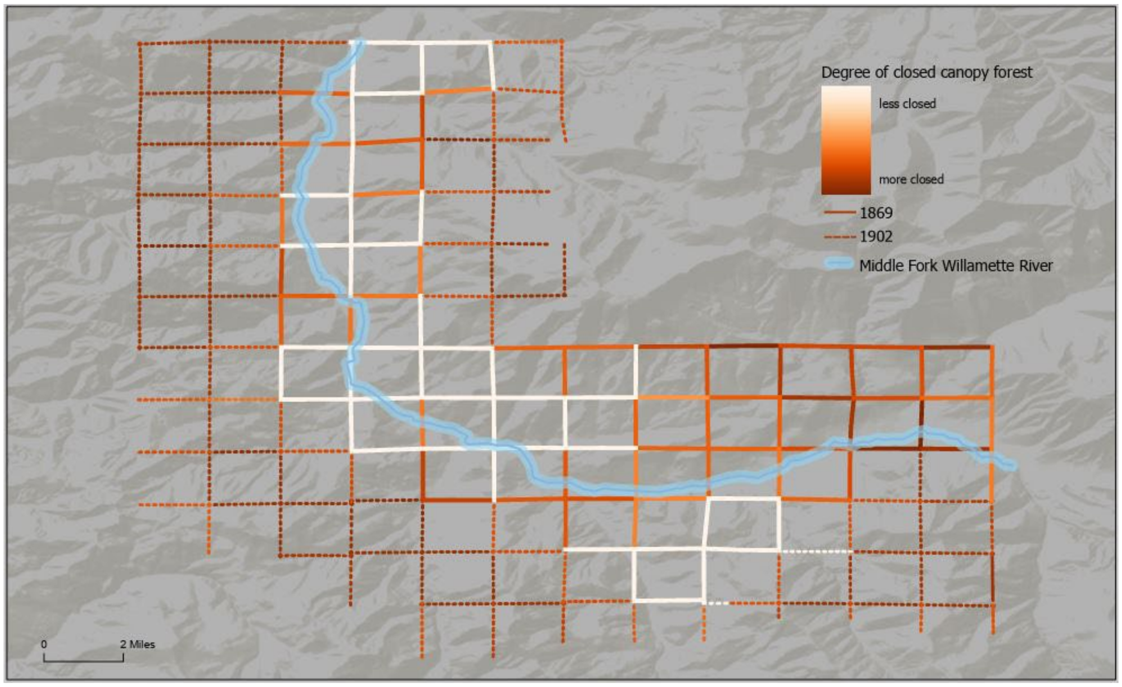


Figure 5: Fuzzy "Sum" Method

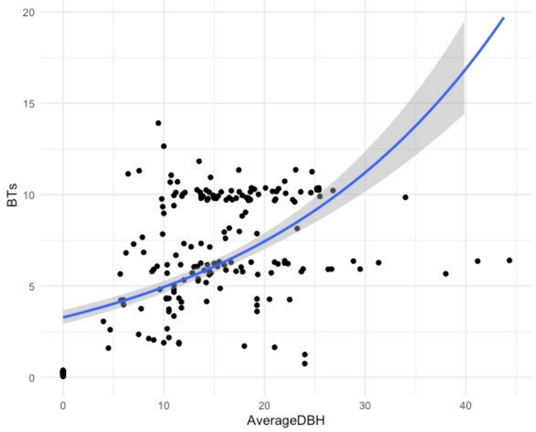


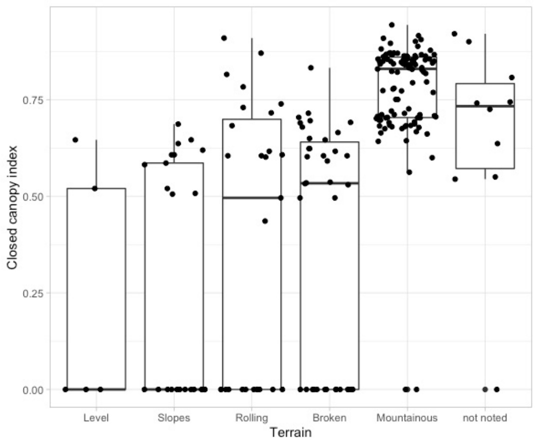
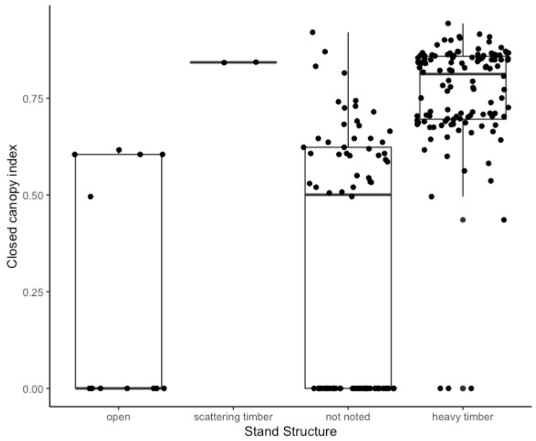
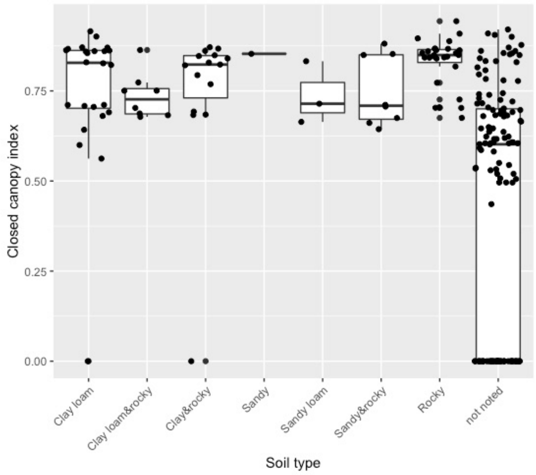
Excluded variables from the final indices for degree of closed canopy forest are shown in Table 2. Poisson regression of average DBH and number of bearing trees had a p value < 0.05 and a pseudo-R squared value of 0.25; DBH may have been included if multiple studies hadn't already exposed tree selection bias (Bourdo, 1956; Noss, 1985; Kronenfield and Wang, 2007). We selected fuzzy "sum" to compare and explain the exclusion of the other GLO variables; the other two methods favor the lower or higher values, but "sum" takes a combination which we felt presented a more holistic view. The box plot of terrain and the fuzzy index shows that a wide range of degrees of canopy closure correspond to lines described as "level", "slopes", "rolling", and "broken"; all first quartiles are 0 and the third quartiles range from 0.52 to 0.69. Comparatively, lines which were described as "mountainous" have a much smaller interquartile range with an overall higher degree of closed canopy: first quartile 0.70, third quartile 0.86, and median value of 0.83. The differences between the box plots for "level" and "mountainous" roughly correspond to the distribution of less and more closed canopy across the topography of the project area; along the riparian corridor the land is flatter, and the forest canopy is less closed, and the surrounding area is more mountainous with a more closed canopy forest. A box plot of stand structure shows that “heavy timber” does apparently coincide with the fuzzy index; the interquartile range is 0.70 to 0.86, the median value 0.81, and the mean 0.76. The box plot for “open” has a larger interquartile range– 0 to 0.61–but still has low median and mean values: 0 and 0.24 respectively. If we look at the lines described as “open”, the indices do coincide with that description: line IDs 111, 113, and 153, for example. Forest structure as described by the surveyors was limited to the three broad categories of “heavy timber”, “scattering timber” and “open” of which the latter two may be reliable descriptions but the foremost is less confident. Instead of being used as a reference to stand density, prior analysis has suggested that “heavy timber” was more likely used in relation to presence of big trees (Powell, 2008).

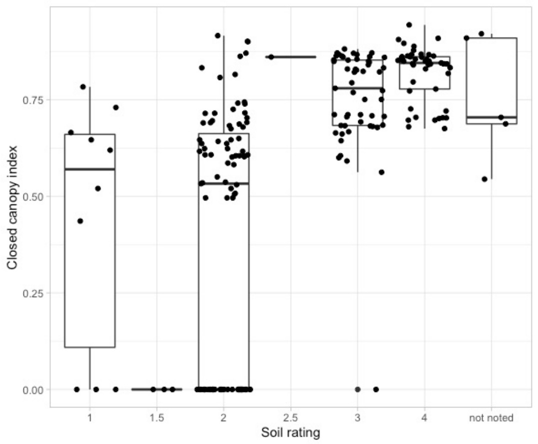
We also attempted to use the tree and undergrowth species listed by surveyors for each line to model forested plant associations to extrapolate the generally accepted percent canopy cover for those associations. To do this, we cross referenced these plant associates with the USFS *Field Guide to the Forested Plant Associations of the Westside Central Cascades of Northwest Oregon* (McCain, 2002). However, limited species information from the historical surveys led to modeled plant associations with the same or similar percent canopy cover. A variation of the fuzzy indices that included these canopy cover estimates produced maps that were much more skewed towards closed canopy forest.

Lastly, both variables relating to soil–type and rating–were also evaluated with box plots. Across the seven soil types, the plots show little variability in relation to degree of canopy closure, and over half of the lines (~60%) don’t have a soil type recorded in the survey. Soil type was excluded because it would require academic training or extensive research in the subject to analyze the relationship with forest canopy cover and the reliability of the survey. The overall pattern of soil rating against the fuzzy index is that ratings 1 and 2 are associated with lower degrees of closed canopy than soil rated 3 or 4 which have tighter interquartile ranges and higher medians. The purpose of soil rating was to evaluate the land for potential development or agricultural use; a soil ranked 1 was supposedly better than a ranked 4 soil (Galatowitsch, 1990; Powell, 2008). Working from the assumption that land with fewer trees is easier to clear and therefore more valuable, the plot supports that trend; however, we felt that it extrapolates too far beyond the data.

Table 2: Excluded variables

VARIABLE	UNITS	REASON FOR EXCLUSION	VISUAL
DBH	Inches	Surveyor bias in species and age of trees selected for bearing trees (Bourdo, 1956; Noss, 1985; Kronenfield and Wang, 2007).	
Terrain	1 - Level	Insufficient data to conduct thorough analysis.	
	2 - Sloping		
	3 - Rolling		
	4 - Broken		

	5 - Mountainous		
Stand Structure	1 - Open	“Heavy timber” may likely have referred to the perceived value of timber rather than the density of trees (Powell, 2008).	
	2 - Scattering		
	3 - Heavy timber		
Soil Type	Clay loam	Would require additional outside research to investigate plant and soil relationships	
	Clay loam & rocky		
	Clay & rocky		
	Sandy		
	Sandy loam		
	Sandy & rocky		
	Rocky		

Soil Rating	1 - 4 ranked	Uncertainty about survey reliability.	
Canopy Closure	Tree & Understory Species presence	Too many unknowns and assumptions to make solid classifications.	See Appendix II for full table

The comparison of resurveyed lines supports the general pattern that the river corridor in 1869 had a less closed canopy forest than the higher elevation uplands in 1902. For instance, a line graph comparing the number of bearing trees of an original survey line in 1869 and the resurveyed lines in 1902 shows a general increase in trees (Figure 7). Two lines that are significant outliers from this pattern are 130 and 137; survey line 130 had the same number of bearing trees from 1869 to 1902, and line 137 had one more bearing tree in 1869 than in 1902. These survey lines cross the Middle Fork of the Willamette River which likely explains why the lines have the same number of bearing trees for both survey years. Similarly, a line graph of DBHs shows an overall increase in tree size for re-surveyed lines; the average DBH of trees in 1869 was 9.15 inches which increased to 18.28 inches in 1902. This suggests that the bearing trees selected for 1902 may have been present in 1869 but were too small to be selected at that time. Many past studies have pointed out surveyor bias when selecting for bearing trees, both in species and DBH (Noss, 1985). A look at differences in tree species revealed the presence of more species in 1902 than in 1869; a survey line in 1869 averaged 1.7 species while a line surveyed in 1902 averaged 3.3. However, the lower total number of bearing trees in 1869 is likely a factor in there being fewer tree species included in that survey.

Figure 6: Comparison of bearing trees of resurveyed lines

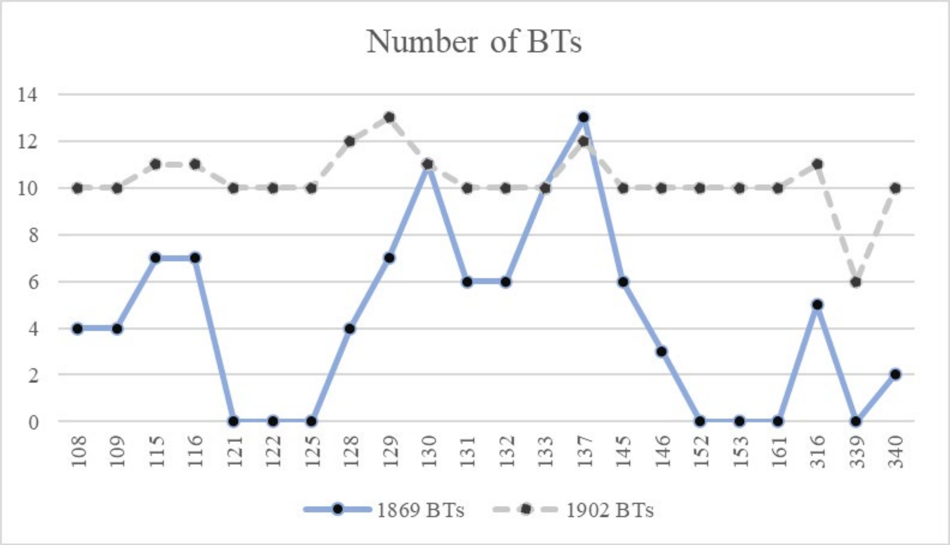


Figure 7: Comparison of DBH of resurveyed lines

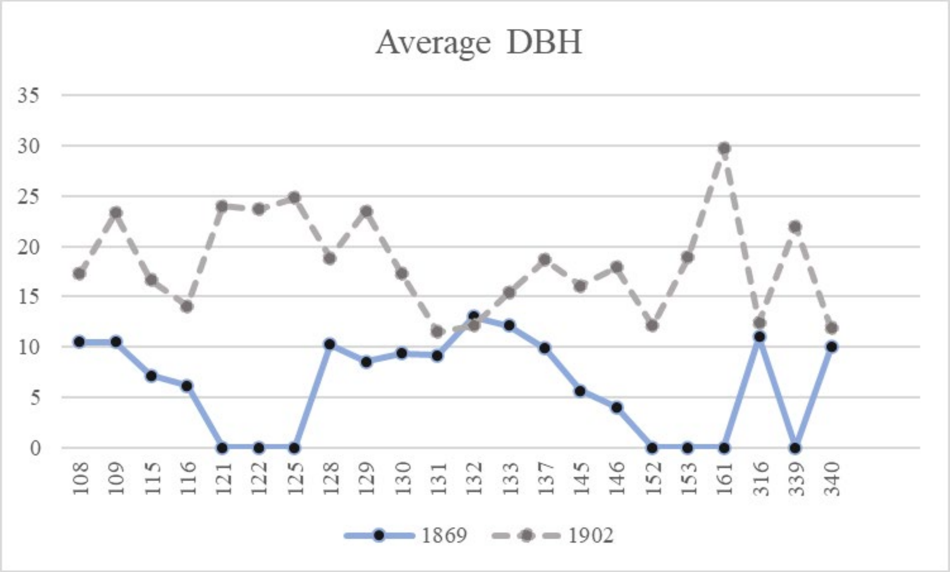
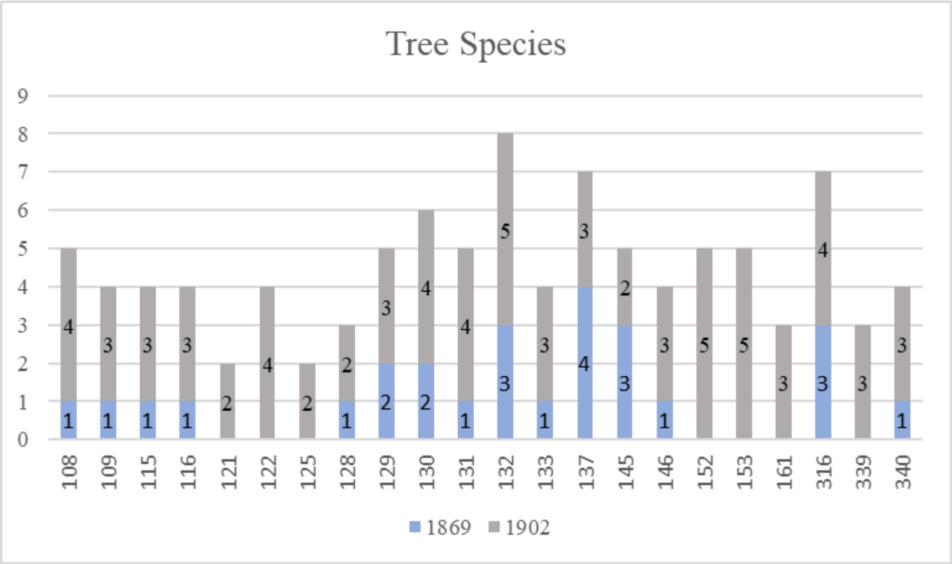


Figure 8: Comparison of number of different tree species on resurveyed lines



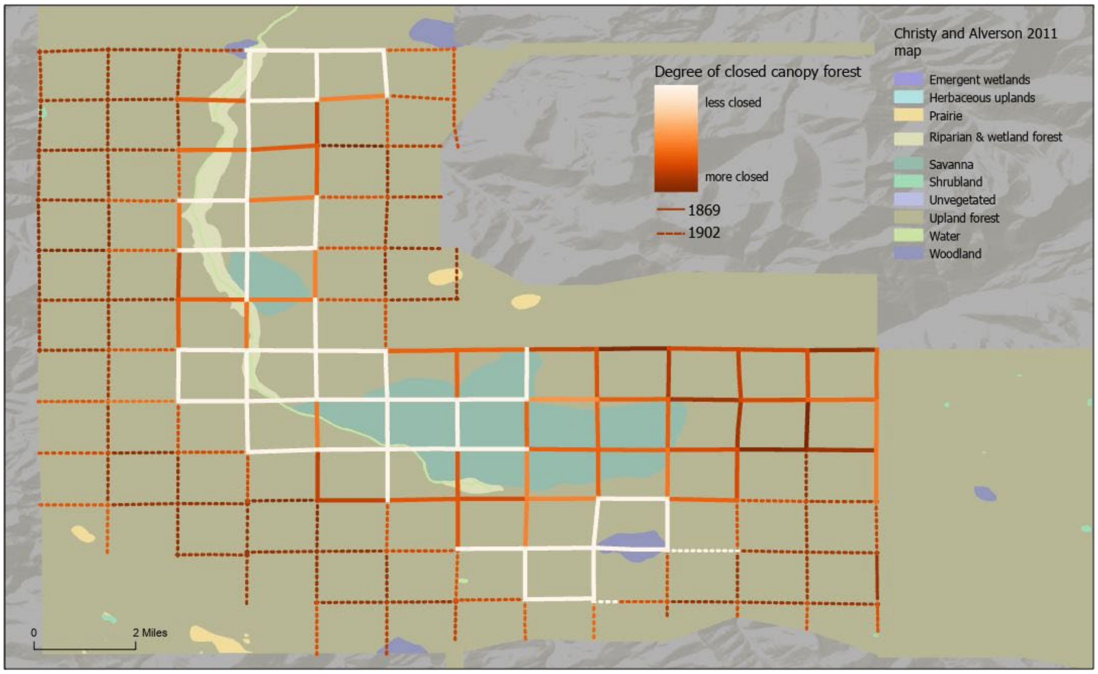
Discussion

Our fuzzy set of closed canopy forest structure showed an overall positive relationship between elevation and degree of closed canopy forest; lower elevations along the river course are associated with lower degrees of membership to closed canopy forest, while higher elevations in the uplands support survey lines with higher degrees of membership to closed canopy forest. Because of limitations and bias inherent in the surveyors' work, using historical land survey data to explore the broader pattern of closed canopy forest was more appropriate than classifying survey lines into discrete vegetation types. While the historical land surveys do provide more information beyond the two variables we used for the fuzzy set, our analysis suggested low confidence in the reliability and relevance of the excluded variables in terms of how they relate to forest canopy structure. Our investigation suggests that on their own, GLO survey data is insufficient in quality or reliability to confidently reconstruct historical forest structure at a spatial grain needed to inform management plans.

Comparing Christy and Alverson's Willamette Valley Historical Vegetation Map

As described above, Christy and Alverson (2011) published a historical vegetation map of the Willamette Valley that features discrete vegetation type boundaries. The upper Middle Fork portion of the map does not appear in the publication but is available on-line in the ArcMap shapefile Version 2001_04 (Christy, et. al., 2011). The map has been used to evaluate restoration schemes for seasonal wetlands (Pfeifer-Meister, et. al., 2018), river corridors (Gregory et. al., 2019; Wohl, et. al., 2021), and prairie ecosystems (Dunwiddie and Bakker, 2011) throughout the valley. The authors supplemented the historical land surveys with aerial photographs from the 1930s (that post-date the period they claim their map represents), plat maps, and soil surveys to better inform their estimations of vegetation boundaries. Despite the difference in methodologies, there is some consistency between our fuzzy set for closed canopy forest and Christy et. al.'s map; as Figure 11 shows, sections lines with lower degrees of closed canopy forest roughly overlap with polygons classified as savanna (blue), woodland (purple), and prairie (light orange). Section line 189 is an interesting example of how our methodologies differ. In the survey notes, a prairie is recorded at 30 links along the line, but because our fuzzy set only included the number of bearing trees and distance, the line was classified as a higher degree of closed canopy forest. The section line had 10 bearing trees recorded and the average distance was 33.3 feet which produced the fuzzy "sum" value of 0.85. As Figure 9 shows, line 189 passes through a small portion of the estimated prairie area, which Christy et. al., likely identified with the aerial photographs. Our fuzzy classification is not wrong, but rather represents the difficulty of mapping small patch vegetation within an otherwise contiguous vegetation type. Ways to mitigate this issue in the future would be to conduct fuzzy classification at a finer grain than the section line and perhaps split the line at the quarter section. Alternatively, small patch vegetation could be symbolized separately as point data.

Figure 9: Discrete versus fuzzy classification



Implications for Future Use of GLO Survey Records

Use of GLO surveys to reconstruct historical forest conditions has been done since before surveys were concluded in the 1930s (Sears, 1925), and since then, numerous studies have adapted their own methodologies to account for data limitations over the decades. Now with hundreds of maps in circulation of reconstructions based on GLO surveys, and the increasing need to manage our forests for resiliency, it is imperative to evaluate the credibility of GLO survey records to be used for reconstruction needs. Our results agree with many previous researchers who have concluded that GLOs are too valuable to put aside, but as a standalone source they may be insufficient (Grimm 1984; Manies, et. al., 2001; Kronenfeld and Wang, 2007; Horne, 2010). Bias is inherent in the survey data because of the systematic way surveyors were required to choose and mark bearing trees; while it provided consistency, the resulting data on bearing trees is a nonrandom sample which must be accounted for during analysis (Levine, et. al., 2017). Researchers' intent to use the surveys for historical vegetation reconstructions differs from the surveys' original intent to inventory land for sale and settlement. This creates conflict between how researchers want to use the data and limitations on how the data can be used. We suggest that GLO survey data should be used only in conjunction with other sources of information (Schulte and Mladenoff, 2001).

Limitations aside, there are simply no other records of historical land conditions like GLOs; as Egan and Howell put it, they are "unexcelled as a source of baseline information" (2001). A key word is "baseline"; with all the data use challenges just discussed, historical land survey data is best suited to complement other data, or to make generalized conclusions. Nonetheless, historical land surveys can be an excellent foundation for fire ecology studies and archaeological investigations. Surveyor instructions from 1850 specifically outlined that surveyors were to record features such as Native American trails, evidence of past fire, windfalls, etc., with location information (Bourdo, 1956), which provide valuable point locations from where researchers can begin their data collection. Plat maps created in association with survey notes were a key historical reference for Pachin et. al.'s (2018) work to reconstruct the locations of Native American settlements on the northwest coast of California, and numerous fire ecology studies have been conducted in conjunction with GLO data (Agee, 1993; Boyd, 1999; Storm 2002). These studies built upon the survey information with other sources in acknowledgement of the surveys' incomplete and flawed nature.

Recommendations for Further Analysis

Despite our cautionary approach to working with the GLO survey data by creating a fuzzy classification, further analysis could be conducted to strengthen our fuzzy set of closed canopy forest structure. Since the resulting fuzzy set does show a positive relationship between degree of closed canopy and elevation, an analysis of topographic variables including elevation, slope, and aspect could provide more detail (Thomas-Van Gundy and Nowacki, 2013). Statistical regression for each topographic variable with the fuzzy “sum” for closed canopy forest could provide insight towards how the environmental factors influence the spatial distribution of vegetation. Additionally, analysis of under- and overstory species could be continued with a different approach. Individual species maps could be plotted and compared visually to evaluate species associations; statistical regressions could be run with topographical variables as well to further the investigation between site and species relationships (Dryer, 2001). Although we did not include the percent canopy closure analysis into the final fuzzy set, that analysis supplemented with outside sources could improve the fuzzy set. For example, fire frequency data, or presence of large trees known to develop in more open structure landscapes such as oak and ponderosa pine. In that vein, any further analysis should strongly consider the use of additional sources because of the fine gradient of the study area; on their own, historical land surveys are limited to discerning broad patterns (Schulte and Mladenoff, 2001).

Conclusion

Despite the broad use of GLO survey data in research, our investigation indicates that the reliability of GLOs as a source depends heavily on the methodology. Fuzzy classification reduces research bias through iterative evaluation and assignment of input variables to degree of membership to closed canopy forest structure. Historical land surveys can be useful for evaluating general trends and patterns as we have shown with our fuzzy "sum" of closed canopy forest structure; however, the reliability and confidence in the accuracy of classification disintegrates as the resolution gets finer grained. The fuzzy "sum" for closed canopy forest could be improved upon through further analysis into topography characteristics, under- and overstory species and fire frequency, but overall represents a carefully evaluated and informed approach to visualizing Contact Era forest structure based on GLO survey notes.

Appendix I

TERM	DEFINITION
Chain	unit of measurement used by surveyors; one chain consists of 100 links and is a total of 66 feet long
DBH	diameter in breast height; standardized metric for measuring around tree trunks
Distance	measurement in chains of the space between a corner or quarter section marker and the bearing tree, or a point on the line and a topographical or cultural feature
Fuzzy Overlay method: And	minimum of the fuzzy memberships from the input
Fuzzy Overlay method: Or	maximum of the fuzzy memberships from the input
Fuzzy Overlay method: Sum	increasive function. When the combination of multiple evidence is more important or larger than any of the inputs alone
Fuzzy Set Theory	a way to categorize data or objects based on a gradient to communicate some uncertainty or ambiguity
Fuzzy Variable	a variable that communicates uncertainty or imprecise boundaries; can be related to linguistic rather than numerical value
Link	unit of measurement used by surveyors; 100 links makes one chain
Normalization	statistical process of transforming data from different scales into one common scale
Soil Description	semantic descriptor of soil materials, i.e., “clay” or “rocky”
Soil Rating	ranking system 1-4 to evaluate the land for agricultural or settlement potential; 1 indicates good quality soil, and 4 is poor
Stand Structure	semantic descriptor of vegetation type, i.e., “heavy timber” or “savanna”
Terrain	semantic descriptor of the land, i.e., “sloping” or “mountainous”
Township and Range	rectangular grid system used to systematically survey land; one township is 36 square miles or 6 miles by 6 miles. Range denotes west or east of the meridian, i.e., T24SR3E (township 24 south range 3 east) is the third township east of the meridian

Willamette Meridian	true north/south line running from Oregon’s southern border to Canada
Witness Tree/Bearing Tree	a tree selected by a surveyor to mark control points along the section lines such as the midpoint or corner. The tree is marked with the township, range, and section number

Appendix II

Line ID	Tree Species	Understory Species	Guidebook Plant Association (s)	% Canopy Cover
188	Fir, cedar	Vine maple, young firs & hemlock	Grand Fir/Vine maple; Douglas Fir/Western Hemlock	63, 67
189	Pine, larch & fir	Salal & huckleberry	Silver Fir/Western Hemlock/Rhododendron/ Salal; Grand Fir/Vine maple; Western Hemlock/ Vine maple/Salal	62, 63, 72
190	Fir, hemlock	Vine maple, huckleberry & salal	Grand Fir/Vine maple; Western Hemlock/ Vine maple/Salal	63, 72
191	Fir, hemlock	Vine maple, huckleberry, young firs & hemlock	Grand Fir/Vine maple; Western Hemlock/ Vine maple/Salal	63, 72
208	Fir, hemlock & pine	Salal & vine maple	Grand Fir/Vine maple; Western Hemlock/ Vine maple/Salal	63, 72
209	Fir, hemlock & cedar	Rhododendron	Western Hemlock/ Rhododendron/Salal	73
211	Fir, hemlock	Rhododendron, dogwood, hemlock & buckbrush	Silver Fir/Western Hemlock/Rhododendron/ Salal; Silver Fir/ Rhododendron/Huckleberry/Dogwood	62, 70

212	Fir, cedar, pine	Rhododendron, dogwood, soap brush & hemlock	Silver Fir/ Rhododendron/ Huckleberry/Dogwood	70
214	Fir, cedar, pine	Soap Brush, vine maple, hemlock	Douglas Fir/Western Hemlock; Grand Fir/Vine maple	63, 67
215	Fir, hemlock	Vine maple, dogwood, madrone & hemlock	Douglas Fir/Western Hemlock	67
216	Fir, pine, cedar	Vine maple, rhododendron & huckleberry	Silver Fir/Rhododendron/ Huckleberry/Dogwood	70
217	Fir, hemlock & larch	Rhododendron & hemlock	Silver Fir/Western Hemlock/Rhododendron/ Salal	62
218	Fir, hemlock, cedar	Rhododendron, alder, soap brush & hemlock	Western Hemlock/ Rhododendron/Salal; Western Hemlock/ Skunk Cabbage	73, 69
219	Fir, hemlock, cedar	Soap brush, alder, fallen trees & limbs	Western Hemlock/ Skunk Cabbage	69
220	Fir, pine, cedar & hemlock	Rhododendron, soap brush & hemlock with much fallen timber & debris	Douglas Fir/Western Hemlock	67
221	Fir, cedar & hemlock	Rhododendron, arrowwood, soap brush & hemlock	Western Hemlock/Dwarf Oregon Grape	74
222	Fir, cedar, hemlock	Snowbrush, soap brush, hemlock	Douglas Fir/Poison Oak	70

223	Fir, cedar, pine & hemlock	Rhododendron, vine maple, hemlock	Western Hemlock/ Rhododendron/Salal	73
224	Fir, hemlock, cedar	Arrowwood, hemlock	Western Hemlock /Rhododendron/Bear grass	72
225	Fir, pine, hemlock, cedar	vine maple, hemlock	Western Hemlock/Vine Maple	78
226	Fir, pine, hemlock, cedar	Rhododendron, vine maple, hemlock	Western Hemlock/ Rhododendron/Salal	73
227	Fir, hemlock, cedar	Vine maple, hemlock	Western Hemlock /Rhododendron/Bear grass	72
228	Fir, hemlock, cedar	Rhododendron, soap brush, vine maple, hemlock	Western Hemlock/ Rhododendron/Salal	73
229	Fir, pine, cedar	Soap Brush, vine maple & broken limbs	Grand Fir/Vine maple; Douglas Fir/Western Hemlock	63,67
230	Fir, hemlock, cedar	Soap Brush, rhododendron, hemlock	Western Hemlock/ Rhododendron/Salal	73
231	Fir, hemlock, cedar	Rhododendron, soap brush	Western Hemlock/ Rhododendron/Salal	73
232	Fir, hemlock	Rhododendron, soap brush	Western Hemlock/ Rhododendron/Salal	73
233	Fir, pine, hemlock, larch & white fir	Rhododendron, soap brush	Western Hemlock/ Rhododendron/Salal	73

234	Fir, hemlock, larch	Rhododendron, soap brush, hemlock	Silver Fir/Western Hemlock/Rhododendron/ Salal	62
235	Fir, hemlock	Rhododendron, debris from dead trees	Western Hemlock/ Rhododendron/Salal	73
236	Fir, hemlock, cedar	Rhododendron, vine maple, hemlock	Western Hemlock / Rhododendron/Bear grass	72
237	Fir, hemlock, pine	Rhododendron, vine maple, soap brush	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
238	Fir, cedar, pine	Rhododendron, vine maple, hazel	Grand Fir/Dwarf Oregon Grape	73
239	Fir, hemlock, cedar	Rhododendron, vine maple, hazel	Western Hemlock/ Rhododendron/Salal; Grand Fir/Dwarf Oregon Grape; Western Hemlock /Rhododendron/Bear Grass	73,73,72
240	Fir, hemlock, larch & pine	Rhododendron, vine maple, hazel & arrowwood	Western Hemlock/ Rhododendron/Salal; Grand Fir/Dwarf Oregon Grape	73, 73
241	Fir, hemlock, larch	Rhododendron, hazel, vine maple & hemlock	Western Hemlock/ Rhododendron/Salal	73
242	Fir, larch, hemlock	Rhododendron, hemlock	Western Hemlock/ Rhododendron/Salal; Silver Fir/Western Hemlock/ Rhododendron/Salal	73, 62

243	Fir, larch, hemlock	Rhododendron, hemlock	Western Hemlock/ Rhododendron/Salal; Silver Fir/Western Hemlock/Rhododendron/ Salal	73, 62
244	Fir, larch, hemlock	Rhododendron, hemlock	Western Hemlock/ Rhododendron/Salal; Silver Fir/Western Hemlock/Rhododendron/ Salal	73, 62
252	Fir, larch & hemlock	Larch, fir & hemlock	Douglas Fir/Western Hemlock	67
272	Fir, pine	Rhododendron, soap brush, hemlock	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
273	Fir, hemlock & pine	Rhododendron, soap brush & hemlock	Western Hemlock/ Rhododendron/Salal	73
274	Fir, hemlock & cedar	Rhododendron, soap brush & hemlock	Western Hemlock/ Rhododendron/Salal	73
276	Fir, cedar & hemlock	Hazel, vine maple, hemlock & soapbush	Western Hemlock/ Rhododendron/Salal; Grand Fir/ Dwarf Oregon Grape	73,73
277	Fir, larch & hemlock	Rhododendron, soap brush & hemlock	Western Hemlock/ Rhododendron/Salal	73
278	Young fir, larch & hemlock	Rhododendron, vine maple & hemlock	Western Hemlock/ Rhododendron/Salal	73
279	Fir, larch & hemlock	Vine maple, soap brush & hemlock	Douglas Fir/Western Hemlock	67

280	Young fir, pine & hemlock	Rhododendron & hemlock	Western Hemlock/ Rhododendron/Salal	73
281	Fir, larch & hemlock	Rhododendron, vine maple, hazel & hemlock	Western Hemlock/ Rhododendron/Salal	73
282	Fir, larch & hemlock	Rhododendron & vine maple	Western Hemlock/ Rhododendron/Salal	73
283	Fir, cedar & hemlock	Vine maple, soap brush, fallen limbs & trees	Western Hemlock /Rhododendron/Bear Grass	72
284	Fir, hemlock & cedar	Vine maple & hemlock	Western Hemlock /Rhododendron/Bear Grass; Grand Fir/ Dwarf Oregon Grape	72, 73
285	Fir, hemlock & cedar	Vine maple & hemlock	Western Hemlock /Rhododendron/Bear Grass; Grand Fir/ Dwarf Oregon Grape	72, 73
286	Fir, hemlock	Vine maple, hemlock	Western Hemlock /Rhododendron/Bear Grass; Grand Fir/ Dwarf Oregon Grape	72, 73
287	Fir, cedar, hemlock	Vine maple, rhododendron & hemlock	Western Hemlock/ Rhododendron/Salal; Western Hemlock /Rhododendron/Bear Grass	73, 72
288	Fir, cedar, hemlock	Vine maple, soap brush & hemlock	Western Hemlock /Rhododendron/Bear Grass	72

289	Fir, hemlock	Vine maple, soap brush & debris from dead trees	Douglas Fir/Western Hemlock	67
290	Fir, hemlock	vine maple, hazel hemlock	Douglas Fir/Western Hemlock; Grand Fir/ Dwarf Oregon Grape	67, 73
291	Fir, larch & hemlock	Hemlock, rhododendron, honey laurel, snowbush	Douglas Fir/Western Hemlock	67
292	Fir, larch, cedar & hemlock	Vine maple, hemlock	Western Hemlock /Rhododendron/Bear Grass; Grand Fir/ Dwarf Oregon Grape	72, 73
293	Fir, larch	not noted	—	—
294	Fir, pine & cedar	Vine maple & dogwood	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
295	Fir, pine, larch & cedar	Rhododendron, dogwood, honey laurel & vine maple	Western Hemlock/ Rhododendron/Salal	73
296	Fir, cedar & hemlock	Hemlock, vine maple & dogwood	Silver Fir/ Rhododendron/ Dogwood; Silver Fir/ Cool wort Foamflower	70, 71
297	Fir, cedar & pine	Rhododendron, hemlock, vine maple & dogwood	Western Hemlock/ Rhododendron/Salal	73
298	Young fir, cedar & pine	not noted	—	—

341	Fir & hemlock	Vine maple, huckleberry	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63, 72
342	Cedar, fir, hemlock	Vine maple, young fir, salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63, 72
343	Fir, hemlock	Vine maple, rhododendron	Douglas Fir/Western Hemlock	67
345	Fir, hemlock, cedar	Vine maple, salal, huckleberry	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63, 72
346	Old growth fir	Vine maple, salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63, 72
347	Fir, hemlock, pine	Vine maple, rhododendron	Douglas Fir/Western Hemlock	67
348	Fir, hemlock	Vine maple, young fir, hemlock	Douglas Fir/Western Hemlock	67
349	Fir, hemlock, cedar	Vine maple, young hemlock, fir	Western Hemlock /Rhododendron/Bear Grass	72
350	Fir, hemlock	Chaparral, vine maple, salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63,72
351	Fir, cedar	Vine maple, huckleberry	Silver Fir/Vine maple; Silver Fir/Dwarf Oregon Grape	75,77

352	Fir, pine	Fir, pine	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
353	Fir, pine	Huckleberry, vine maple	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
354	Fir, cedar	Huckleberry, vine maple	Silver Fir/Vine maple; Silver Fir/Dwarf Oregon Grape	75,77
355	Larch, fir, pine	Huckleberry, vine maple, salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal; Silver Fir/Western Hemlock/Rhododendron/ Salal	63,72,62
356	Larch, fir	Young fir, larch	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
357	Larch, fir, cedar	Young larch, fir	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
358	Fir, larch, cedar	Huckleberry, salal, vine maple	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal; Silver Fir/Western Hemlock/Rhododendron/ Salal	63,72,62
359	Larch, fir, cedar	Young fir, larch	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
360	Larch, hemlock, fir, pine	Young fir, hemlock	Western Hemlock /Rhododendron/Bear Grass; Silver Fir/ Rhododendron/ Dwarf Oregon Grape	72,73

361	Fir, larch, pine	Vine maple, young fir, larch	Silver Fir/ Rhododendron/ Dwarf Oregon Grape	73
362	Larch, fir, cedar	Vine maple, huckleberry & salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63,72
363	Fir, hemlock, cedar	Huckleberry, vine maple, salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63,72
364	Fir, hemlock & cedar	Vine maple, young firs, hemlock	Western Hemlock /Rhododendron/Bear Grass	72
365	Fir, hemlock	Vine maple, young fir, hemlock	Western Hemlock /Rhododendron/Bear Grass	72
366	Fir, pine, hemlock, cedar	Rhododendron, manzanita, huckleberry	Mountain Hemlock/ Manzanita	25
368	Fir, pine, hemlock, cedar	Vine maple, chaparral brush	Mountain Hemlock/ Manzanita	25
370	Fir, hemlock, pine	Vine maple, chaparral brush	Mountain Hemlock/ Manzanita	25
371	Fir, hemlock	Vine maple, young fir, young hemlock	Douglas Fir/Western Hemlock	67
372	Fir, hemlock, cedar	Vine maple, fir, hemlock	Western Hemlock/ Rhododendron/Bear Grass	72
373	Fir, hemlock, pine	Vine maple, salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63,72

374	Fir, hemlock	Young fir, hemlock	Douglas Fir/Western Hemlock	67
375	Fir, hemlock	Vine maple, rhododendron	Douglas Fir/Western Hemlock	67
376	Fir, hemlock	Vine maple, salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63,72
377	Fir, pine	Vine maple, young fir	Grand Fir/ Prince's Pine	73
378	Fir, pine, hemlock	Huckleberry, manzanita	Mountain Hemlock/ Manzanita	25
379	Fir, hemlock, cedar	Vine maple, huckleberry & salal	Grand Fir/Vine maple; Western Hemlock/Vine maple/Salal	63,72
380	Fir, hemlock	Vine maple, manzanette, rhododendron	Douglas Fir/Western Hemlock	67
381	Fir, hemlock	Vine maple, manzanette, rhododendron	Douglas Fir/Western Hemlock	67
382	Fir, cedar, hemlock	Rhododendron, manzanette, salal	Mountain Hemlock/ Rhododendron	62
383	Fir, cedar, hemlock	Rhododendron, manzanette	Mountain Hemlock/ Rhododendron	62
384	Fir, cedar, hemlock, pine	Rhododendron, manzanette	Douglas Fir/Western Hemlock; Mountain Hemlock/ Rhododendron	67,62
385	Fir	Chaparral, manzanette	Mountain Hemlock/ Manzanita	25

386	Fir, pine	Chaparral, manzanette	Mountain Hemlock/ Manzanita	25

Note: Lines 293 and 298 were too difficult to classify because of the absence of understory information.

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