AN ABSTRACT OF THE THESIS OF

Michele Meadows Dailey for the degree of Master of Science in Geography presented on November 30, 2007.

Title: Meadow Classification in the Willamette National Forest and Conifer Encroachment Patterns in the Chucksney-Grasshopper Meadow Complex, Western Cascade Range, Oregon.

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Julia A. Jones

This study delineates and characterizes the distribution of montane meadows in the Willamette National Forest, identifies encroachment patterns in relation to topographic features and proximity to trees in the Chucksney-Grasshopper meadow complex, and examines tree species and age distributions in relation to distance from forest edges or isolated tree clusters in the West Middle Prairie meadow.

The Willamette National Forest covers approximately 6780 km^2 and intersects two main physiographic provinces comprised of the Cascade Crest Montane Forests and Subalpine/Alpine regions to the east, and the Western Cascades Montane, Lowland, and Valley regions to the west. Tree species commonly found in the study area include firs, cedar, pine, larch, spruce, and hemlock. Non-forested openings, including meadows, are distributed throughout the study area. Matched Filtering analysis was applied to Landsat ETM+ imagery acquired in September 2002 and combined with ancillary data that delineates stand replacing fire and harvest

disturbances that occurred between 1972 and 2004 to create a vegetation classification of the Willamette National Forest that identifies meadows. The meadow classification was then combined with data depicting topographic position, slope, aspect, and elevation. Chi-squared statistics were applied to determine if meadows were significantly concentrated in areas characterized by these physical factors. In the western extent of the Willamette National Forest, meadows are concentrated on steep, south and east facing ridges between 1000 and 2000m in elevation. In the eastern extent of the Willamette National Forest, meadows are concentrated in valleys between 500 and 1000 meters in elevation and occur on both gentle and steep, east and south facing slopes. The vegetation classification provides a consistent and comprehensive dataset of meadow distribution in the Willamette National Forest.

The Chucksney -Grasshopper meadow complex is contained by the Chucksney Mountain roadless area and comprised of approximately 8 distinct meadows located 27 kilometers northeast of Oakridge in the Willamette National Forest. The meadows occur on mostly south and east facing steep slopes near the ridgeline, and host varied dry and mesic plant communities. Herbaceous cover for three snapshots in time was classified using aerial photographs taken in 1947, 1972, and 2005 to determine conifer encroachment into the meadows. Chi-squared statistics were applied to determine if encroachment patterns were associated with slope, aspect, or proximity to tree cover. Encroachment occurred significantly closer to existing trees in all meadows suggesting the ameliorating effects of forest create conditions favorable for seedling establishment. Encroachment was also significant on steep, south and east facing slopes in some meadows, but also on gentle, west facing slopes in other meadows indicating a complex interaction of land use history, physical, and biological factors. The encroachment history analysis provides the preliminary framework for a model that can be used to identify meadows at risk for invasion.

The West Middle Prairie of the Chucksney-Grasshopper complex, also known as Meadow 4, is a 21 hectare meadow characterized by a dry meadow community at the northern boundary, a mesic forest-meadow mosaic towards the southern boundary, and a rock garden at the western boundary. This meadow underwent mechanical tree removal in 1964 and a prescribed burn in 1996 to thwart conifer invasion. Four transects intersecting burned and unburned areas at the forest edge and through isolated tree clusters were sampled to determine the distribution of tree species and ages relative to their position in the transect. Data imply *Pinus contorta* invasion was promoted by the 1996 burns and that seedling establishment has occurred progressively from forest edges as well as simultaneously in a band along the forest edge. These findings suggest the prescribed burn was not adequate to control invasion and such management methods should be reviewed in the context of on-going research into alternate eradication measures. This research also supports other work that suggests initial seedling establishment accelerates subsequent seedling establishment and that eradication of early invaders is important for efficient management.

This study can inform meadow habitat maintenance and restoration in three ways: it provides and inventory of meadows in the Willamette National Forest, a framework for a tool to predict which meadows are at risk for invasion and therefore are potential targets for action, and finally a report on past maintenance efforts and observation of invasion patterns at a fine scale.

Meadow Classification in the Willamette National Forest and Conifer Encroachment Patterns in the Chucksney-Grasshopper Meadow Complex, Western Cascade Range, Oregon

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Major Professor, representing Geography

Chair of the Department of Geosciences

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.

Michele Meadows Dailey, Author

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

LISTS OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure Page

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

Meadow Classification in the Willamette National Forest and Conifer Encroachment Patterns in the Chucksney-Grasshopper Meadow Complex, Western Cascade Range, Oregon

1 Introduction

Meadows, sometimes called prairies or non-forested openings, are generally considered to be treeless areas surrounded by forest. They occur on all types of soils, slopes, and topographic positions. In montane areas, they occur mostly on "steep south-facing slopes, in small hydric basins, and in areas of flat, but poorly drained topography" (Miller and Halpern, 1998). In subalpine areas they occur mostly on gentle slopes and in broad basins, but also on plateaus and high ridges (Miller and Halpern, 1998). Meadow plant communities vary by geography, site conditions and land use history. In the Oregon Cascade Range, they are "biological hotspots" supporting a large number of plant and animal species (Takaoka and Swanson, 2006; Thompson, 2007).

Encroachment into montane meadows by conifers endangers the diversity and existence of meadow species (Haugo and Halpern, 2007). Most research suggests that encroachment is caused by a combination of factors including climate change, impacts of grazing, and disruption of aboriginal and natural fire regimes (Haugo and Halpern, 2007; Miller and Halpern, 1998; Vale, 1981; Franklin et al., 1971; Takaoka and Swanson, 2006). Land managers have begun to counteract meadow losses with maintenance and restoration efforts, such as mechanical tree removal and prescribed burning.

This research examines meadows in the Willamette National Forest at three scales. Chapter 3 describes the methods and results of a small scale meadow inventory that was completed using Landsat ETM+ imagery and GIS analysis that modeled the distribution of meadows in the Willamette National Forest (WNF). Distribution is characterized by slope, aspect, elevation, and location within the western or high Cascade Ecoregional provinces. Chapter 4 examines the methods and results of historic and current photo-interpretation used to detect medium scale historic meadow encroachment for a complex of eight meadows in the Chucksney Mountain-Grasshopper Ridge area of the WNF. Encroachment patterns and rates are analyzed for their relationship to slope, aspect, and proximity to tree cover. Chapter 5 chronicles the methods and results of a field sampling exercise in one meadow in the complex used to determine fine scale encroachment patterns in four transects. Species and age distributions are examined in their relation to distance from forest edges and isolated tree clusters. The apparent effect of a 1996 prescribed burn on species composition is also examined.

Although meadows have been managed in the Willamette National Forest since at least the 1960s, the state of geographically referenced data reflects the timber intensive strategies of the past. Two readily available datasets provide a partial inventory of meadows and a forest cover class that could potentially identify meadows. However, neither of these datasets provides a specific and consistent inventory of meadows. The “Special Habitats” (SHABS) data developed by the WNF (WNF-GIS 2006) provides polygons of meadow areas for the northern and southern portions of the forest extent.

Meadows in the middle portion of the WNF have not been delineated. The 1988 Western Oregon Composite Forest Vegetation Layer contains a <30% cover class that could potentially be useful in identifying meadows (Cohen et al., 1988). However, as described in Chapter 3, it was not appropriate for this purpose.

The Chucksney Mountain-Grasshopper Ridge meadow complex has a complicated land use history. It was probably burned by Native Americans before white settlers arrived. Its sheep grazing history is documented in United States Forest Service records. It has been actively managed for conifer invasion since the 1960s. Historic aerial photographs from 1947 and 1972 were used in conjunction with 2005 aerial photographs to delineate a pattern of encroachment in the complex. Though the eight meadows are relatively similar, they exhibit different rates and patterns of encroachment. These are examined in Chapter 4.

Meadow 4 in the Chucksney-Grasshopper complex was chosen for field sampling because of its management history, patterns of tree encroachment, and varied slopes and vegetation. Mechanical tree removal was conducted in this meadow in 1964 and a prescribed burn was conducted in 1996. The meadow includes areas where encroachment has occurred as a wave from the edge or radially from tree islands. It has areas of dry plant communities on the flatter, though still relatively steep, northern slope and more mesic communities on the steeper southern slope (Salix, 2005). Field sampling revealed the chronology of tree establishment and growth rates as well as expected species specific-behaviors related to shade and moisture tolerances based on site conditions. This meadow also reveals (see Chapter 5) the complexity of trying to isolate causes of encroachment when drivers are synchronous and the specific history of the landscape is unknown.

2 Previous Research

Virtually all previous research on conifer encroachment into meadows considers two main drivers: climate change and changes in land use and management. The impacts of these drivers differ depending on the physical environment occupied by different types of meadows. The mechanisms by which encroachment occur also depend on physical as well as biological characteristics.

Climate change affecting tree invasion rates into high-elevation meadows has been noted to occur as far back as approximately 5,000 years ago. The Absaroka Mountains, in the Rocky Mountains of Montana and Wyoming, have areas of tree expansion that occurred during the warmer periods and contractions that occurred during the drier periods of the mid-Holocene (Jakubos and Romme, 1993). Changes in temperature and precipitation are not synchronous across all regions, however. Recent climate change in western North America is thought to have begun when cooler summers ended in the mid 1800s (Dunwiddie, 1977; Jakubos and Romme, 1993). Miller and Halpern (1998) used precipitation and temperature data compiled by WeatherDisc Associates, Inc. and NOAA to describe the following climatologic trends in the west-slope Cascades. Mean annual and mean summer temperatures rose from about 1900 to 1940 while precipitation remained below average. The period between 1920 and 1945 was unusually warm and dry. Snow pack was below average during this time as well. The years between 1945 and 1985 remained warm but were wetter than the period of 1920 to 1945. Between 1985 and 1993 temperatures were above average and precipitation dropped to below average (Miller and Halpern, 1998). Increasing spring temperatures have led to decreased snow pack since the 1970s (Lepofsky et al., 2003). Westerling et al. (2006) have also associated warming trend in the western US with earlier snowmelts since the mid-1980s.

Changes in land use and land management are primarily changes in natural or anthropogenic disturbance regimes. They generally take the form of grazing and fire suppression. Grazing began in western North America in the late 1800s. Stock included sheep, cattle and horses. The timing and intensity of grazing varies widely and is species and site specific. Aboriginal burning of meadows is known to have occurred throughout the Pacific Northwest. However, oral histories and sparse evidence provide only a vague account of this practice (Boyd, 1999; French, 1999; Robbins, 1999; Whitlock, 2004, Lepofsky, 2003). Fire suppression began when European settlers stopped the Native American practice of burning and continues today with suppression of natural and human caused wildfires.

Studies have revealed patterns of encroachment based on changes of climate and disturbance regimes associated with specific physical factors (Franklin et al., 1971; Dunwiddie, 1977; Vale, 1981; Taylor, 1990; Evans and Fonda, 1990; Jakubos and Romme, 1993; Miller and Halpern, 1998; Lepofsky et al., 2003; Takaoka and Swanson, 2006; Norman and Taylor, 2005; Coop and Givnish, 2007; Haugo and Halpern, 2007). Slope gradient, slope aspect, soil moisture, and proximity to forest cover are among those physical factors. Results are as varied as study site characteristics and it is difficult to tease consistent patterns from these studies. However, Miller and Halpern (1998) note that patterns and correlates of invasion are similar on sites with similar physiography and vegetation. Because certain changes in climate and land management occurred simultaneously, it is not always possible to tell which is responsible for invasion. More importantly, there usually is not one single driver of conifer invasion but rather a combination of drivers.

There are some common themes in the reviewed studies. The impact of climate change depends on the effect it has on length of growing season, temperature extremes, and soil moisture content and if these factors cause conditions that limit plant growth when climate change is not a consideration. Topographic gradients are also important because of their effects on insolation and soil moisture. Meadows created by fire are more vulnerable to invasion when fire is suppressed than meadows not created by fire. The type of stock and intensity of grazing impacts the levels of soil disturbance and seedling damage differently, resulting in different encroachment responses. Finally, the alteration of the environment by tree establishment not only provides an immediate benefit to subsequent seedling establishment but can also have long-term effects on environmental conditions even after tree removal. Specific findings related to these themes are found in Franklin et al., 1971; Dunwiddie, 1977; Vale, 1981; Taylor, 1990; Evans and Fonda, 1990; Jakubos and Romme, 1993; Miller and Halpern, 1998; Wearne and Morgan, 2001; Lepofsky et al., 2003; Takaoka and Swanson, 2006; Taylor, 2005; Norman and Taylor, 2005; Coop and Givnish, 2007; Haugo and Halpern, 2007.

The timing of snowmelt in the central and western Cascade Range controls soil moisture, soil temperature, and growing season (Evans and Fonda, 1990). In areas where snow pack is deep and persistent, climate warming leads to decreased snow packs and earlier melting of snow packs. This results in longer growing seasons which promotes conifer invasion (Franklin et al., 1971: Evans and Fonda, 1990; Miller and Halpern, 1998; Norman and Taylor, 2005; Lepofsky et al., 2003). In areas where snowpack is not deep or persistent, however, warming can lead to soil moisture stress and limit conifer invasion (Lepofsky et al., 2003; Taylor, 1990; Coop and Givnish, 2007; Miller and Halpern, 1998).

Elevation and latitude are related to occurrence of persistent snow packs. Norman and Taylor (2005) attribute tree invasion in high elevation meadows to climate warming that reduced snow pack persistence, but they speculate that tree invasion of lower elevation meadows may be due more to complex land use histories such as fire suppression and grazing. Miller and Halpern (1998) distinguish invasion patterns in montane versus subalpine areas and predict that subalpine meadows are more susceptible to climate change effects, although the impacts vary depending on aspect.

The insolation and precipitation received on different aspects can have dramatically different impacts on tree invasion in meadows. North facing slopes may react to decreased precipitation and therefore snowpack with an increase in invasion due to a longer growing season. South facing slopes may react to a decrease in precipitation with drought and an inhibition of seedling establishment (Miller and Halpern, 1998).

Moisture status is a function of many physical factors including aspect, hydrology, slope, and climate change. High water tables associated with hydric meadows may inhibit seedling establishment and explain their relative stability. Steep south facing montane meadows, usually limited by moisture, react to increased precipitation, often combined with a cessation of grazing, with an increase in invasion. Cooler and wetter conditions may allow more seedlings to survive the otherwise warm and dry conditions on xeric sites (Miller and Halpern, 1998; Coop and Givnish, 2007; Jakubos and Romme, 1993).

The historic fire regime seems to determine an area’s reaction to fire suppression. In areas where aboriginal burning took place, fire suppression is considered at least partly responsible for increased rates of invasion, usually in combination with climate change (Lepofsky, 2003). Vale (1981) found that fire suppression had a greater effect on invasion of meadows in southern Oregon compared to those in the central Cascades, but that the cessation of aboriginal burning may have coincided with a period of cooler wetter weather. Takaoka and Swanson (2006) found that mesic meadows adjacent to forests that burned in the last 150 years tended to contract more than those adjacent to forests that had not burned. This suggests that fire suppression impacts the meadows in their study that were dependent on fire for maintenance more than those not dependent on fire. In areas where fire had not historically created or maintained meadows, summer cold air drainage in valley bottoms may inhibit seedling establishment, and increases in minimum summer temperatures may lead to increased invasion (Coop and Givnish, 2007).

The intensity of grazing has different impacts on conifer establishment. Any level of grazing exposes mineral soils, preparing the seedbed for conifer establishment. Sheep are particularly avid grazers and intense grazing by sheep reduces conifer seedling survival dramatically. Cattle or limited sheep grazing has much less impact on seedling survival and allows for moderate levels of encroachment. When intense grazing ceases, significant invasion occurs (Franklin et al, 1971; Norman and Taylor, 2005; Dunwiddie, 1977; Vale, 1981; Taylor, 1990) However, Miller and Halpern (1998) determined that there was no relationship between grazing and invasion in hydric basins, poorly drained flats, or in subalpine areas.

Tree establishment occurs in distinct patterns: from the edge of the forest or from tree islands and either continuously or episodically. According to Vale (1981), trees invade mostly from the edge. Lepofsky et al. (2003) found that invading trees in their study area did not decrease in age with increasing distance from the forest edge but were established all at approximately the same time. Jakubos and Romme (1993) found that tree age declined towards the meadow center. Taylor (1990) studied the relationship between tree age and distance from the forest edge and determined that some trees established progressively from the edge toward the center of the meadow or randomly with no relationship to distance from forest edge. Norman and Taylor (2005) describe invasion at their study area as “leap and fill”. Franklin et al. (1971) described a similar strategy of invasion occurring as clumps with isolated seedlings in between.

Positive feedbacks from tree establishment help subsequent seedling invasion. Tree establishment can reduce wind speed, change soil moisture, increase temperature, and increase nitrogen availability (Coop and Givnish, 2007; Haugo and Halpern, 2007). Wearne and Morgan (2001) describe the frost protection and photo-inhibition effects of adjacent forest. Haugo and Halpern (2007) describe the change in soil microbial activity and establishment of ectomycorrhizal mats by tree roots; they found that even recently encroached soils exhibited conditions similar to soils found underneath old forest.

Tree establishment ameliorates micro-climate and soil conditions, affecting tree seedling success over the short and long term. The establishment of one tree can alter the environment to reduce herbaceous competition and create other favorable conditions that allow increased rates of invasion around the tree (Miller and Halpern, 1998; Coop and Givnish, 2007). Also, conditions that may limit the establishment of a seedling do not necessarily limit tree growth (Takaoka and Swanson, 2006; Franklin et al, 1971; Miller and Halpern, 1998).

Limits to meadow restoration include length and intensity of encroachment, seed availability, and soil disturbance. Even after tree removal, the lasting impacts of changes in soil pH and ectomycorrhizal mats may make it difficult for herbaceous meadow species to reestablish themselves (Haugo and Halpern, 2007; Jakubos and Romme, 1993). Lang and Halpern (2007) determined that the majority (70%) of meadow species do not rely on persistent seed banks but rather on vegetative means or transient seed banks. Ruderals, weedy species that are the first to colonize disturbed sites, often dominate seed banks and out-compete restoration target species even with artificial seeding. Furthermore, restoration activities that “expose or heat mineral soils” may favor the germination of these species (Lang and Halpern, 2007). Tree removal and fire exposes mineral soils which are good seedbeds for conifers, though some meadow species do require some amount of disturbance. Tree removal on snow and burning slash piles may mitigate disturbance and subsequent invasion over larger areas (Lang and Halpern, 2007).

3 A Remote Sensing Classification of Non-Forest Openings in the Willamette National Forest

3.1 Introduction and Objectives

The objective of this chapter’s analysis was to create a consistent dataset of meadows within the Willamette National forest and explore the relationship between meadow occurrence and topographic position, elevation, slope, and aspect. The study was motivated by an increased interest in non-forest openings for restoration and management, the lack of comprehensive data, and the availability of previous work (e.g. Cohen and Lennartz, 2004) to assist in creating the map.

3.2 Study Area

The Oregon Western Cascade Ecoregion covers 28,890 square kilometers (km^2) and runs the length of the state just west of the crest of the high Cascade Range to the foothills of the Willamette, Umpqua, and Rogue River valleys. The Willamette National Forest stretches 177 km from Mt. Jefferson in the north to the Calapooya Mountains in the south, covering 6,780 km^2 of the western Cascade Range. (Figure 3.1.) Elevation of the western Cascade Range ranges from 5 to 3425 m.

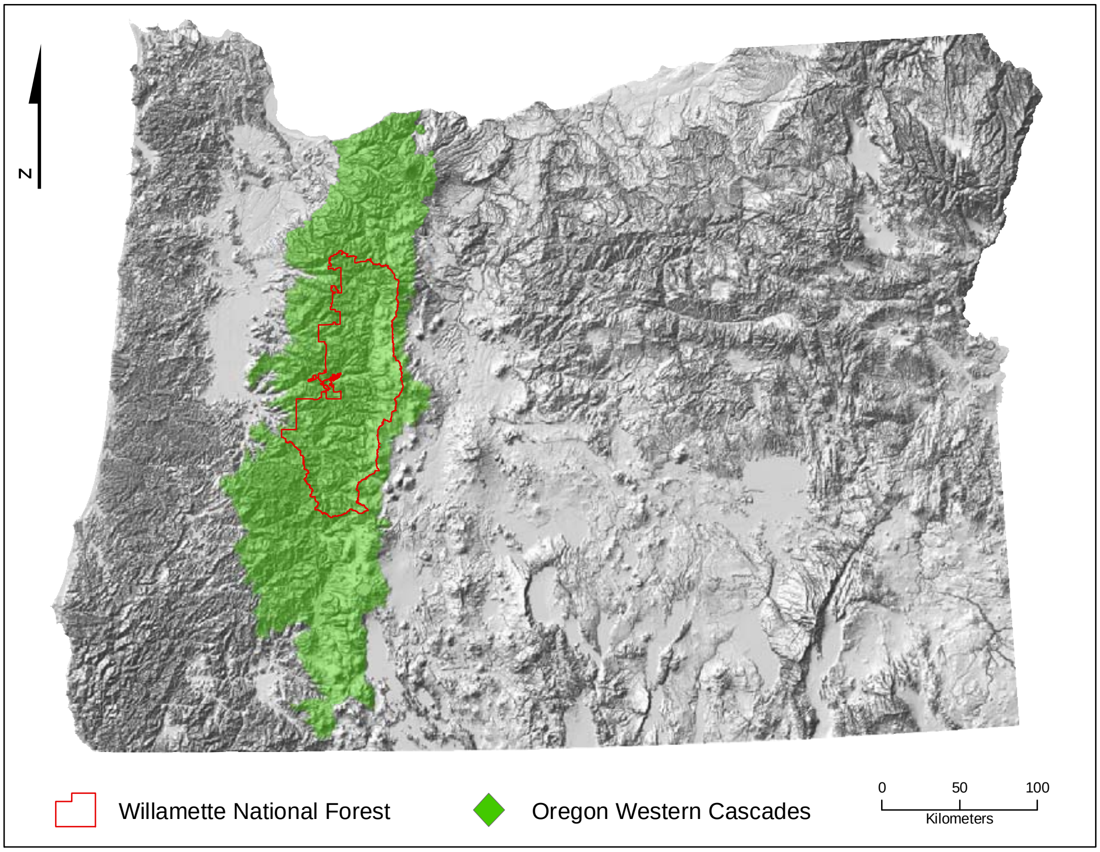


Figure 3.1. Location of Willamette National Forest within the Oregon Western Cascades physiographic province.

3.2.1 Geology and Topography

The western Cascade Range was formed approximately 40 million years ago by volcanic activity and erosion, resulting in steep slopes and high relief (Orr & Orr, 2002). The Western Oregon Cascades arose along what was then the Pacific coast as “broad volcanic cones and low domes” above the melt zone that occurred east of the subduction of the Farallon oceanic plate under the North American plate (Orr & Orr, 2002). Volcanic activity ceased in the western Cascade Range about nine million years ago as tectonic plate movement proceeded eastward to where the high Cascade Range is now

(Orr & Orr, 2002). Pyroclasts are abundant in the area but basalt and andesite are the most common type of bedrock (Franklin and Dyrness, 1988). Glacial deposits are also found scattered within valleys of large streams (Franklin and Dyrness, 1988). The western Cascade Range is separated from the high Cascade Range by horst and graben morphology along north-south marginal boundary faults (Taylor, 2007). The deeply eroded andesites and basalts of the western Cascade Range formed well developed drainage networks which contrast with the less developed drainage networks and low relief of the younger high Cascade Range (Franklin and Dyrness, 1988).

3.2.2 Climate

The western Cascade Range experiences a highland climate with complex variation at small scales. Altitude and exposure drive this variability but in general the climate is similar to the low lying areas adjacent to the region (McKnight, 1999). The climate is marine west coast with temperatures moderated by a marine influence and maximum precipitation during the winter months. In the winter, moist maritime polar air masses bring precipitation to the study area. In the summer, subtropical high-pressure cells move poleward, allowing dry continental air to dominate the region (Strahler and Strahler, 2002). Precipitation and temperature information were modeled using data from monitoring stations throughout the western Cascade Range over the period 1971 and 2000 by the PRISM Group at Oregon State University (PRISM Group - GIS, 2004). The mean average annual precipitation in the western Cascade Range in the form of rain and snow is approximately 1738 millimeters (mm). Over 75% of precipitation in the western

Cascade Range occurs between November and April with a total average of about 1317 mm (PRISM Group - GIS, 2004). May through October averages approximately 421 mm of precipitation. The mean average minimum daily temperature in the western Cascade Range for the month of January is about -3.1 ºC with a range of -13.3 to 1.9 ºC. The mean average maximum daily temperature for the month of July is about 24.6 ºC with a range of 10.0 to 31.3 ºC.

3.2.3 Soils

The soils of the western Cascade Range generally fall within two main groups: those that developed from igneous parent material (basalt and andesite) and those that developed from pyroclastic parent material (tuffs and breccias). The pyroclastic parent material produces "deep and fine textured" (Franklin and Dyrness, 1988) soils that are often poorly drained, highly erodable, and prone to mass movements (Franklin and Dyrness, 1988). These soils are of the Haplumbrepts and Xerumbrepts great groups. Soils that developed from the igneous parent material tend to be well drained, coarse textured, and less prone to mass erosion. They fall within the Argixerolls, Haplohumults, Haplumbrepts and Xerumbrepts great groups (Franklin and Dyrness, 1988). Depending on the particular soil, it may contain amorphous material, volcanic ash, iron, aluminum, or humus. Generally, soils have an udic moisture regime where the amount of stored moisture in addition to rainfall is greater than or equal to moisture lost by evapotranspiration (USDA NRCS, 2006; USDA Forest Service, 2007). At higher elevations, soils have a frigid soil temperature regime with a mean annual temperature of less than 8°C and a difference of greater than 6°C between mean summer and mean winter temperatures. Lower elevations tend to have mesic temperature regimes with an annual range between 8°C and 15°C and a difference between mean summer and mean winter temperatures of at least 6°C (USDA NRCS, 2006; USDA Forest Service, 2007.)

3.2.4 Rivers/Basins

The western Cascade Range and WNF include several hydrological sub-regions and sub-basins within Oregon (Figure 3.2). The western Cascade Range is mostly contained within the Willamette, Oregon-Washington Coastal, and Lower Columbia hydrological sub-regions. The Willamette National Forest lies within the Willamette sub-region which contains 12 east-west sub-basins that drain into the north-south Willamette River. The North Santiam, South Santiam, Middle Fork Willamette, and McKenzie Rivers drain westward in the WNF. The McKenzie River and the North Fork of the Middle Fork of the Willamette River are designated as Wild and Scenic Areas under the Wild and Scenic Rivers Act of 1968. There are more than 2,400 kilometers of streams and more than 375 lakes with generally very good water quality in the WNF (WNF, 2007; USDA Forest Service, 2007).

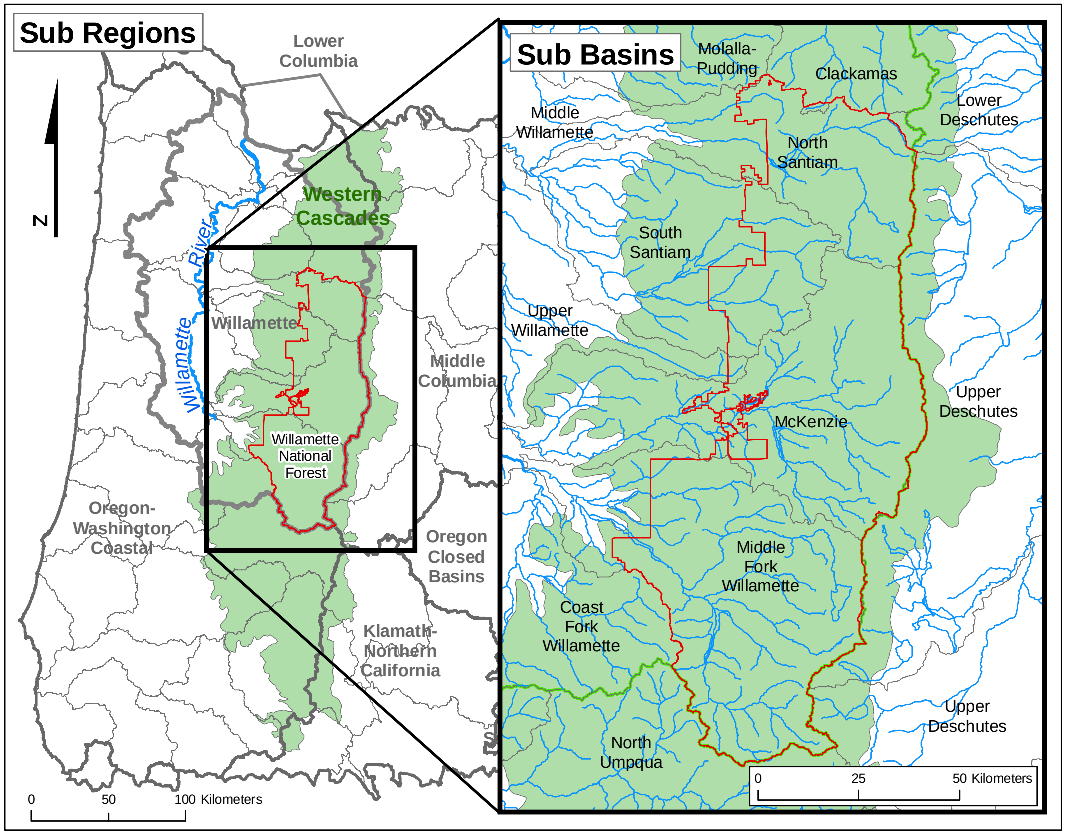


Figure 3.2. Location of the western Cascade Range within hydrological sub-regions and location of the WNF within river sub-basins.

3.2.5 Vegetation

Five major vegetation zones occur in the western Cascade Range of Oregon (Franklin and Dyrness 1988): (1) *Abies grandis* and *Pseudotsuga menziesi*i, (2) mixed conifer and mixed evergreen, (3) sub-alpine forests, (4) timberline and alpine, and (5) *Tsuga heterophylla* (Figure 3.3). See Table 3.1. for a list of scientific names and associated common names.

Table 3.1. Scientific and common names of commonly found tree species in Oregon western Cascade Range (Franklin and Dyrness, 1988).

Scientific name	**Common name**
Abies amabilis	Pacific silver fir
Abies grandis	grand fir
Abies lasiocarpa	subalpine fir
Abies magnifica shastensis	Shasta red fir
Abies procera	noble fir
Larix occidentalis	western larch
Libocedrus decurrens	Incense cedar
Lithocarpus densiflorus	Tanbark oak
Picea engelmannii	Engelmann spruce
Pinus albicaulis	whitebark pine
Pinus contorta	lodgepole pine
Pinus lambertiana	sugar pine
Pinus monticola	western white pine
Pinus ponderosa	Ponderosa pine
Pseudotsuga menziesii	Douglas-fir
Thuja plicata	western redcedar
Tsuga heterophylla	western hemlock
Tsuga mertensiana	mountain hemlock

Abies grandis and *Pseudotsuga menziesi*i

The *Abies grandis* and *Pseudotsuga menziesii zones* are found adjacent to each other in the vegetation area of the same name. *Abies grandis* is the “most extensive mid-slope forest zone” in the Oregon Cascades, usually occurring between 1100 and 1500 meters in elevation and dominated by *Abies grandis, Pinus ponderosa, Pinus contorta*, *Larix occidentalis,* and *Pseudotsuga menziesii* (Franklin and Dyrness, 1988). The *Pseudotsuga menziesii* zone is comprised mainly of *Pseudotsuga menziesii, Pinus ponderosa*, *Pinus contorta,* and *Larix occidentalis* (Franklin and Dyrness, 1988).

Mixed Evergreen and Mixed Conifer

The mixed evergreen and mixed conifer area consists of the *Pseudotsuga-Sclerophyll* and *Pinus-Pseudotsuga-Libocedrus-Abies* zones. The major tree species in the *Pseudotsuga-Sclerophyll* zone are *Pseudotsuga menziesii* and *Lithocarpus densiflorus*. *Pseudotsuga menziesii, Pinus lambertiana, Pinus ponderosa, Libocedrus decurrens,* and *Abies grandis* are the major trees found within the *Pinus-Pseudotsuga-Libocedrus-Abies* zone at elevations between 750 – 1400 meters (Franklin and Dyrness, 1988).

Subalpine

Subalpine refers to an area of forest-meadow mosaic between the forest and scrub zones. Often referred to as parkland, it is well developed on the highest mountain ranges of Oregon and Washington. Deep, long-lasting snow packs may be responsible for subalpine vegetation occurring in wide elevational bands of 300 – 400 meters. It includes *Abies amabilis, Abies lasiocarpa, Abies magnifica shastensis,* and *Tsuga mertensiana* zones. Trees typical of the *Abies amabilis zone* are *Abies amabilis, Tsuga heterophylla, Abies procera*, *Pseudotsuga menziesii*, *Thuja plicata* and *Pinus monticola*. *Abies lasiocarpa, Picea engelmannii,* and *Pinus contorta* are the major species in the *Abies lasiocarpa* zone. The dominant tree of the *Abies magnifica shastensis* zone is its namesake. The *Tsuga mertensiana* zone is the highest forested zone of the Cascades. Dominant species depend on location. *Tsuga mertensiana* usually dominates in old growth stands, *Abies lasiocarpa* and *Pinus contorta* in drier areas, and *Abies amabilis* in northern Oregon (Franklin and Dyrness, 1988).

Timberline and Alpine

The timberline and alpine vegetation area in the Oregon Cascades consists of a transitional region that supports mostly *Tsuga mertensiana* and *Abies lasiocarpa. Pinus albicaulis* also occurs as a dominant species in both timberline and alpine areas. The alpine regions of Oregon are mostly comprised of “glaciers, snow fields, bare rock, and rubble” (Franklin and Dyrness, 1988).

Tsuga heterophylla

The *Tsuga heterophylla* zone is the most extensive zone in Oregon and very important for timber production. It can occur between 150 to 1000 meters depending on latitude. The subclimax dominant species is *Pseudotsuga menziesii*. The climax dominant species on “environmentally median” sites are *Tsuga heterophylla* and *Thuja plicata* with *Pseudotsuga menziesii* replacing *Tsuga heterophylla* on dry sites (Franklin and Dyrness, 1988).

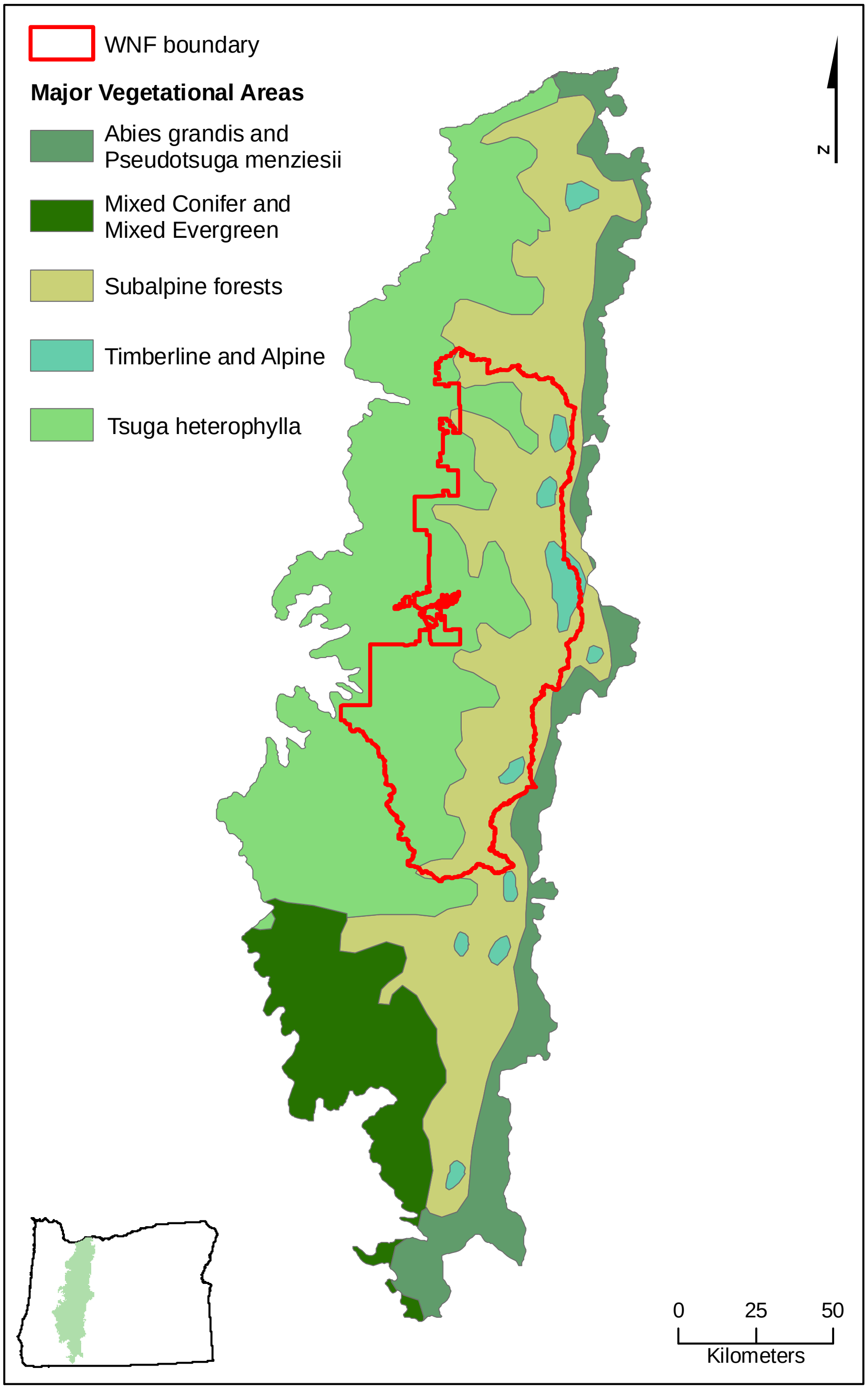


Figure 3.3. Major vegetational zones of the Oregon western Cascade Range. Adapted from Franklin and Dyrness (1988).

3.2.6 Fauna

The western Cascade Range is host to a number of species of mammals, birds and fish. Black-tailed and mule deer, black bear, Roosevelt elk, cougar, coyote, beaver, otters, and wolverines are found within the region. The northern bald eagle, golden eagle, peregrine falcon, northern spotted owl, osprey, blue and ruffed grouse, mountain quail, and pileated woodpecker also occur in this area in varying degrees of abundance. Fish inhabiting the rivers include steelhead, bass, chinook and kokanee salmon, and cutthroat trout (WNF, 2007; USDA Forest Service, 2007).

3.2.7 Land Use History

Early Native American and Euro-American Land Use

Landscapes of the western Cascade Range have been modified both by Native Americans prior to the mid-1800s and Euro-Americans since the mid-1800s. Native Americans used the area for hunting, gathering, and as a trade route. Archaeological sites can be found at elevations ranging from 274 to 1828 meters. Most sites are at lower elevations but most intensively used sites occur above 1200 meters. Native American sites and trails also occur on ridge lines and on benches or ridge noses above valleys and lakes. Trails used for trade or access to resources were most often found on gentle topography and often avoided valley bottoms (Burke, 1980). Fur trapping brought Euro-Americans to the Cascades and then gave way to farming and ranching when the Donation Land Act of 1850 offered 320 acres of land to while males over 18 and their wives. By 1850, 13,000 settlers inhabited Oregon and population growth forced cattle and sheep ranchers into and over the Cascades to the East side. Timber resources increased in value with the building of the Transcontinental Rail Road in the 1860s (Burke, 1980; Rakestraw and Rakestraw, 1991).

The Willamette National Forest

The Willamette National Forest has experienced a varied history of land use, management, and administration since 1893. The precursor of the WNF, the Cascade Range Forest Reserve, was established in 1893 under the Forest Reserve Act of 1891. It stretched from the Columbia River to the northern California border. The Willamette National Forest was established as an administrative unit in 1933 (Rakestraw and Rakestraw, 1991).

Grazing

Sheep grazing, widely established in the Oregon Cascades in the 1880s, became subject to government regulation with the establishment of the Cascade Range Forest Reserve which prohibited sheep grazing within its boundaries. After complaints from sheepmen, the 1897 Organic Administration Act authorized the Secretary of the Interior to allow grazing as long as it did not affect timber growth rates. A permit system was established to limit the area in which sheepmen could graze their stock to prevent overgrazing and conflicts with recreationists and other stockmen (Rakestraw and Rakestraw, 1991).

Though once the most important economic sector in the Willamette Valley, the sheep industry began to decline in the 1930s. The numbers of sheep grazing in the WNF declined from 40,810 in 1922 to 38,075 in 1932 due to the reduction in grazing land caused largely by lodgepole pine encroachment into meadows (Rakestraw and Rakestraw, 1991). It is not known if the encroachment was caused specifically by grazing disturbance creating favorable conditions for conifer invasion. It is possible that grazing was but one factor that caused encroachment, and fire suppression another (Rakestraw and Rakestraw, 1991). By 1947, only 290 cattle or horses grazed in the WNF and sheep were absent (Rakestraw and Rakestraw, 1991).

Fire

Fire has played a role in maintaining and changing landscapes since the Mesozoic, and interactions between climate, vegetation, and fire are evident in the Pacific Northwest since the last period of glaciation. Evidence of these interactions is especially clear for the last 1000 years because some tree species can live that long and provide evidence in the form of fire scars and stand structure (Agee, 1993). During the last 500 years, the *Tsuga heterophylla* zone of Oregon has experienced fires of variable intensity, frequency, and size. The upper montane and subalpine zones have experienced fires as well but less often (Whitlock, 2004). Human caused fires, whether intentional or accidental, have also played a role in the fire history of the western Cascade Range, as has human induced suppression.

There is significant ethnographic evidence of fire use by Native American tribes in the Pacific Northwest since the 1800s (Robbins, 1999; Boyd, 1999; French, 1999; Whitlock, 2004). However, the alteration of the landscape by aboriginals predates this evidence. Modern humans have existed in the Pacific Northwest since the Pleistocene, about 13,000 years ago (Robbins, 1999). “Neolithic agricultural practices” were not adopted by Native Americans, so hunting and gathering practices were dominant until the Northwest was settled by Europeans (Robbins, 1999). These practices included the use of fire to “intensify resources” and remove encroaching coniferous trees (Boyd, 1999; French, 1999). Burning was used to drive deer and elk to forage in remaining unburned areas, creating concentrated targets. Fire also helped to create better environments for roots, berries, and other plants. There is no direct evidence of Native American use of fire in the Oregon Cascades, but evidence of fire use by tribes in other parts of the Pacific Northwest is relatively abundant. The indigenous people of the Upper Rogue ecoregion used fire along trails and ridges, creating “chains of prairies” and grass-dominated ridgetops (Boyd, 1999). The Klikitat created trails that connected settlements and subsistence areas, which were commonly burned prairies. The Kalapuya are known to have intentionally ignited grasslands in the Willamette Valley each fall in order to facilitate the harvest of tarweed, a wild wheat. Burning by Native Americans ended in the mid-1800’s when it was banned by white settlers (Boyd, 1999).

Fire suppression has long been in practice to protect valuable forest resources. Suppression efforts in the WNF began as early as 1897, when sheepmen were urged to prevent human-caused fires when issued grazing permits. The Weeks Act of 1911, the Clarke-McNary Act of 1924, and multiple state acts established a policy of fire control and suppression. Fire lookouts were first built in the 1910s and military planes carried Forest Service personnel to spot fires in the 1910s and 1920s (Williams, 2007). In the 1930s, fire suppression was accelerated by new technology (newly developed chainsaws) and labor (the Civilian Conservation Corps (CCC) and Federal Emergency Relief Act (FERA) labor force) removed snags and slash and built roads (Rakestraw and Rakestraw, 1991).

Fire suppression modifies the forest: stands become denser, and vegetation composition shifts to more fire intolerant species (Taylor, 2000). Altered fire-dependent plant communities may be more prone to exotic species invasions. Additionally, fuel buildup due to suppression increases the risk of stand-replacing fires. Fire suppression and subsequent conifer encroachment is responsible for meadow loss (Courtney et al., 2004).

3.2.8 Current Land Cover/Land Use

Land cover in the western Cascade Range is dominated by federally owned forest. Ninety six percent of the area is forest and woodland with virtually no urban areas. Rural populated places account for less than 1% of the land area. Seventy six percent of the region is under federal ownership, mostly that of the USDA Forest Service (ODFW, 2006). The WNF is managed according to the 1990 Willamette National Forest Plan as amended by the 1994 Northwest Forest Plan (WNF, 2007).

Two datasets provide information describing the nature of forest cover and the recent stand-replacing disturbance history of the west side of the Oregon Cascade Range (Cohen et al., 1995; Cohen et al. – GIS, 1988; Cohen et al. 2002; Cohen and Lennartz – GIS, 2004). Cohen et al. (1988) created the Land Cover of Western Oregon raster dataset using Landsat TM imagery acquired August 1988. These data only cover the western portion of the WNF study area. Figure 3.4 shows the 1988 cover classes projected forward to 2007. The projected cover classes present in this chapter's study area and their spatial extents can be found in Table 3.2. The main objective of the Land Cover of Western Oregon remote sensing effort was to capture forest cover (Cohen et al. 1995). Meadows were not identified as a target land cover class. Cohen et al. (2002) produced a Stand Replacement Disturbance dataset that captured stand-replacing harvests and fires between 1972 and 1995. Later Cohen and Lennartz (2004) updated this dataset to cover the time period 1972 to 2004 (Figure 3.5). Multiple Landsat images acquired over the period 1972 to 2004 and change detection techniques were used to differentiate between disturbed and undisturbed pixels at each image capture date (Cohen et al. 2002 and Cohen and Lennartz 2005). These data do not attempt to capture meadows but provide important information regarding non-forested areas that are not meadows. Four classes of disturbance can be found in Table 3.3

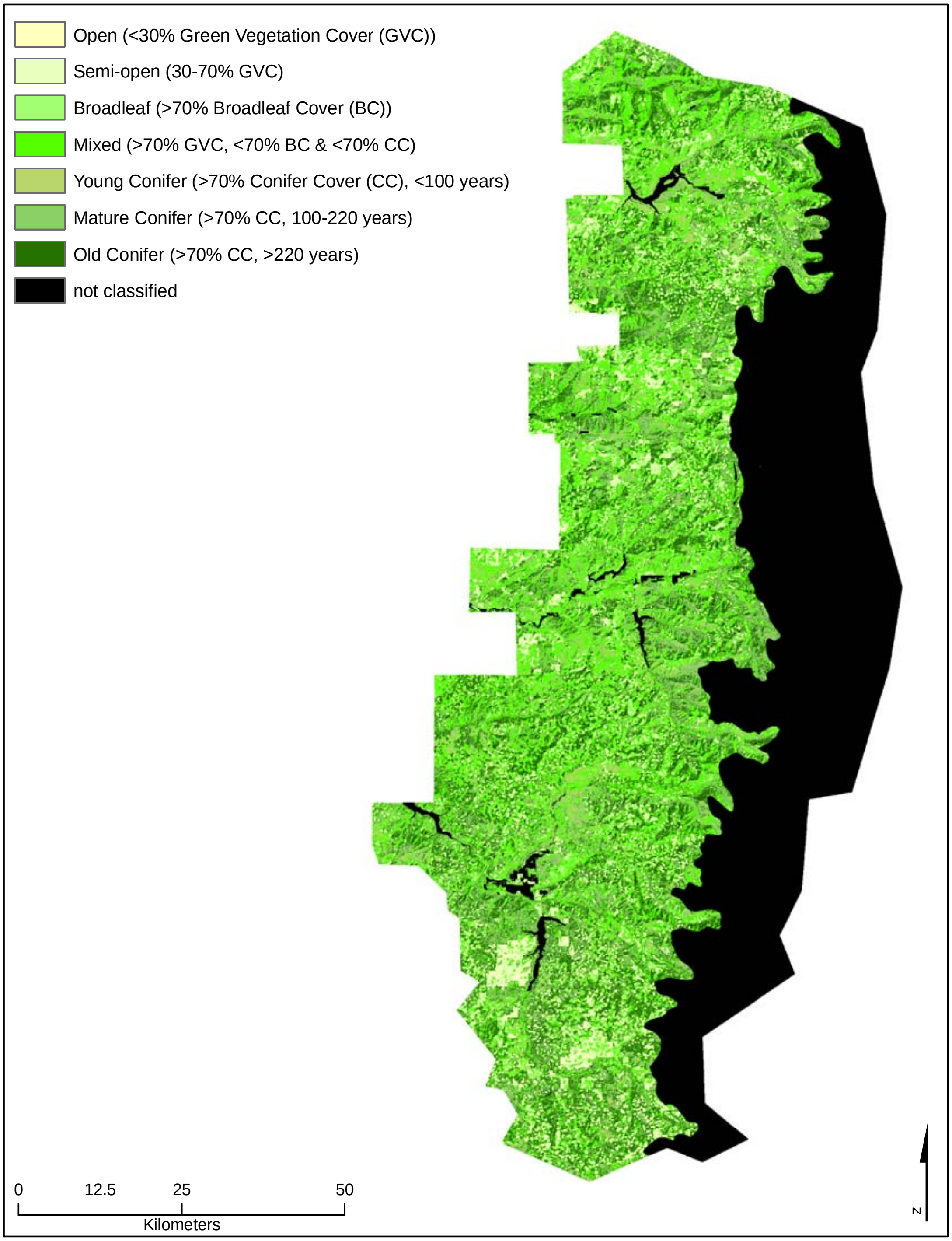


Figure 3.4. Cohen et al. (1988) Land Cover of Western Oregon data, clipped to the WNF study area extent and projected forward to reflect current stand ages.

Table 3.2. Area of the 1988 Land Cover of Western Oregon cover classes projected to 2007 for the portion of this chapter's study area the original data covers.

Cover class	Area (km^2)
Open vegetation (<30% green vegetation cover)	132
Semi-open vegetation (30-70% green vegetation cover),	666
Broadleaf (>70% broadleaf cover)	112
Mixed (> 70% green vegetation cover, < 70% broadleaf cover, and <70% conifer cover)	2023
Young conifer (> 70% conifer cover less than 100 years old)	337
Mature conifer (>70% conifer cover between 100 and 220 years old)	1081
Old conifer (>70% conifer cover greater than 220 years old)	1403

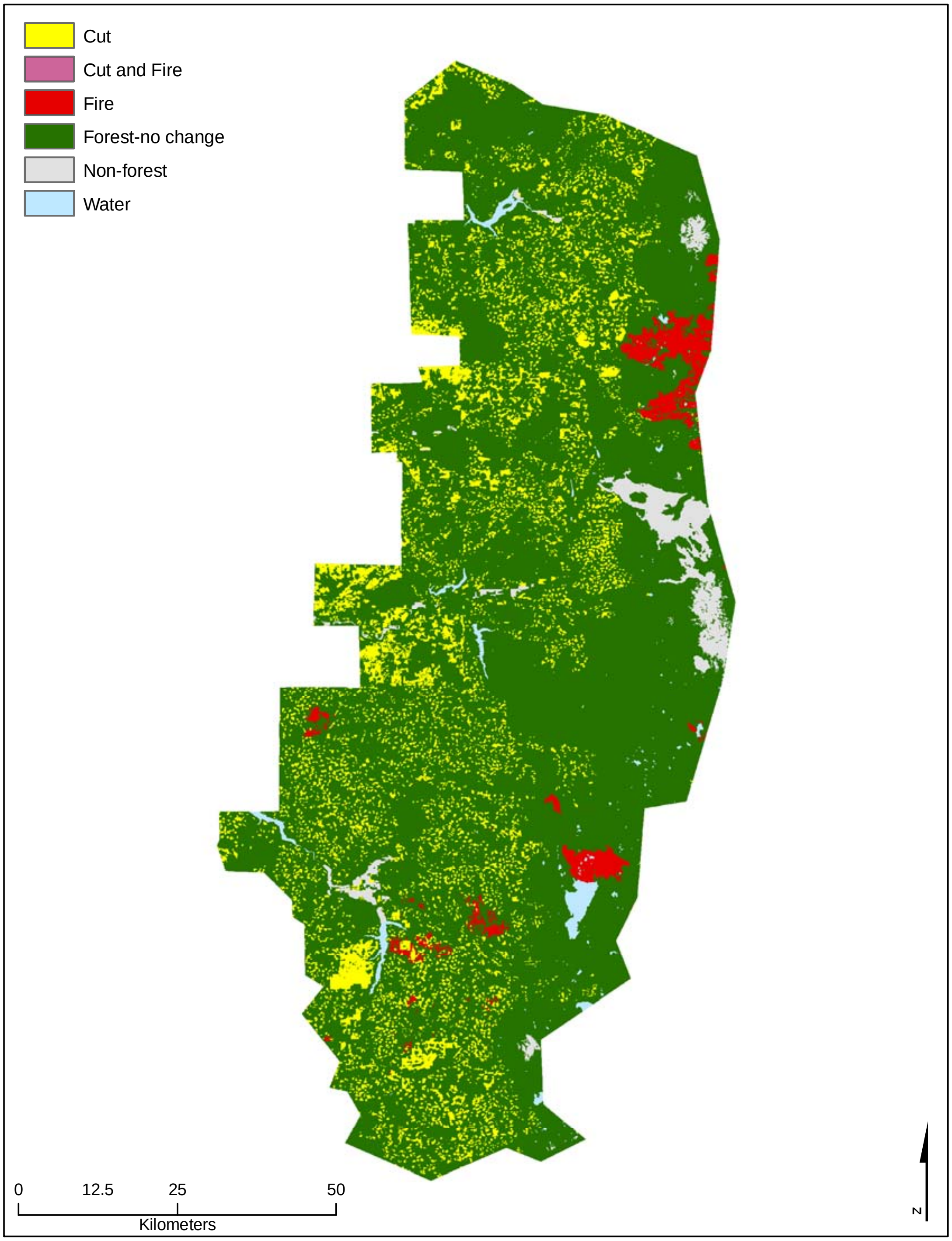


Figure 3.5. Cohen and Lennartz (2004) Stand Replacement Disturbance data clipped to the WNF study area extent.

Table 3.3. Area and percent of WNF study area of the Stand Replacement Disturbance classes (1972-2004).

Disturbance class	Area (km2)	% of WNF study area
Forest - no change	6947	86%
Cutover forest	985	12%
Burned forest	192	2%
Cutover and burned forest	0.4	< 0.01%

3.3 Methods

This chapter describes a classification of non-forest vegetation types for the WNF study area conducted using satellite remotely sensed imagery. (The study area boundary is slightly larger than the WNF administrative boundary (Figure 3.6).) Cohen et al. (1988) produced a Western Oregon Composite Forest Vegetation dataset through classification of Landsat imagery captured in August, 1988. The classification resulted in seven forest attribute classes: open, semi-open, broadleaf, mixed, young conifer, mature conifer, and old conifer. Though the open class (< 30% cover) could potentially be used to identify meadows, the purpose of the classification was to delineate forest attributes, not meadows. The objective of this chapter is to create a current and consistent inventory of meadows and associated topographical characteristics for the entire WNF using satellite remote sensing image interpretation.

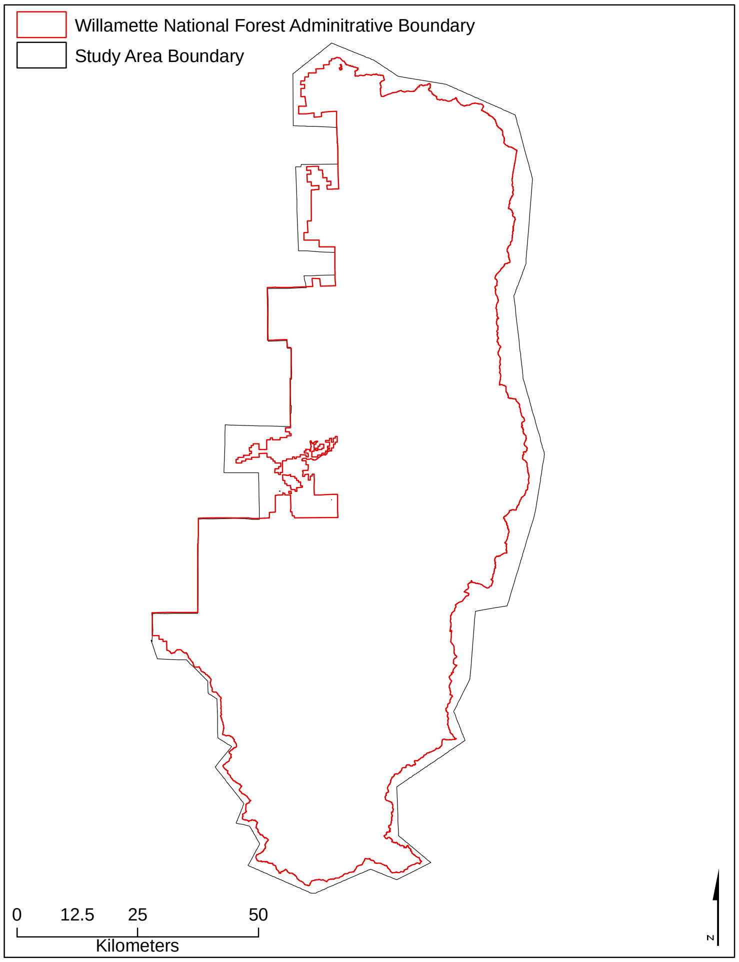


Figure 3.6. WNF administrative and study area boundaries compared.

3.3.1 Data Description

Satellite imagery, digital elevation models (DEMs), orthorectified color photographs, and previously produced vegetation and forest stand disturbance datasets were used for this analysis. Landsat Enhanced Thematic Mapper (ETM+) images of the study area were acquired on 24 September 2002. The radiometrically corrected and georeferenced images were obtained (with permission) from the website of the Laboratory for Applications of Remote Sensing in Ecology (LARSE; http://www.fsl.orst.edu/larse).

Bands used included band 1 (0.45 – 0.52 µm), band 2 (0.52 – 0 60 µm), band 3 (0.63 – 0.69 µm), band 4 (0.76 – 0.90 µm), band 5 (1.55 – 1.75 µm), and band 7 (2.08 – 2.35 µm). The panchromatic and thermal bands were not used in this analysis. Ten meter DEMs were obtained from the Oregon Geospatial Data Clearinghouse http://www.oregon.gov/DAS/EISPD/GEO/). National Agricultural Imagery Program (NAIP) mosaicked photographs flown in June and July and August of 2005 with a one meter resolution were obtained from the USDA Geospatial Data Gateway website (http://datagateway.nrcs.usda.gov/). The 1988 Western Oregon Composite Forest Vegetation Layer (Cohen et al., 1988) and the Stand Replacing Disturbance (Cohen and Lennartz, 2004) datasets were also obtained from the LARSE website.

3.3.2 Image Processing

Standardization

The Landsat ETM+ image was atmospherically corrected using the dark pixel subtraction method. Dark pixel subtraction uses the minimum digital number (DN) value in each band and subtracts it from all other values in that band (Crippen, 1988; Hadjimitsis et al., 2004). The images were reprojected into a Universal Transverse Mercator (UTM) projection (Zone 10 North, North American Datum 1983) to be consistent with the other data used in this study. Image processing was performed using the Research Systems Incorporated Environment for Visualizing Images (ENVI) version 4.2 software.

Classification

Matched Filtering, a type linear spectral unmixing, was applied to the Landsat ETM+ imagery to classify meadows and other cover types in the WNF. Linear spectral unmixing is based on the assumption that a pixel's spectral reflectance is a linear combination of the "individual material reflectance functions" of the pixel (van der Meer and de Jong, 2000). It attempts to discern the fraction of "pure spectral components" or endmembers that explain the reflectance spectrum of the mixed pixel (van der Meer and de Jong, 2000). Unlike traditional linear spectral unmixing, Matched Filtering only requires knowledge of the spectral reflectance of the endmember of interest rather than all potential endmembers within a scene. Widely used in signal processing, Matched Filtering computes the correlation between the known signal (the spectral reflectance of the endmember) and that of each pixel's spectral reflectance. Pixels having a high correlation with the endmember have a high score indicating a high proportion of the selected endmember in those pixels. The assumption is that the correlation is linearly related to the fraction of the endmember in the pixel. This method "uncouples processing complexity from scene complexity" by limiting the number of endmembers analyzed to only those of greatest interest (Boardman et al., 1995; ENVI, v. 4.2).

Three endmembers for use in Matched Filtering were identified visually using orthorectified aerial photographs. Because meadows may consist of a combination of herbaceous vegetation, shrubs, and trees (Figure 3.7), each 30-m Landsat ETM+ pixel may contain a fraction of these or other land cover types (Figure 3.8). Therefore, the endmembers chosen for the purposes of meadow delineation are herbaceous vegetation, shrubs, and closed forest canopy. Using the orthorectified NAIP aerial photographs, representative examples of "pure" land cover types were identified. The boundaries of four examples of meadow, seven examples of closed forest canopy, and nine examples of shrub were digitized as polygons in ArcGIS software. The endmember polygons were imported into ENVI as "Regions of Interest" (ROIs) for use in the Matched Filtering process. Examples of typical spectral profiles for each endmember can be found in Figure 3.9.

Figure 3.7. 2005 photograph of meadow, outlined in yellow, comprised of herbaceous vegetation, shrub, and tree cover near Grasshopper Mountain.

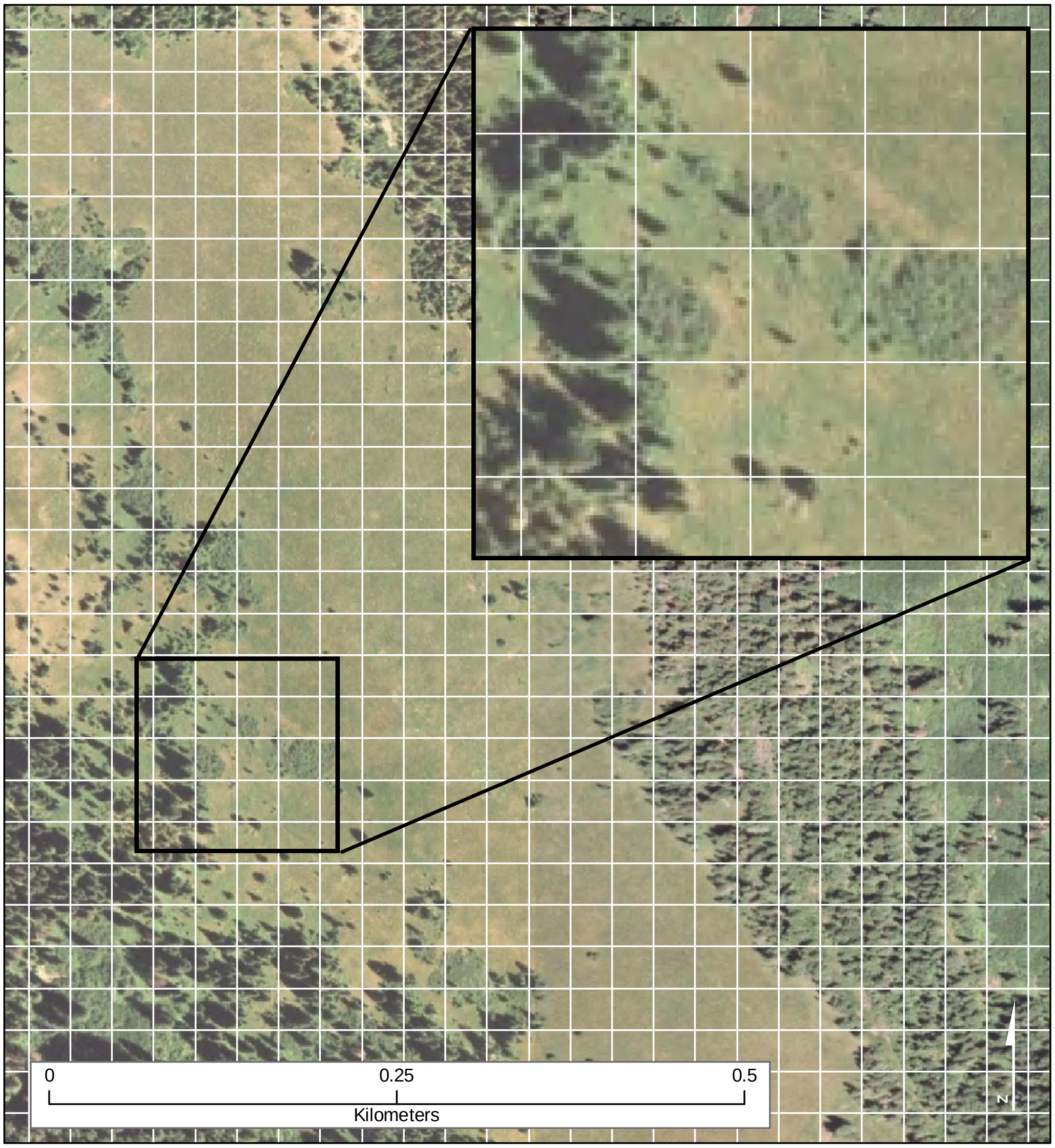


Figure 3.8. Thirty meter grid superimposed over a 2005 aerial image of a portion of the study area, demonstrating potential proportion of herb, shrub, or tree within each 30-m pixel.

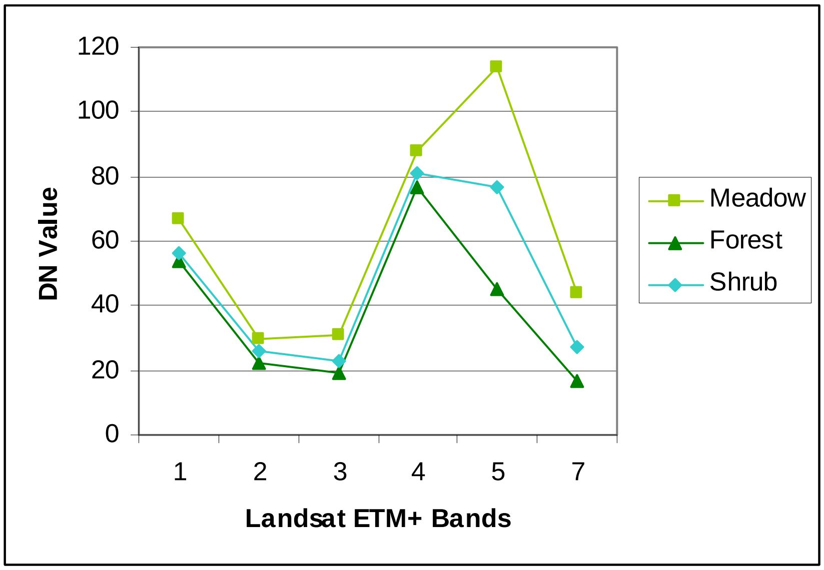


Figure 3.9. Landsat ETM+ spectral profiles of meadow, forest, and shrub endmembers.

The Matched Filtering process was performed in ENVI using the endmembers that were selected from the Landsat ETM+ image using the region-of-interest (ROI) tool. Each ROI contained between 87 and 222 pixels. Bands 1-5, and 7 were used to spectrally characterize each endmember. (Band 6, the thermal band, is not useful for the purposes of this analysis.) Matched Filtering produces an “abundance” image for each endmember that represents the fraction of that particular endmember in each 30-m pixel. Negative values signify a poor correlation with the reference endmember spectrum and indicate a zero abundance of the endmember. Positive values correspond to larger abundances. Resulting values had the following ranges for each of the three abundance images: forest (-10.081 to 6.437), shrub (-6.526 to 6.261), and meadow (-2.461 to 2.954).

Four land cover classes were selected to represent the land cover of interest in this study, meadows, as well as three general land cover types that encompassed the surrounding vegetated land cover. To determine the classes of land cover, the three endmember results were compared to each other and to the orthorectified NAIP aerial photographs with a spatial resolution of one meter. The cover classes were determined based on the proportion of the endmembers in the classified pixels: meadow/barren (0-15% cover), shrub/very open forest (15-60% cover), open forest (60-90% cover), and closed forest (90-100% cover). A flow chart displaying the classification process can be found in Figure 3.10 and is described below. The meadow endmember alone was useful in assigning three classes. If the value was between 0.5 and 2.954, it was classified as meadow/barren, if between 0.25 and 0.5, it was classified as shrub/very open forest, and if between 0 and 0.25, it was classified as open forest. These thresholds, as well as those described below, were determined by visually inspecting the land cover using the aerial photographs and each endmember classification. The end member classifications were symbolized using a variety of intervals until the symbolization corresponded with a pattern of land cover displayed on the photograph. The range of the end member classifications and the land cover were noted and the thresholds of endmember values were determined. Where the meadow endmember value was less than or equal to 0, the forest endmember class was used to determine the classification. If the forest endmember was greater than 0 in this circumstance, the closed forest class was assigned regardless of the shrub endmember value. If the forest and meadow endmembers were both less than or equal to 0, the shrub endmember value was examined. If it was greater than 0, the closed forest class was assigned. If it was less than or equal to 0, an unknown class was assigned.

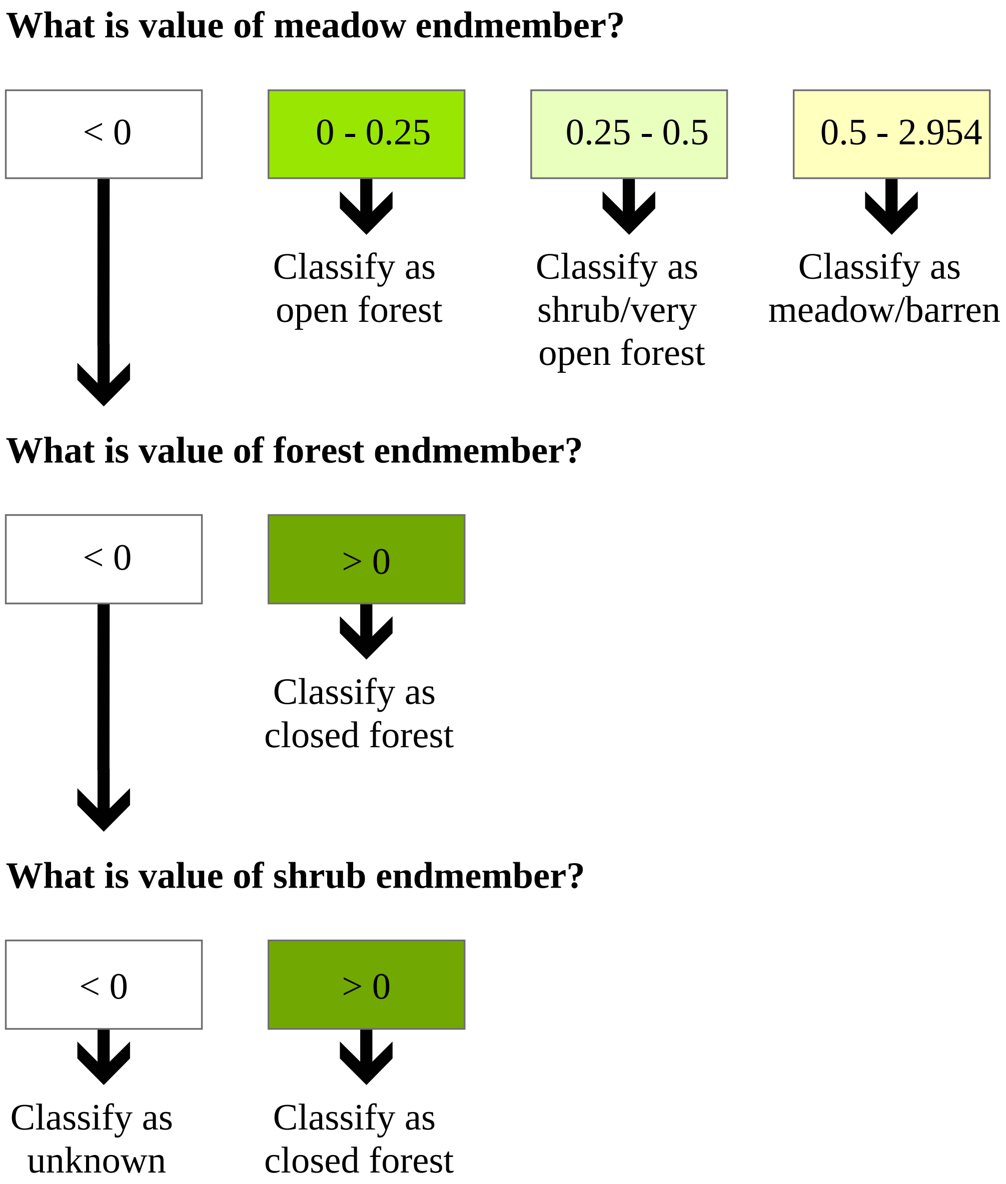
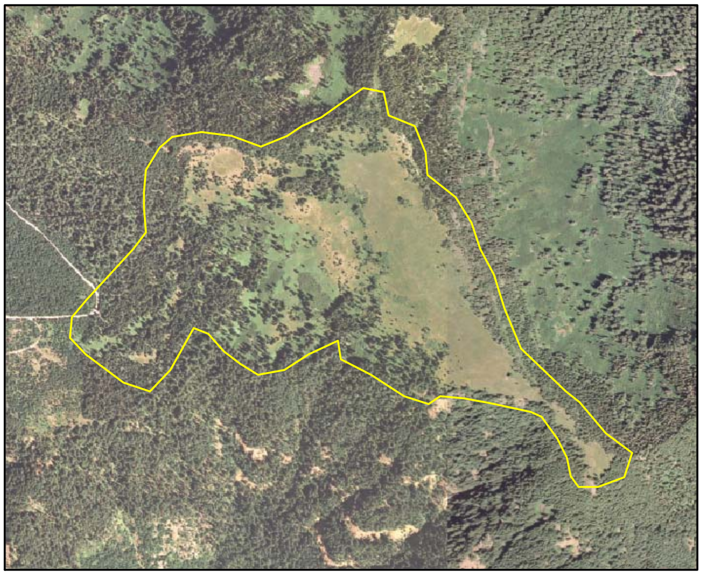


Figure 3.10. Flow chart of endmember classification decision process based on endmember values compared to each other and aerial photography.

Because the Matched Filtering classification only targeted three endmembers, it was not expected to identify land cover not characterized by those end members. Land cover not composed of the endmembers identified should theoretically have produced negative values in the Matched Filtering classification. However, due to the low spectral resolution of the Landsat ETM+ bands, misclassification was not unexpected (van der Meer and de Jong, 2007). The mixture tuned matched filter (MTMF) option in ENVI was used to indicate the degree to which the matched filter results were a feasible mixture of endmembers. However, visual inspection of the MTFM results compared to the aerial photography and original matched filter results did not provide increased accuracy so the MTMF feasibility results were not used for further analysis. In order to improve the non-meadow representation in the classification, other datasets were investigated.

Two datasets of forest attributes and stand disturbance were examined to determine if they would be useful in meadow classification. The 1988 Western Oregon Composite Forest Vegetation Layer (vegmap) provides additional information regarding forest composition and age (Cohen et al., 1988). The Stand Replacing Disturbance dataset (disturbance) provides information regarding non-vegetated areas, water, and stand replacing disturbance by harvest or fire between 1972 and 2004 (Cohen and Lennartz , 2004) Both datasets were compared to aerial photographs and the Matched Filter classification (Figures 3.11 and 3.12).



2005 aerial photograph.

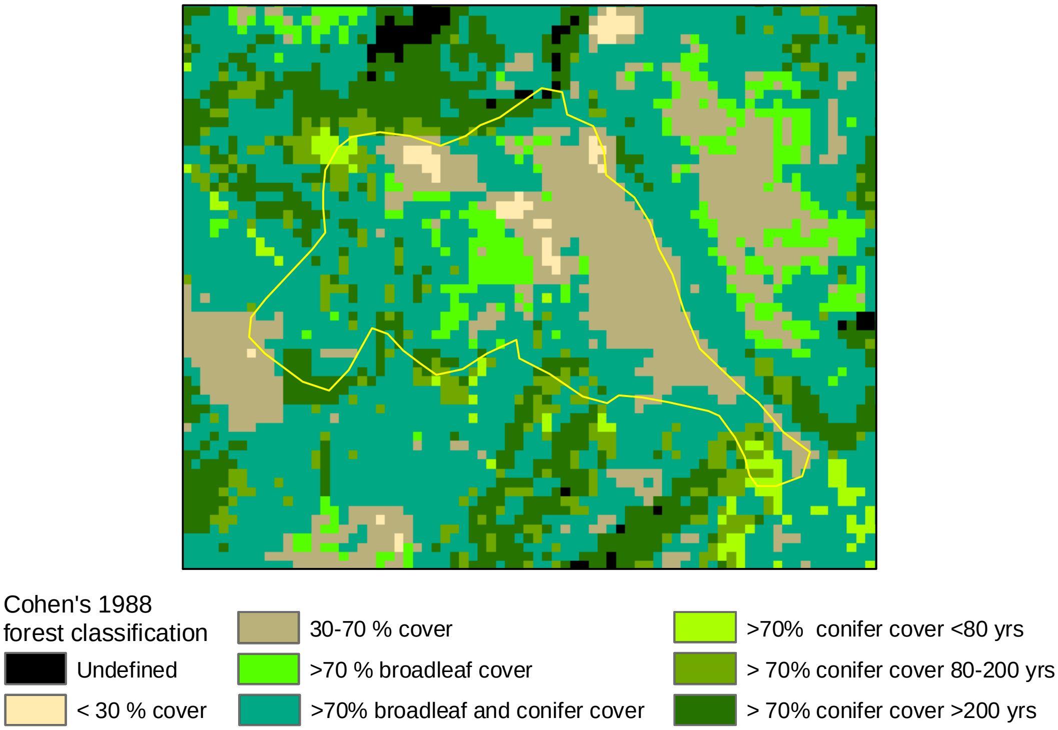
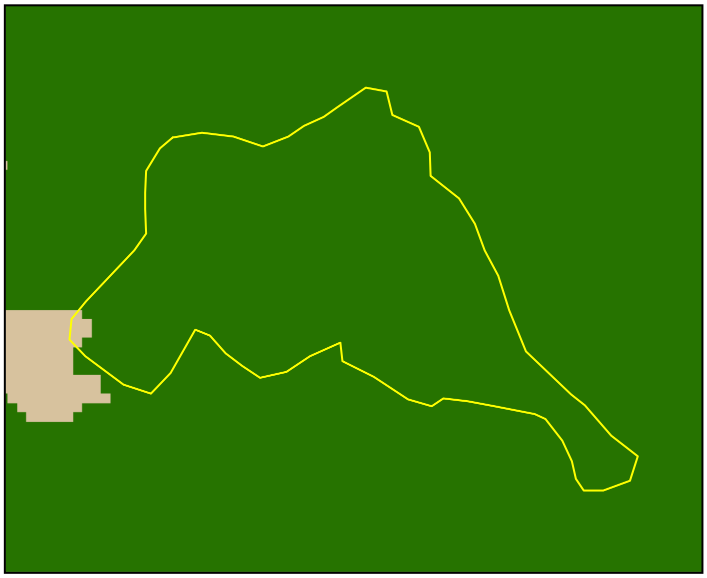
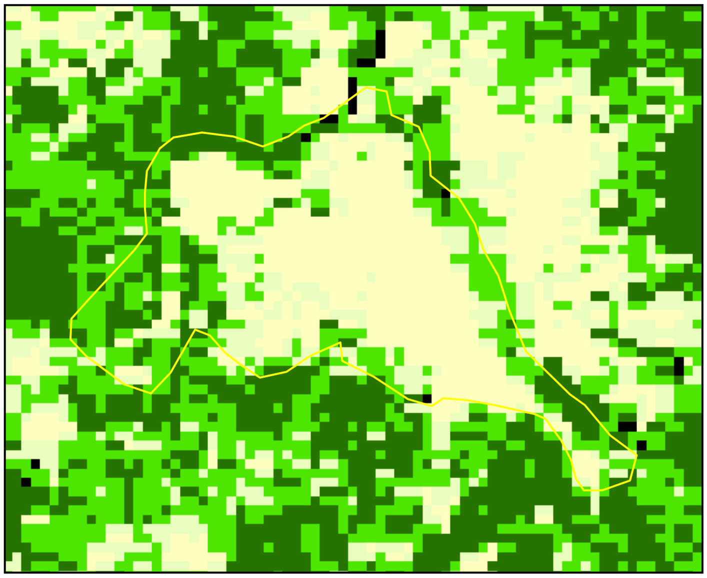


Figure 3.11. 2005 aerial photograph and Cohen et al.'s 1988 forest vegetation (vegmap) classification of the Grasshopper Mountain meadow, demonstrating the vegmap classification of herbaceous vegetation as 30-70% cover.



Cohen and Lennartz 2004 "disturbance" classification.

🟩 Forest no-change 🟫 Previously cut



Classification produced by this chapter.

- ▭ Meadow/Barren
- ▭ Shrub/Very open forest
- 🟩 Open forest
- 🟩 Closed forest
- ■ Unknown

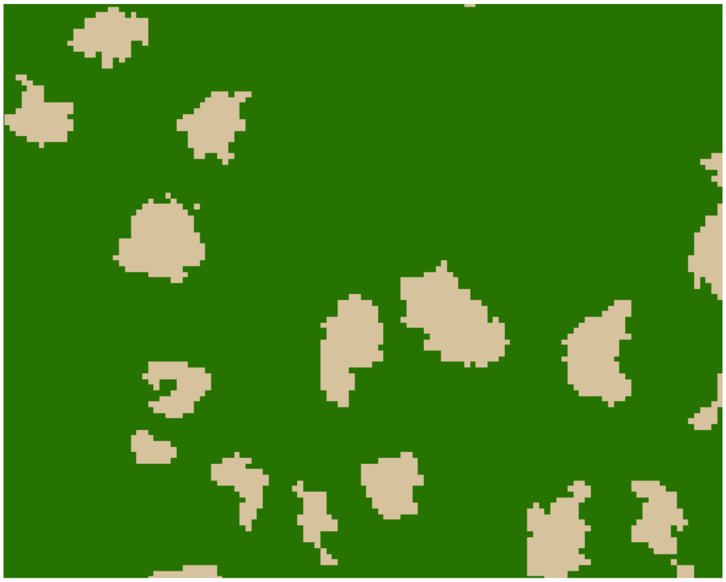
Figure 3.12. Cohen and Lennartz 2004 stand replacing disturbance dataset and the vegetation classification of the Grasshopper meadow, demonstrating the disturbance dataset's classification of meadow as "forest no-change".

The <30% cover class in the Cohen 1988 Land Cover of Western Oregon (vegmap) data was of particular interest to determine if it would be useful for meadow identification. The emphasis of the vegmap classification was to map forest. However, it was thought that if a cover class contained less than 30% tree cover, it might indicate that a meadow or other non-forest land cover type occurred there. If this is true, the Cohen vegmap data could help train or validate the meadow classification described in this chapter. However, comparison of the vegmap data and aerial photographs indicates that it is not appropriate for these purposes. Figure 3.11 shows that the Grasshopper Mountain area meadow is classified mostly as >30% cover, >70% broadleaf, and >70% broadleaf and conifer cover.

A new classification was created by incorporating the Cohen and Lennartz 1972-2004 Stand Replacement Disturbance data's water, burned, and cut classes, a refinement of the its non-forested class, and this chapter's vegetation classification (Table 3.4). The Cohen and Lennartz 1972-2004 Stand Replacement Disturbance dataset (henceforth referred to as the disturbance dataset) was not appropriate for meadow identification specifically but provided additional information that improved the overall classification. Figure 3.12 shows that the disturbance dataset classifies the Grasshopper Mountain area meadow as "forest un-changed". However, the water and non-forested classes of the disturbance dataset identify specific land cover types not targeted in the Matched Filtering process. This chapter's classification tended to misclassify water as closed forest. The use of the water class from the disturbance data prevented this misclassification. This chapter's classification did not distinguish between meadow and lawn or agriculture. It did not target rock or ice and subsequently classified those areas as unknown. The disturbance dataset's non-forested class includes areas of agriculture, bare land, man made features, and non-woody vegetation (Lennartz, 2005). Through photo interpretation, the non-forested disturbance dataset class was further classified into three categories: (1) populated places, agriculture, and man made features, (2) rock/ice, and (3) consistent with this chapter's vegetation classification. Including these revised classes prevented misclassification of agriculture and lawns as meadow/barren and misclassification of bare rock and ice as unknown. This chapter's classification results, when compared to the disturbance dataset's classes, show that regenerating clear cuts and burned forest stands are very similar spectrally to meadows (Figure 3.13). Therefore the disturbance dataset's classes representing cut and burned areas were also combined with this chapter's classification to prevent misclassification of regenerating stands as meadow. The combined classification (henceforth referred to as the "final classification") consists of approximately 6953.7 km^2 (82.5 %) of land cover derived from this chapter's vegetation classification with the remaining 1470.4 km^2 (17.5 %) derived from the disturbance dataset.

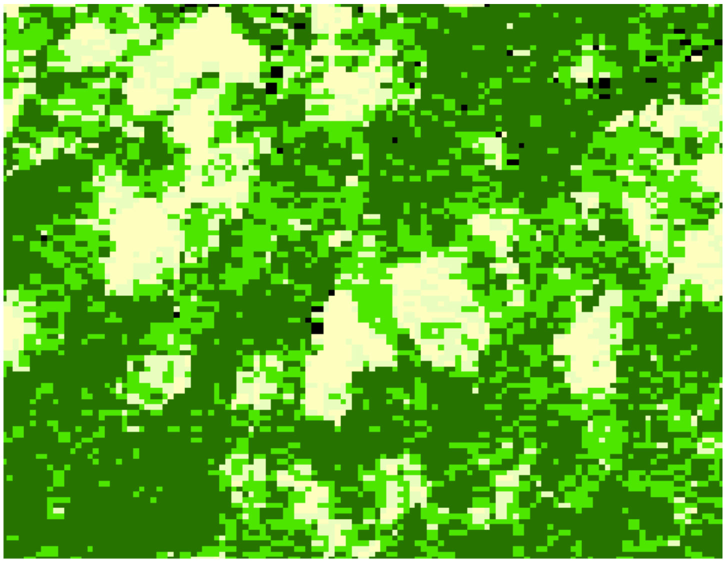
Table 3.4. Final classification categories and source. Water, cut and burned classes Were derived from the Cohen Lennartz disturbance data (2004). The “agriculture, populated places, man made features” class and Rock/Ice class was derived from refining Cohen and Lennartz disturbance class “non-forested” with photo interpretation.

Class	**Source**
Water	Cohen Lennartz disturbance data
Cut 02-04	Cohen Lennartz disturbance data
Cut 00-02	Cohen Lennartz disturbance data
Cut 95-00	Cohen Lennartz disturbance data
Cut 91-95	Cohen Lennartz disturbance data
Cut 88-91	Cohen Lennartz disturbance data
Cut 84-88	Cohen Lennartz disturbance data
Cut 77-84	Cohen Lennartz disturbance data
Cut 72-77	Cohen Lennartz disturbance data
Fire 02-04	Cohen Lennartz disturbance data
Fire 00-02	Cohen Lennartz disturbance data
Fire 95-00	Cohen Lennartz disturbance data
Fire 91-95	Cohen Lennartz disturbance data
Fire 88-91	Cohen Lennartz disturbance data
Cut 72-77, Fire 02-04	Cohen Lennartz disturbance data
Cut 77-84, Fire 02-04	Cohen Lennartz disturbance data
Cut 84-88, Fire 02-04	Cohen Lennartz disturbance data
Cut 88-91, Fire 02-04	Cohen Lennartz disturbance data
Cut 91-95. Fire 02-04	Cohen Lennartz disturbance data
Cut 95-00, Fire 02-04	Cohen Lennartz disturbance data
Cut 00-02, Fire 02-04	Cohen Lennartz disturbance data
Meadow/Barren	This chapter’s classification
Shrub/Very open forest	This chapter’s classification
Open forest	This chapter’s classification
Closed forest	This chapter’s classification
Agriculture, populated places, man made features	Refined Cohen Lennartz disturbance data
Rock/Ice	Refined Cohen Lennartz disturbance data
Unknown	This chapter’s classification



Cohen and Lennartz 2004 "disturbance" classification.

🟩 Forest no-change 🟫 Previously cut



Classification produced by this chapter.

🟨 Meadow/Barren 🟩 Open forest ⬛ Unknown
⬜ Shrub/Very open forest 🟩 Closed forest

Figure 3.13. Two maps of the same extent comparing the Cohen and Lennartz disturbance dataset and the vegetation classification demonstrating the misclassification of regenerating clear cuts as meadow in the vegetation classification.

Accuracy Assessment

The accuracy of the original vegetation classification was assessed by comparing the classification of pixels to orthorectified aerial photographs and then performing statistical analyses. Those classes extracted from the Cohen and Lennartz disturbance data were not validated in this process because they had already undergone validation when that dataset was created and updated (Lennartz, 2005). The sampling area frame, or extent of potential pixels to validate, is the extent of the WNF study area. The sample units are randomly chosen classified pixels from the original classification that had not been replaced by the incorporated disturbance classes. Orthorectified aerial photographs acquired in 2005 or 2000, depending upon availability, were used to validate the classification. Overall Accuracy, Producer's Accuracy, and User's Accuracy were calculated and Kappa analysis was performed to quantify the accuracy of the classification.

The sample size of pixels used to validate the classification was determined by using a multinomial distribution algorithm. Although multiple vegetation datasets are available for the WNF, none of them used the same class scheme as the final classification. Therefore, one can not presume to know the true proportions of each class in the data. Therefore, the following "worst case" multinomial distribution algorithm was used to ensure the sample size would be large enough for sufficient statistical analysis (Nolin, 2007; Jensen, 2005):

$$N = \frac{B}{4b^2}$$

Where N is the sample size, b is the desired precision and B is the upper percentile of the Chi-square distribution with one degree of freedom.

Given b= 0.05 (95% confidence interval),

B = 1-(alpha/k) = 1-(0.05/4) = 0.875

$X^2_{0.875}$ = 2.354

N = 2.354/(4*(0.05^2)

N = 235

The 235 samples were subdivided among four cover classes used in this chapter's vegetation classification, and 60 samples per class were validated. In the validation procedure, a random number generator and ArcInfo GRID were used to identify 60 random pixels from each class. Each pixel was visually compared to the area it covered on an aerial photograph. An error matrix was created to compare the land cover designation of the classification and the aerial photo-interpretation for the 240 sample locations.

Overall, Producer's, and User's Accuracy were calculated based on the error matrix table. The overall classification accuracy was derived by calculating the percentage of the total number of sampled pixels that were classified correctly based on the photo interpretation. Producer's Accuracy, a measure of omission error, is determined by calculating what percent of each class of pixels was classified correctly compared to the total number of pixels with that assigned class. User's Accuracy, a measure of commission error, tabulates the percent of pixels classified correctly per class (Jensen, 2005).

Kappa analysis is a "discrete multivariate technique" used in accuracy assessment (Jensen, 2005). The K_{hat} coefficient of agreement is an estimate of Kappa and measures the agreement between the vegetation classification and the photo interpretation (Jensen, 2005). The formula follows:

$$\hat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+} \times x_{+i})}$$

Where *k* is the number of rows in the error matrix, x_{ii} is the number of observations in row $_{i}$, column $_{i}$, and x_{i+} and x_{+i} are the totals for row $_{i}$ and column $_{i}$ respectively, and *N* is the total number of observations (Jensen, 2005).

The Conditional K_{hat} coefficient of agreement was used to describe the agreement between the vegetation classification and the photo interpretation for a particular class (Jensen, 2005). Conditional K_{hat} is

$$\hat{K}_i = \frac{N(x_{ii}) - (x_{i+} \times x_{+i})}{N(x_{i+}) - (x_{i+} \times x_{+i})}$$

Additional assessment was performed by comparing meadows identified in the WNF Special Habitats (SHABS) polygon data to the final classification, including the Cohen and Lennartz disturbance data. Fifty meadow polygons, which had not been used as end member ROIs, were extracted from the SHABS data. Each polygon was assigned a unique identification value and converted to raster format. Essentially, this converted each meadow polygon into a “zone” with which to perform statistics in ArcInfo GRID. Zonal statistics in GRID are commands that perform basic statistical functions, like mean, maximum, and majority, using the identified zone as a grouping mechanism for the pixels. A “zonal majority” command was run, which analyzed the pixel values of the classification and determined what the majority of values were for each zone. This determined if the area defined by the original polygon was classified mostly as meadow or one of the other vegetation classes.

3.3.3 GIS Analysis

The final classification grid was reclassified so that meadow/barren class was assigned a value of ‘1’ and the remaining classes were assigned a value of ‘0’.

The potential meadow/barren class or “meadow class” was combined with data derived from the DEMs to further characterize the meadows. Ten meter DEMs were reprojected to UTM, NAD 83, Zone 10N, and mosaicked. The resulting DEM was used to model topographic position, 500 meter elevation bands, slope, and aspect. Level IV ecoregion data were used to differentiate the area of the WNF in the high versus western Cascade Ranges (Woods, Bryce, and Omernik, 2003). The application of the attributes of these datasets to the final classification is described below.

Topographic Position

Topographic position is a scale dependent description of relative landform position (Coops et al., 1998). This analysis modeled ridges, slope, toe slopes, and valleys using an Arc Macro Language script (aml) developed by Zimmerman (2000).

To characterize topographic position, the Zimmerman aml uses a technique applied to a DEM that calculates the difference between the elevation value of the center of a circle and the mean elevation value of the entire circle. This is done by creating multiple circular windows with increasing radii around each cell in a DEM and subtracting the average elevation value of each window from the center pixel elevation value. If the elevation value of the center pixel is higher than the mean elevation of the window, the center cell is a ridge or peak at the particular scale determined by the radius of the circle. If the value is lower, the center cell is a valley or toe-slope. The circular window radius parameter is determined by the user. The aml asks the user for the minimum and maximum radii values and the increment value with which to increase each window radius until it reaches the maximum size specified. These inputs ultimately determine the scale of the final output which is a single hierarchical combination of relative topographic positions (Figures 3.14 and 3.15) (Zimmerman, 2000). The final classification was attributed with topographic position attributes of valley, toe slope, slope, and ridge by combining the data grid in ArcInfo (Figure 3.16).

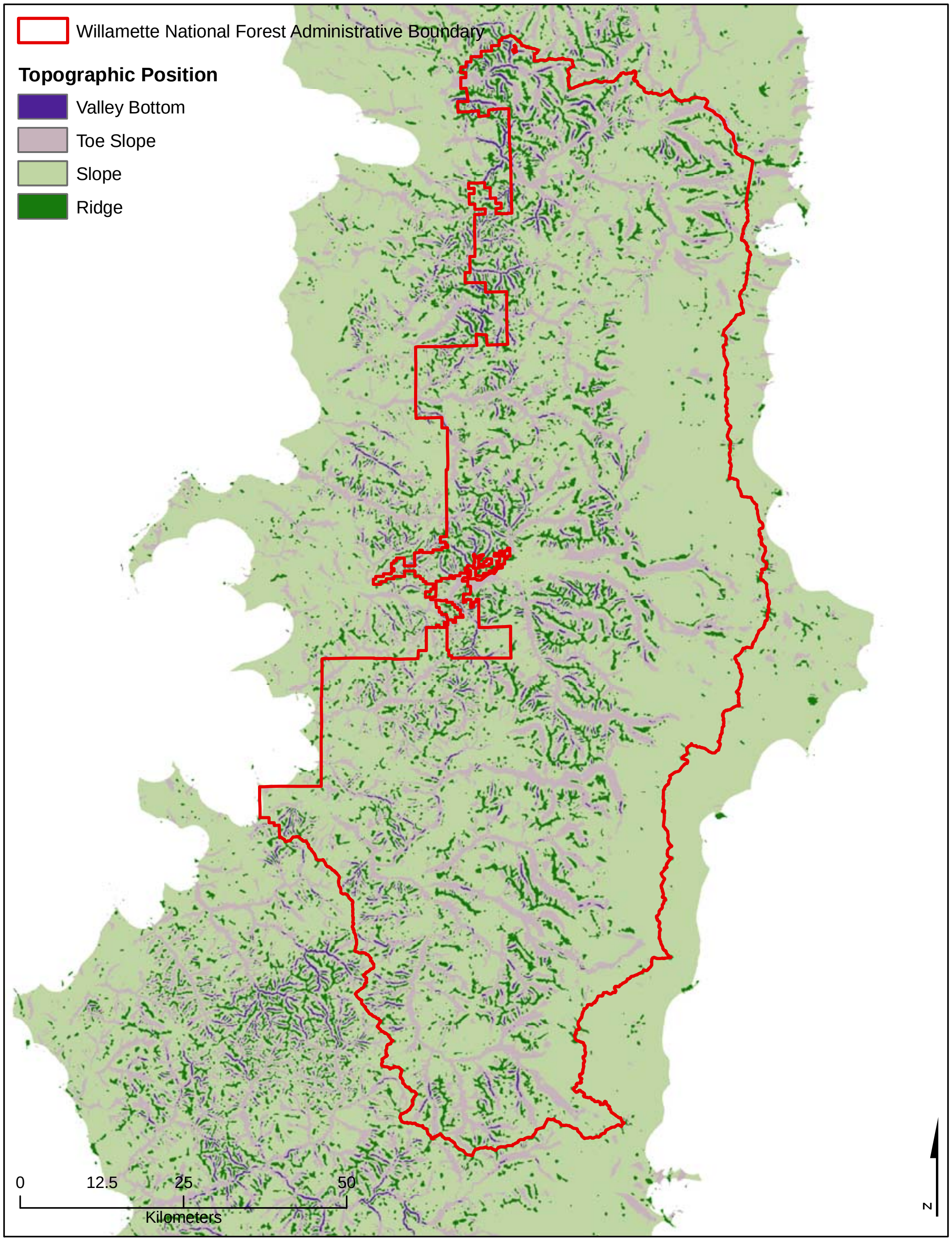


Figure 3.14. Topographic position model output for Oregon western Cascade Range.

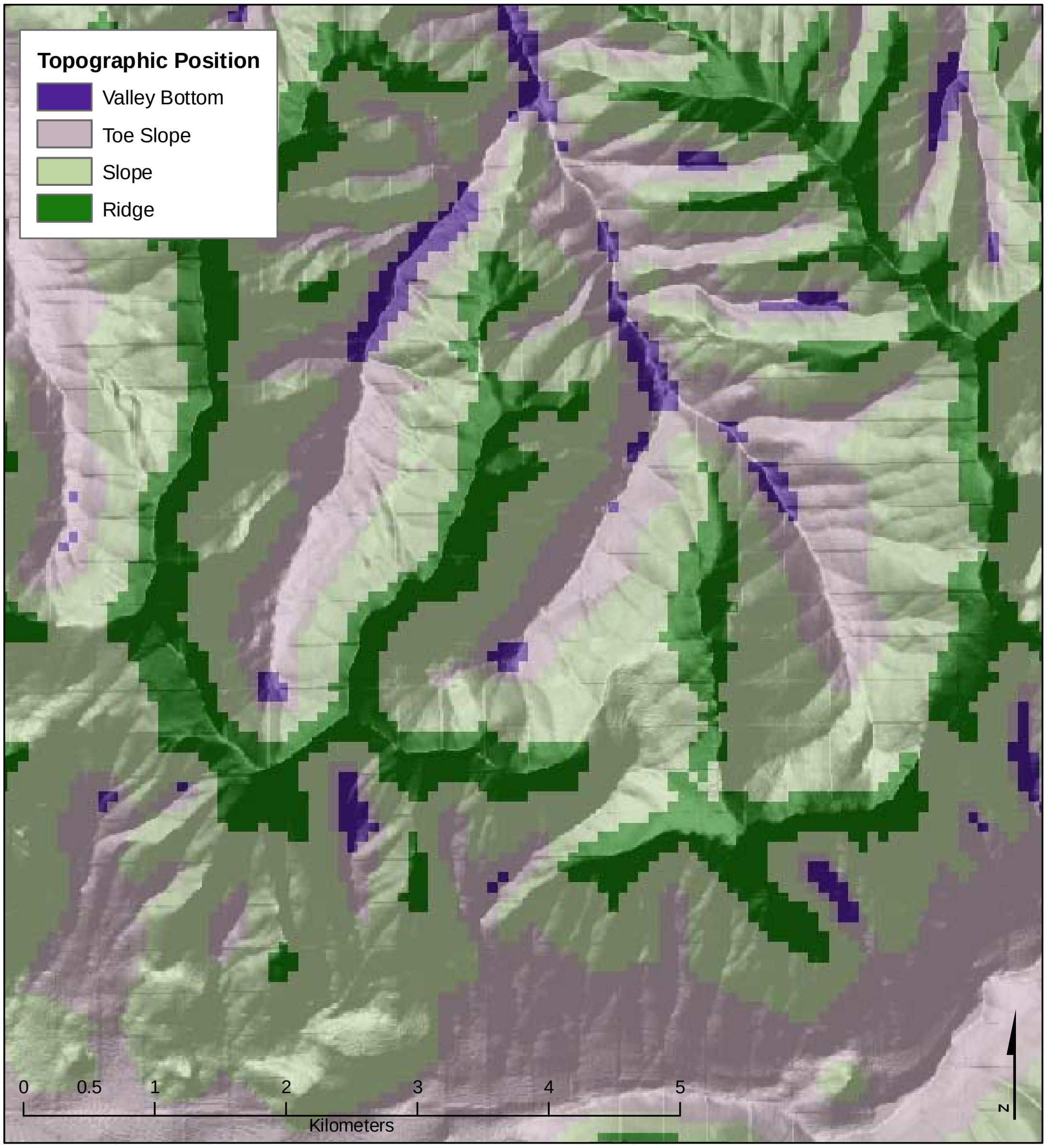


Figure 3.15. Topographic position model output for Chucksney-Grasshopper meadow complex area.

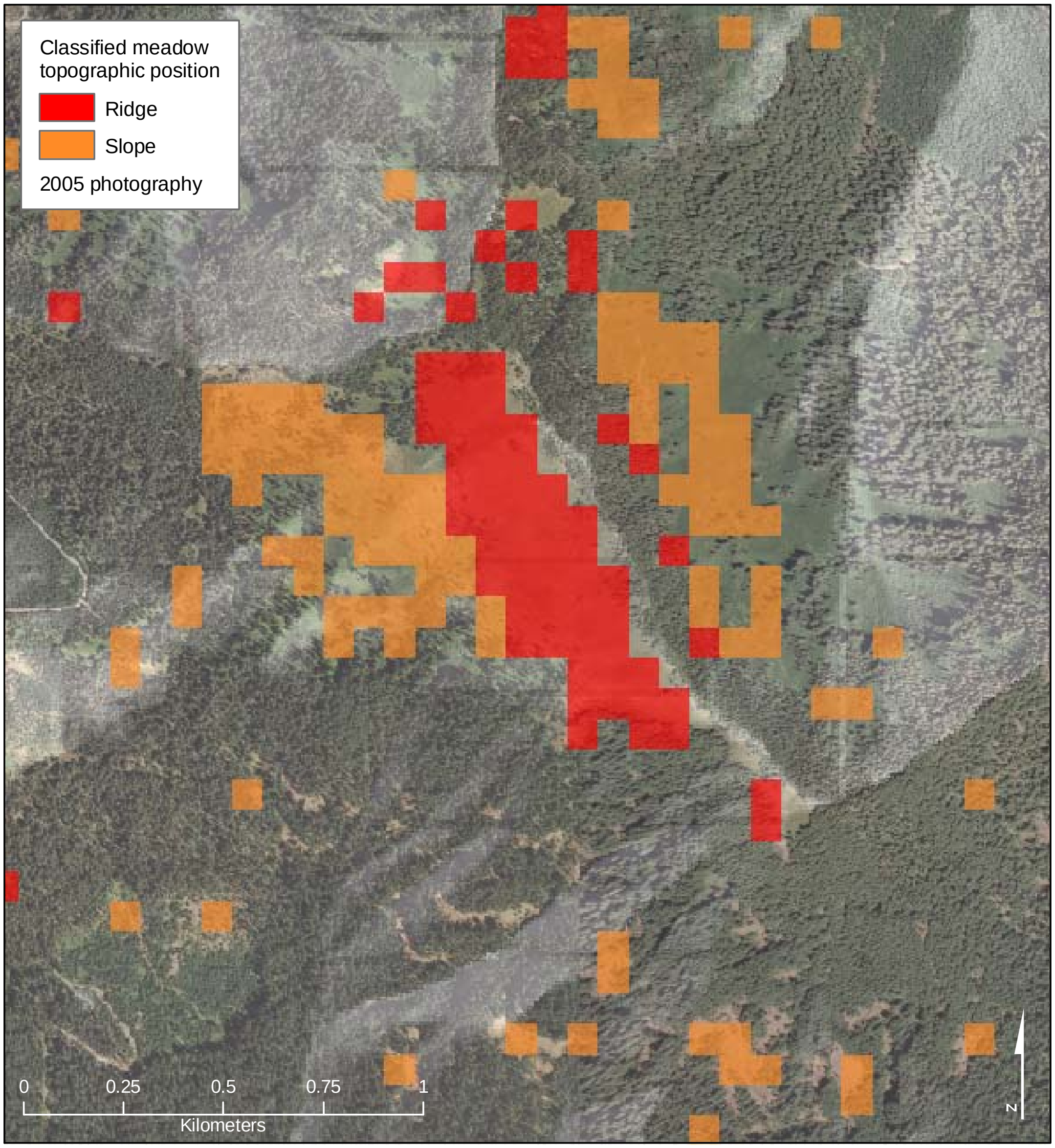


Figure 3.16. Example of meadow/barren class from final classification combined with topographic position output at Grasshopper Ridge.

Elevation

The mosaicked 10m DEM was used to derive 500 meter elevation bands. In ArcGIS, the DEM was reclassified into 500 meter intervals and saved as a new raster (Figure 3.17). It was then combined with the final classification so each pixel could be evaluated based on vegetation class and the elevation band in which it occurred.

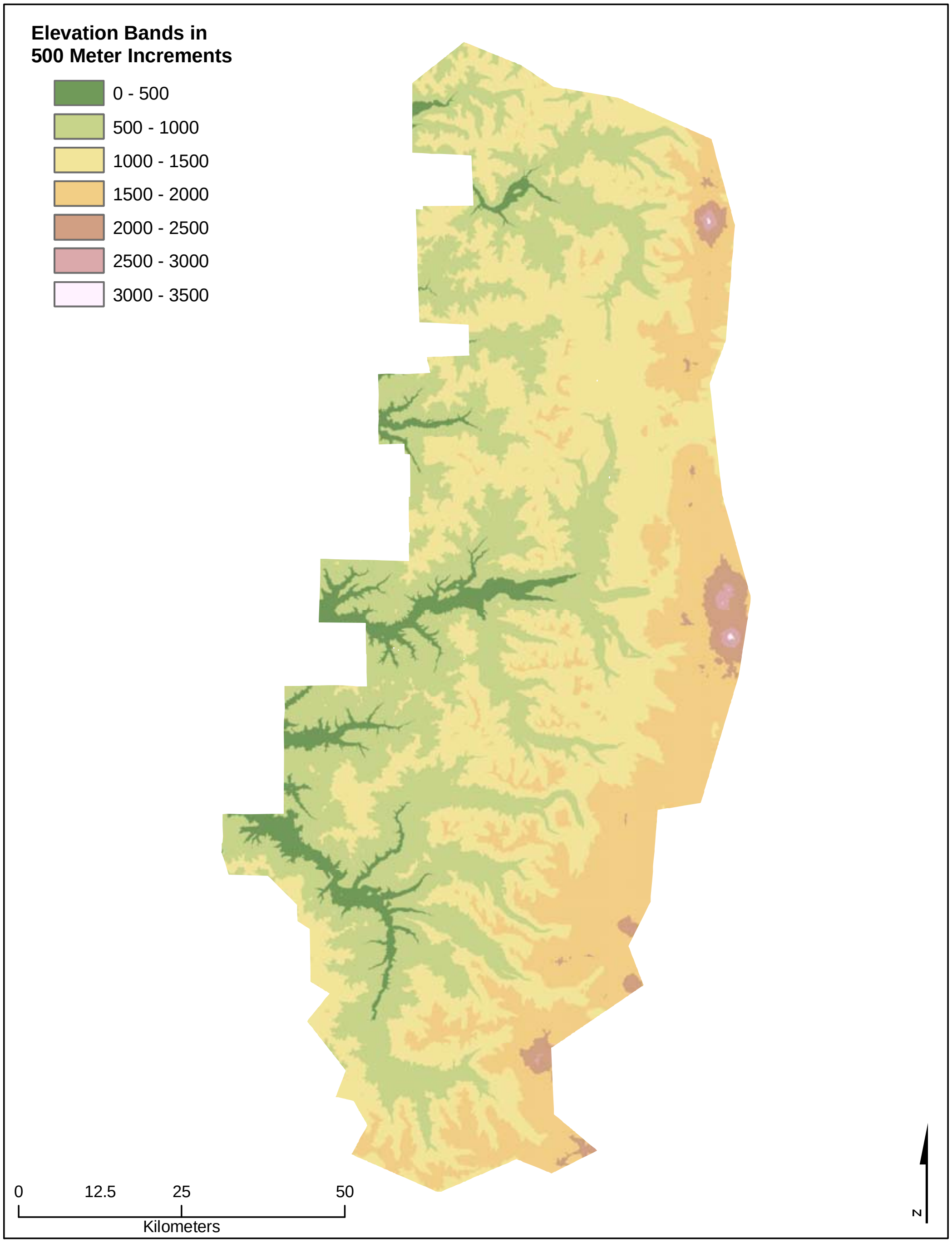


Figure 3.17. Five-hundred meter increment elevation bands for the WNF.

Slope

Slope was derived from the 10 meter DEM. ArcInfo was used to calculate slope in terms of degrees and reclassify values into eight slope classes (Figure 3.18): 1 (0-10º), 2 (10-20º), 3 (20-30º), 4 (30-40º), 5 (40-50º), 6 (50-60º), 7 (60-70º), 8 (70-80º). The slope class grid was then combined with the final classification.

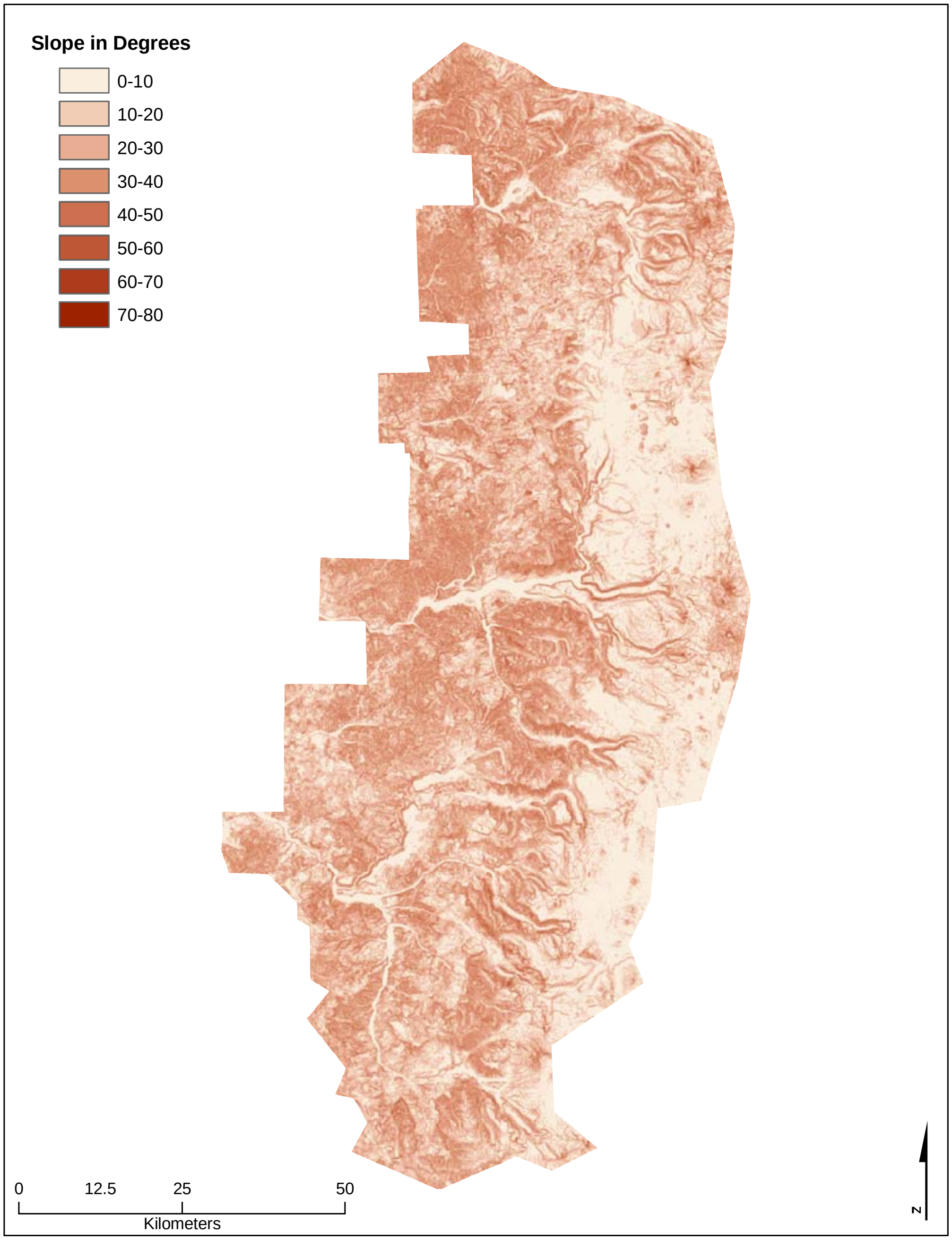


Figure 3.18. Eight classes of slope for the WNF.

Aspect

Aspect, or slope exposure, was modeled using the 10 m DEM in ArcInfo. The resulting raster provided continuous aspect information and was reclassified to provide eight cardinal directions of aspect: NNE (0° - 45°), ENE (45° – 90°), ESE (90° – 135°), SSE (135° – 180°), SSW (180° – 225°), WSW (225° – 270°), WNW (270° – 315°), and NNW (315° – 360°) (Figure 3.19). The reclassified aspect dataset was combined with the final classification to characterize the meadow class.

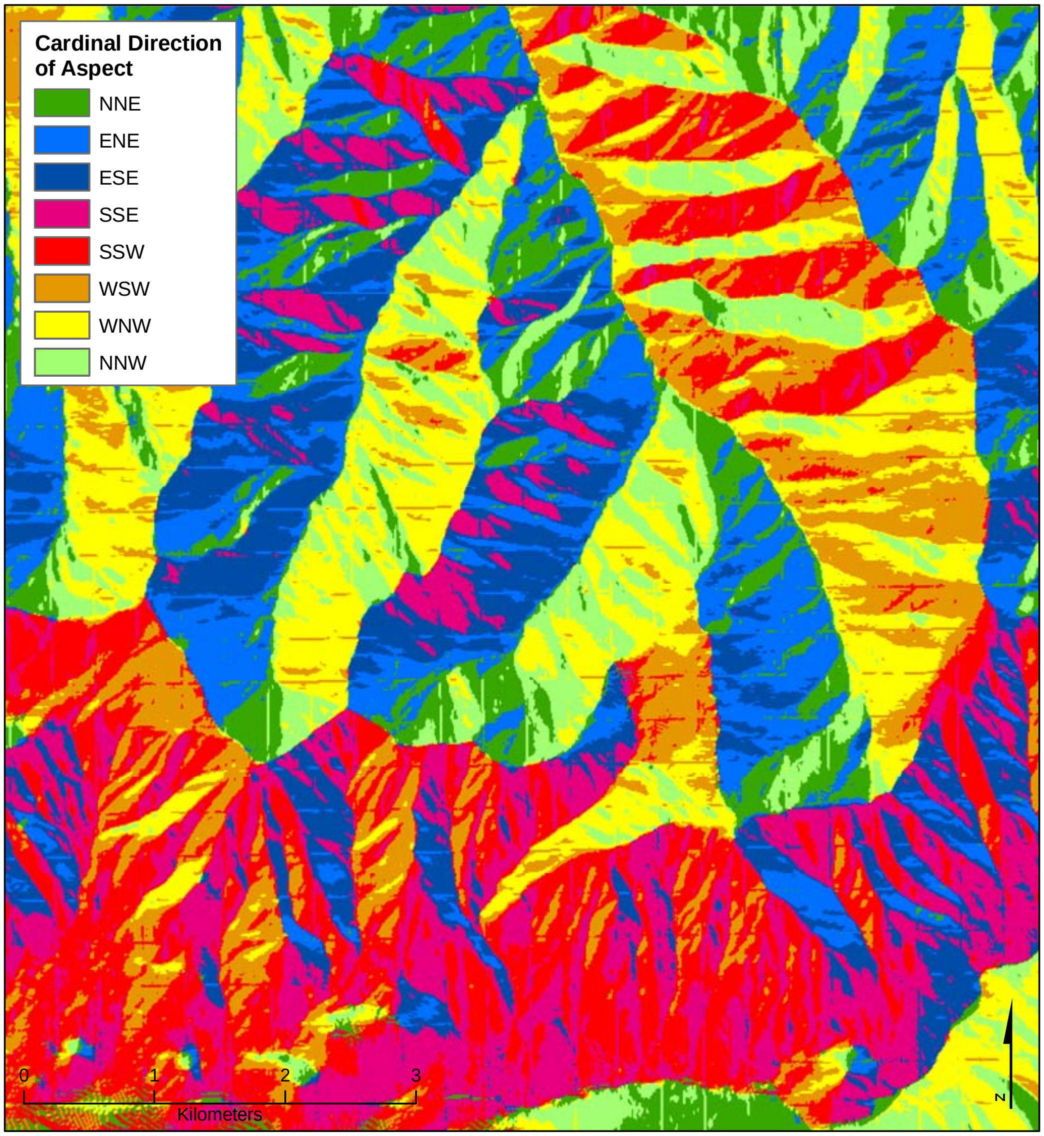


Figure 3.19. Aspect reclassified into eight cardinal directions at Chucksney-Grasshopper.

Ecoregion

The Oregon western Cascade Range physiographic province is further subdivided into six Level IV Ecoregions by the US Environmental Protection Agency (EPA) (Figure 3.20). The boundaries of the Oregon western Cascade Range differs between agencies and organizations delineating them based on if the eastern extent is defined by the crest of the high Cascade Range or the normal fault that creates the horst and graben geomorphology between the High and western Cascade peaks. This chapter has been using the boundary defined by the Oregon Natural Heritage Foundation and The Nature Conservancy which uses the crest of the high Cascade Range as the boundary. The EPA uses the fault as the eastern boundary so its Level IV Ecoregion nomenclature will refer to high Cascade Range for areas previously defined as western Cascade Range here. For future reference, western Cascades Range refers to the EPA fault-defined physiographic province. The Level IV Ecoregions are based on a region’s unique geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Woods, Bryce, and Omernik, 2003).

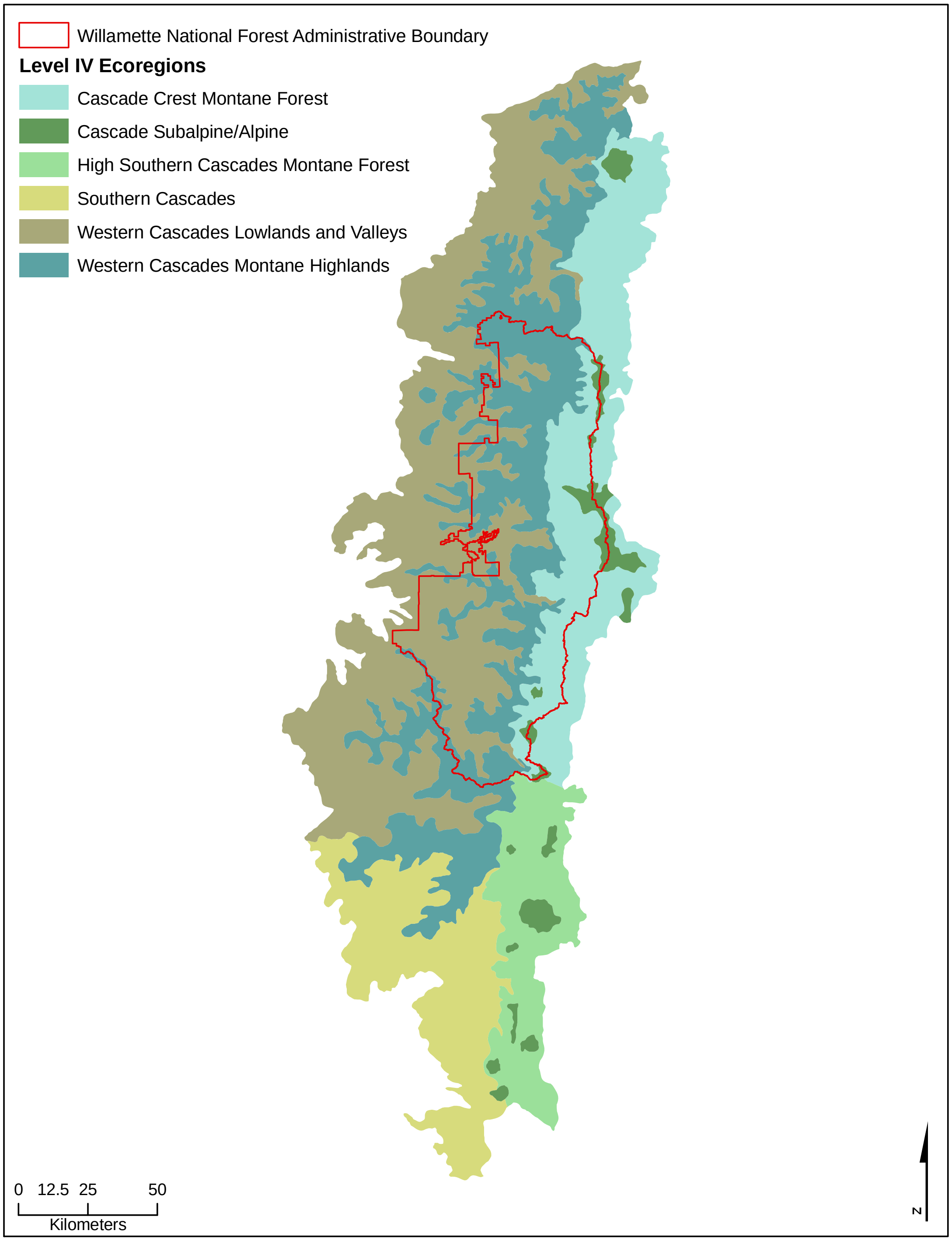


Figure 3.20. EPA Level IV Ecoregion designations of western Cascade Range and WNF boundary.

For the purposes of analysis, the Level IV Ecoregional data have been separated into physiographic provinces that delineate different vegetational and physical characteristics of the WNF. The Western Cascades Lowlands and Valleys and Western Cascades Montane Highlands have been aggregated and combined with the WNF extent and named "WNF – west". The Cascade Crest Montane Forest and the Cascade Subalpine/Alpine Zone have been aggregated and combined with the WNF extent and named "WNF – east".

3.4 Results

3.4.1 Results of Image Processing

Accuracy Assessment

The final classification resulted in 28 classes derived from Matched Filter endmember analysis using Landsat ETM+ and the incorporation of the "disturbed" data layer created by Cohen and Lennartz (Figure 3.21). The Landsat ETM+ imagery source date is 2002 and the Disturbance data source date is as recent as 2004. Therefore, the final classification currentness is approximately 2002-2004. Area and percentages of each class are found in Table 3.5.

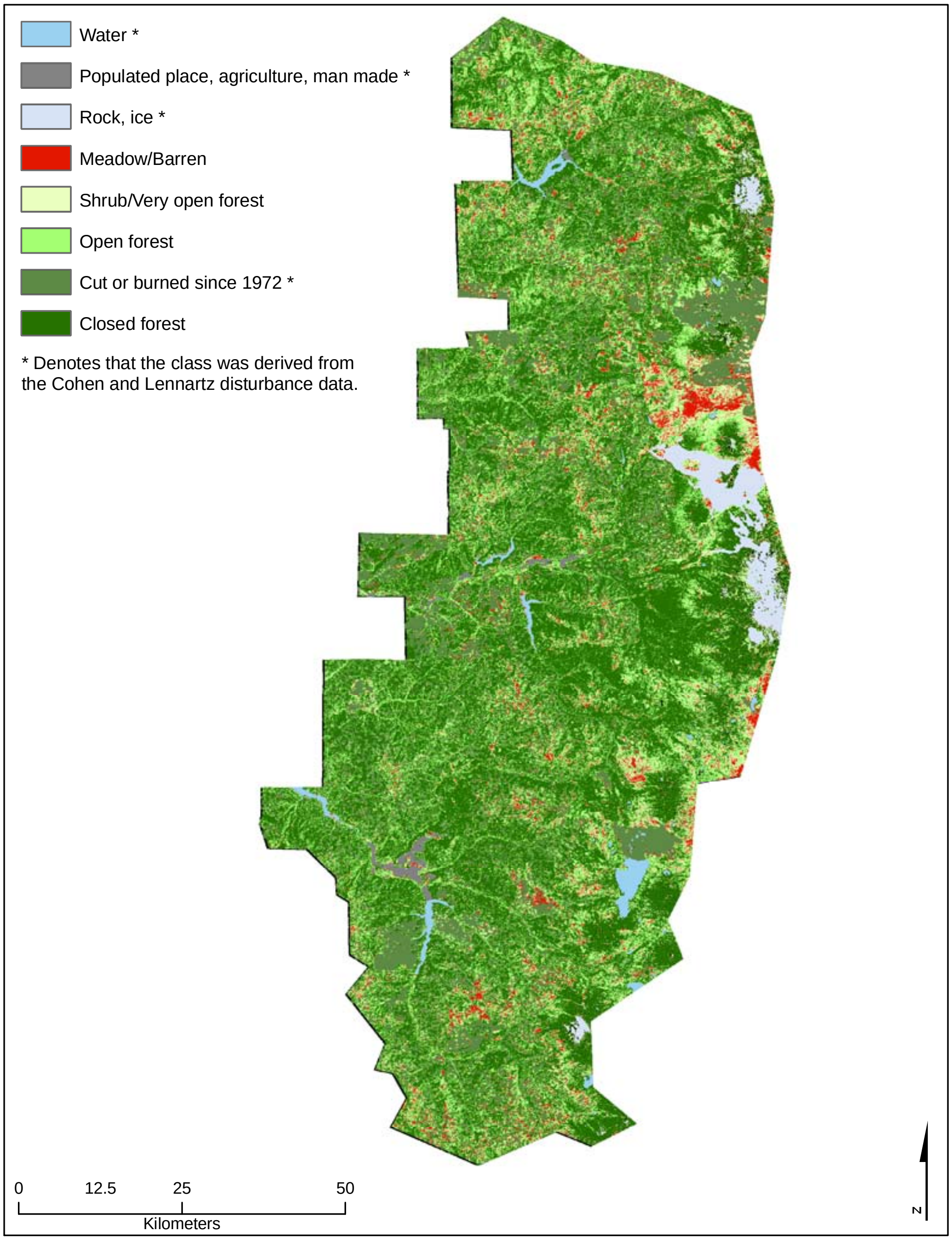


Figure 3.21. Final land cover classification of WNF study area incorporating vegetation classification and Cohen and Lennartz 2004 disturbance data.

Table 3.5. Percent and area of classes in final classification. An * denotes a class derived from the Cohen Lennartz disturbance data (2004), ** denotes that the class was originally derived from Cohen but further defined with photo interpretation.

Class	**Area (km2)**	**% total**
Water *	84.93	1.01
Cut 02-04 *	28.95	0.34
Cut 00-02 *	7.30	0.09
Cut 95-00 *	40.91	0.49
Cut 91-95 *	39.63	0.47
Cut 88-91 *	127.47	1.51
Cut 84-88 *	264.21	3.14
Cut 77-84 *	317.60	3.77
Cut 72-77 *	159.04	1.89
Fire 02-04 *	120.60	1.43
Fire 00-02 *	0.05	0.00
Fire 95-00 *	47.76	0.57
Fire 91-95 *	12.41	0.15
Fire 88-91 *	11.54	0.14
Cut 72-77, Fire 02-04 *	0.03	0.00
Cut 77-84, Fire 02-04 *	0.19	0.00
Cut 84-88, Fire 02-04 *	0.05	0.00
Cut 88-91, Fire 02-04 *	0.03	0.00
Cut 91-95. Fire 02-04 *	0.07	0.00
Cut 95-00, Fire 02-04 *	0.01	0.00
Cut 00-02, Fire 02-04 *	0.02	0.00
Meadow/Barren	394.11	4.68
Shrub/Very open forest	616.98	7.32
Open forest	1826.63	21.68
Closed forest	3987.33	47.33
Agriculture, populated places, man made features **	34.17	0.41
Rock/Ice **	173.45	2.06
Unknown	128.69	1.53

Error

The error matrix and Producer’s and User’s Accuracies (Table 3.6) showed that in total, 177 out of 240 pixels were classified correctly resulting in 74 % overall accuracy. This is the average of the User’s Accuracy. The range of User’s Accuracy results is 53% to 95%. The range of Producer’s Accuracy results is 62% to 91%. The meadow/barren classification produced the highest Producer’s Accuracy result (91%) but lowest User’s Accuracy result (53%) (Table 3.6). Across the vegetation cover spectrum (i.e., with meadow/barren as the lowest and closed forest as the highest) there is a trend of classifying a significant number of pixels as having less cover than indicated by photo interpretation. For example, 42% of pixels classified as meadow/barren were validated with photographic interpretation as the next level of cover: shrub/very open forest. Similarly, 17% of pixels classified as shrub/very open forest class were verified with photographic interpretation as open forest, and 22% of pixels classified as open forest was verified with photographic interpretation as closed forest (Table 3.6).

Table 3.6. Classification validation error matrix and Producer's and User's accuracies. Pixel classification classes are shown in the far left column and photographic validation classes are shown in the top row.

	Meadow/ barren	**Shrub/ very open forest**	**Open forest**	**Closed forest**	**Producer's accuracy**
Meadow/ Barren	32	25	2	1	91%
Shrub/ very open forest	1	44	10	5	62%
Open forest	1	2	44	13	76%
Closed forest	1	0	2	57	75%
User's accuracy	53%	73%	73%	95%	

The Kappa Analysis (Table 3.7) produced two statistical measures of coefficient of agreement. The K_{hat} coefficient of agreement for the overall classification is 65%. The range of the conditional K_{hat} coefficient of agreement is 45% to 93% with the Meadow/Barren class being the lowest.

Table 3.7. Classification Conditional K_{hat} results per class.

Class	**Conditional K_{hat}**
Meadow/barren	45%
Shrub/very open forest	62%
Open forest	65%
Closed forest	93%

The validation of the final classification using the SHABS data was a simple count of how each polygon was classified based on the majority of pixels in the polygon. It included the classes derived from the Cohen and Lennartz 1972-2004 disturbance data. The majority of the SHABS meadow polygons were classified as mostly meadow/barren (48%) followed by mostly clear cut (18%), mostly open forest (16%), and mostly closed forest (6%) (Table 3.8).

Table 3.8. Results of SHABS polygons being attributed with the majority class of the final classification.

Majority Class	**Percent of polygons**
Mostly meadow/barren	48%
Mostly clear cut	18%
Mostly open forest	16%
Mostly closed forest	6%

The accuracy assessment provides sufficient evidence that the classification is satisfactory. Given the coarse resolution and geolocational accuracy of the satellite imagery and the nature of the size, shape, and vegetation cover of meadows, these results are not unexpected. As shown in Figure 3.8, a 30 meter resolution pixel may encompass mixed land cover. Matched filtering assumes a linear combination of spectral signatures from materials and does not account for the three dimensional aspect of these materials and the effect on transmission, absorption, and reflectance if incident radiation which may also impact classification accuracy.

3.4.2 Results of GIS Analysis

The meadow/barren and shrub/very open forest classes occupy a relatively small potion of the landscape (Table 3.9). In both the east and west extents, shrub cover is greater than meadow cover.

Table 3.9. Area and percent of east and west study areas covered by meadow/barren (meadow) and shrub/very open forest (shrub) classes.

	Area (km^2)		Percent of total cover	
	Meadow	Shrub	Meadow	Shrub
West extent	233.5	356.1	4.0	6.1
East extent	160.6	260.9	6.2	10.1

Topographic Position

In the WNF-west extent, areas classified as meadow occurred most frequently on mid slopes (61%), followed by ridges (22%), slopes (15%), and valleys (2%). Meadow occurred more frequently than expected on areas classified as ridgetops, slightly less frequently than expected in valleys and on mid slopes, and much less frequently than expected on toe slopes. (Table 3.10, Figure 3.22).

In the WNF-west extent, meadow is significantly concentrated on ridges relative to the frequency of these hill slope positions in the WNF (Chi-squared = 11.41, 3 df, $p < 0.01$) (Table 3.10).

Table 3.10. Area and percent of WNF and meadow class per topographic position for the WNF-west extent.

Topographic position	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
valley	145.1	5.59	2.5	2.4
toe slope	1382.5	35.61	23.6	15.3
mid slope	3635.3	140.98	62.1	60.6
ridge	687.2	50.45	11.8	21.7

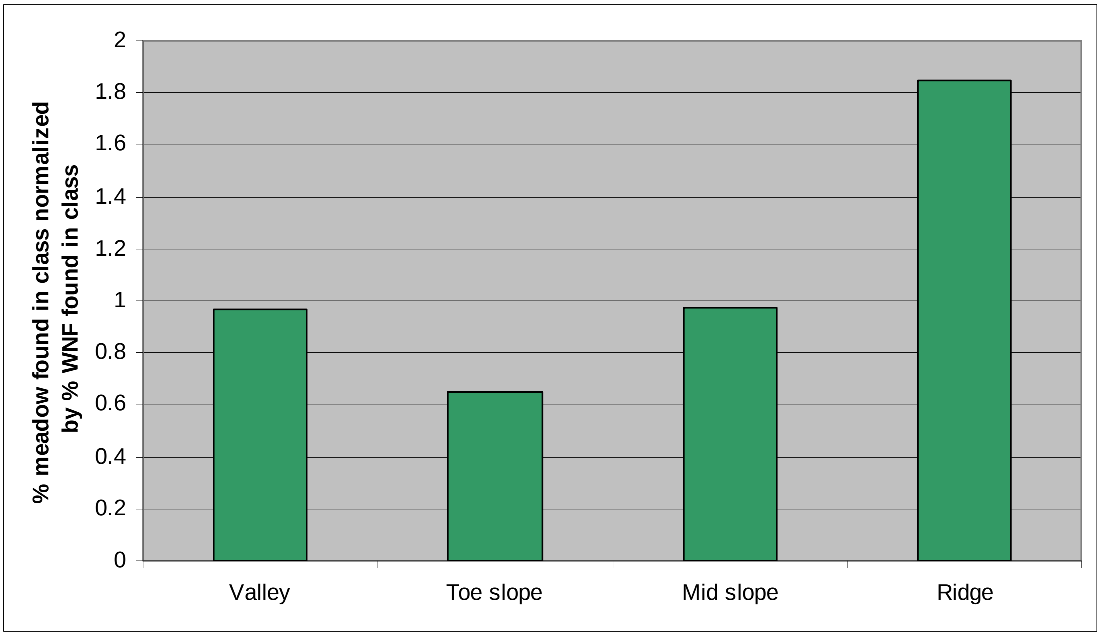


Figure 3.22. Distribution of meadow class by topographic position normalized by distribution of the WNF by topographic position for the WNF-west extent.

In the WNF-east extent, areas classified as meadow occurred most frequently on mid slopes (92%), followed by toe slopes (4%), ridges (3%), and valleys (< 1%). Meadow occurred more frequently than expected on areas classified as valleys, mid slopes and ridges, and less frequently than expected on toe slopes (Table 3.11, Figure 3.23).

In the WNF-east extent, meadow is slightly, but not significantly, concentrated in valleys relative to the frequency of this hill slope position in the WNF (Chi-squared = 0.46, 3 df, p > 0.25) (Table 3.11).

Table 3.11. Area and percent of WNF and meadow class per topographic position for the WNF-east extent.

Topographic position	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
valley	4.6	0.9	0.2	0.2
toe slope	151.1	18.5	5.9	4.4
mid slope	2312.3	382.0	90.6	92.0
ridge	83.1	12.6	3.3	3.0

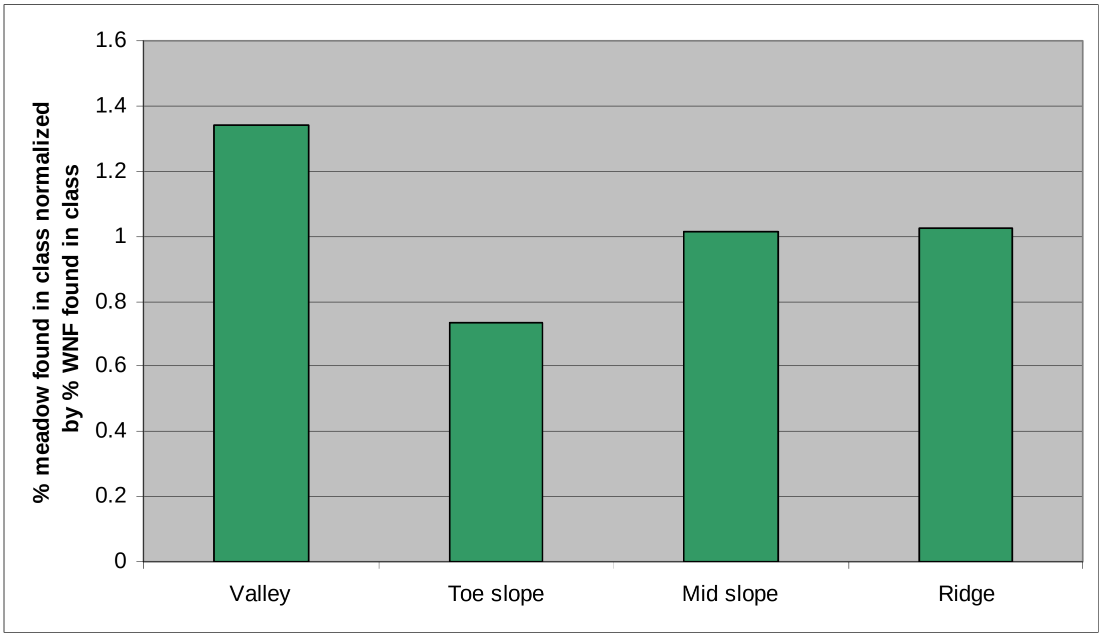


Figure 3.23. Distribution of meadow class by topographic position normalized by distribution of the WNF by topographic position for the WNF-east extent.

Elevation

In the WNF-west extent, areas classified as Meadow occurred most frequently in elevation band 1000-1500 m (56%), followed by elevation band 500-1000m (20%), elevation band 1500-2000m (19%), and elevation band 0-500m (4%). Meadow occurred more frequently than expected in elevation bands 1000-1500m and 1500-2000m, and less frequently than expected in elevation bands 0-500m and 500-1000m (Table 3.12, Figure 3.24).

In the WNF-west extent, Meadow is significantly concentrated in elevation bands 1000-1500m and 1500–2000m relative to the frequency of these elevation bands in the WNF (Chi-squared = 55.28, 3 df, $p < 0.0001$) (Table 3.12).

Table 3.12. Area and percent of WNF and meadow class per 500m elevation band for the WNF-west extent.

Elevation Band	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
0-500m	385.3	10.0	6.6	4.3
500-1000m	2724.7	47.1	46.6	20.2
1000-1500m	2415.8	131.3	41.3	56.2
1500-2000m	325.5	45.1	5.6	19.3

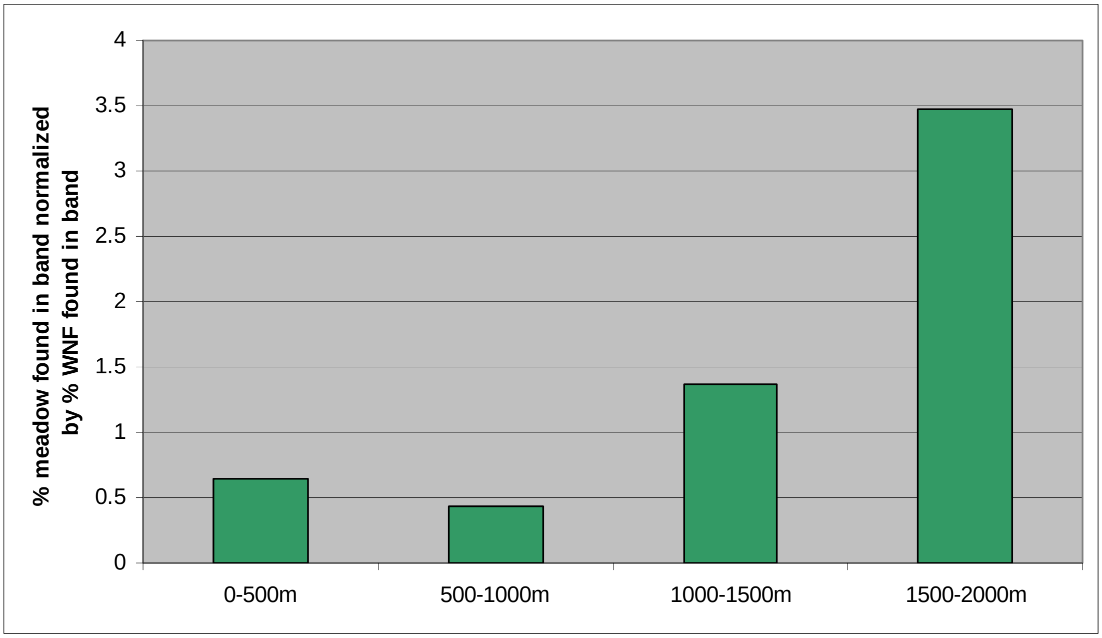


Figure 3.24. Distribution of meadow class by elevation band normalized by distribution of the WNF by elevation band for the WNF-west extent.

In the WNF-east extent, areas classified as Meadow occurred most frequently in elevation band 1000-1500 m (51%), followed by elevation band 500-1000m (44%), elevation band 0-500m (2%), elevation band 1500-2000m (2%), elevation band 2000-2500m (< 1%). Meadow occurred more frequently than expected in elevation band 500-

1000m, and less frequently than expected in elevation bands 0-500m, 1000-1500m, 1500-2000m, and 2000-2500m (Table 3.13, Figure 3.25).

In the WNF-east extent, Meadow is slightly, but not significantly, concentrated in elevation bands 500-1000m relative to the frequency of this elevation band in the WNF (Chi-squared = 4.75, 5 df, p > 0.25) (Table 3.13).

Table 3.13. Area and percent of WNF and meadow class per 500m elevation band for the WNF-east extent.

Elevation Band	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
0-500m	84.2	3.7	3.3	2.3
500-1000m	951.5	71.4	37.0	44.4
1000-1500m	1378.3	82.3	53.6	51.2
1500-2000m	138.7	3.2	5.4	2.0
2000-2500m	19.2	< 1	0.7	< 0.1
2500-3000m	0.9	0.0	0.0	0.0

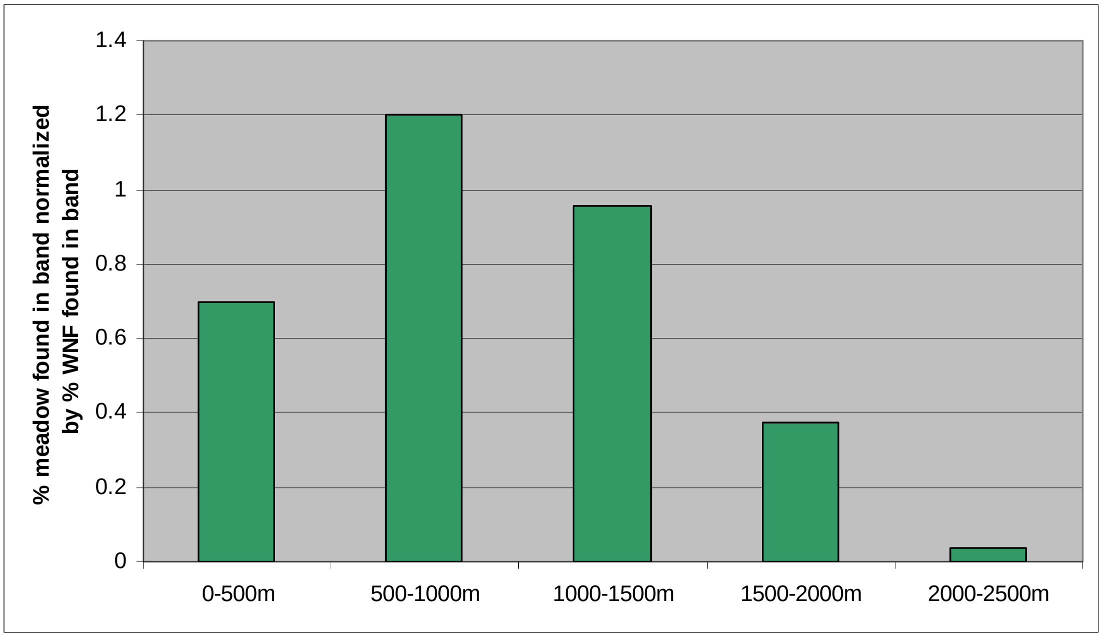


Figure 3.25. Distribution of meadow class by elevation band normalized by distribution of the WNF by elevation band for the WNF-east extent.

Slope

In the WNF-west extent, areas classified as Meadow occurred most frequently on slopes classified as 20-30º (28%) followed by slopes classified as 10-20º (26%), 30-40º (20%), 0-10º (19%), 40-50º (5%), 50-60º (< 1%), 60-70º (< 1%), and 70-80º (< 0.1 %). Meadow occurred more frequently than expected on slopes classified as 30-40º, 40-50º, 60-70º, and 70-80º and less frequently than expected on slopes classified as 0-10º, 10-20º, and 20-30º (Table 3.14, Figure 3.26).

In the WNF-west extent, Meadow is slightly, but not significantly, concentrated on slope classes 30-40º, 40-50º, and 60-70º relative to the frequency of these slope classes in the WNF (Chi-squared = 1.93, 6 df, p > 0.25) (Table 3.14). (The Chi-squared test did not include the slope class 70-80° because fewer than five pixels with this value occurred.)

Table 3.14. Area and percent of WNF and meadow class per degree slope class for the WNF-west extent.

Slope Class	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
0-10	1158.2	112.4	19.8	19.1
10-20	1680.8	151.6	28.7	25.7
20-30	1713.3	168.5	29.3	28.6
30-40	1062.6	121.5	18.2	20.6
40-50	217.4	31.6	3.7	5.4
50-60	17.6	3.6	0.3	0.6
60-70	1.3	0.4	0.0	0.1
70-80	0.08	0.04	0.00	0.01

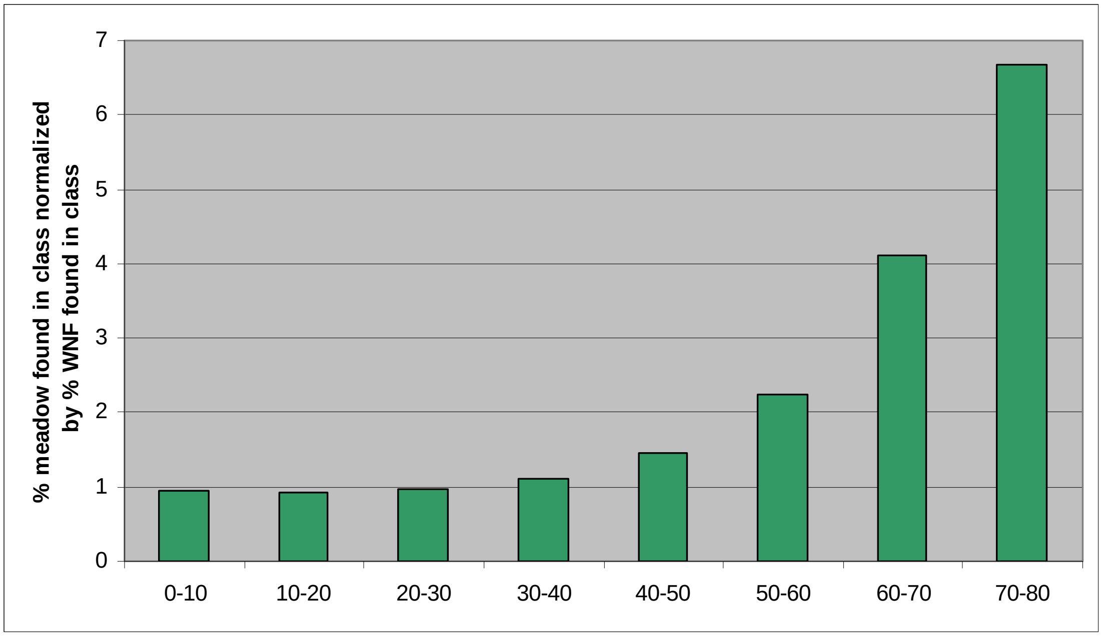


Figure 3.26. Distribution of meadow class by slope in degrees class normalized by distribution of the WNF by slope in degrees class for the WNF-west extent.

In the WNF-east extent, areas classified as Meadow occurred most frequently on slopes classified as 0-10º (68%) followed by slopes classified as 10-20º (18%), 20-30º (9%), 30-40º (4%), 40-50º (<1%), 50-60º (< 1%), 60-70º (<.1%), and 70-80º (<.01%). Meadow occurred more frequently than expected on slopes classified as 0-10º, 30-40º, 40-50º, 50-60º, 60-70º, and 70-80º and less frequently than expected on slopes classified as 10-20º and 20-30º. (Table 3.15, Figure 3.27).

In the WNF-east extent, Meadow is slightly, but not significantly, concentrated on slopes between 0-10º and slopes between 30-90º relative to the frequency of these slope classes in the WNF (Chi-squared = 2.76, 7 df, p > 0.25) (Table 3.15).

Table 3.15. Area and percent of WNF and meadow class per degree slope class for the WNF-east extent.

Slope Class	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
0-10	1560.5	109.1	60.7	67.9
10-20	629.3	28.6	24.5	17.8
20-30	255.2	14.7	9.9	9.2
30-40	103.9	6.6	4.0	4.1
40-50	20.4	1.3	0.8	0.8
50-60	2.9	0.3	0.1	0.2
60-70	0.4	< 0.1	0.0	< 0.1
70-80	0.1	< 0.1	0.0	< 0.1

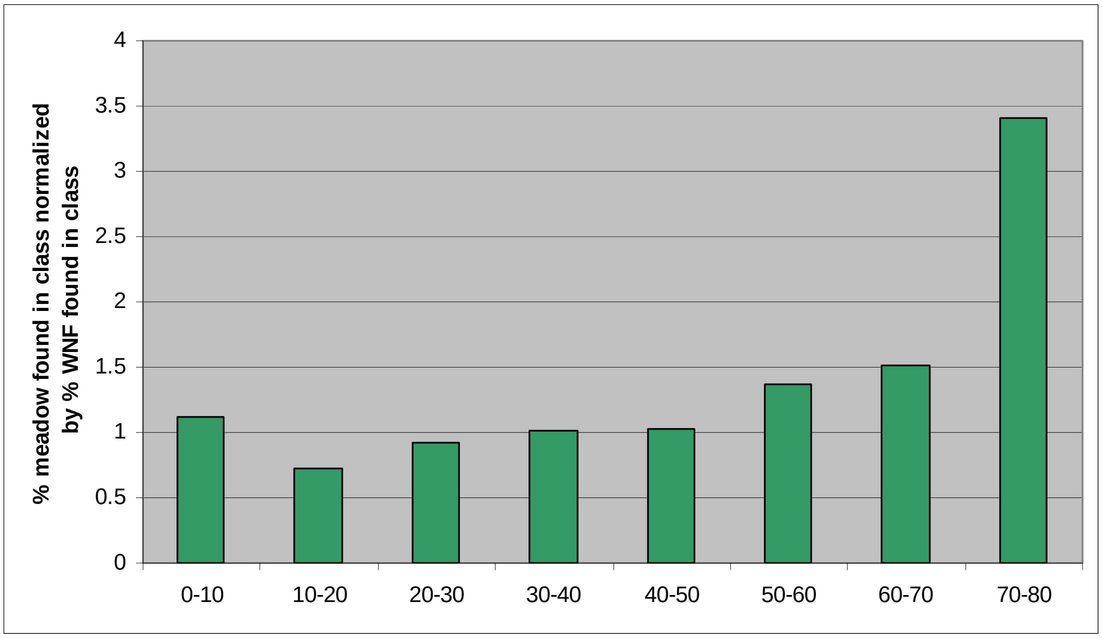


Figure 3.27. Distribution of meadow class by slope in degrees class normalized by distribution of the WNF by slope in degrees class for the WNF-east extent.

Aspect

In the WNF-west extent, areas classified as Meadow occurred most frequently on aspect class SSE (18%) followed by aspect classes ESE (17%), SSW (16%), ENE (14%), NNE (12%), WSW (10%), WNW (7%), and NNW (6%). Meadow occurred more frequently than expected on aspect classes ENE, ESE, SSE, and SSW, and less frequently than expected on aspect classes NNE, WSW, WNW, and NNW (Table 3.16, Figure 3.28).

In the WNF-west extent, Meadow is slightly, but not significantly, concentrated on aspect classes ENE, ESE, SSE, and SSW relative to the frequency of these aspect classes in the WNF (Chi-squared = 13.92, 7 df, $p > 0.05$) (Table 3.16).

Table 3.16. Area and percent of WNF and meadow class per aspect range for the WNF-west extent.

Cardinal Direction	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
NNE	911.1	28.7	15.6	12.3
ENE	661.8	33.2	11.3	14.2
ESE	619.2	38.5	10.6	16.5
SSE	702.0	42.9	12.0	18.4
SSW	819.7	37.3	14.0	16.0
WSW	767.1	22.4	13.1	9.6
WNW	711.2	16.3	12.2	7.0
NNW	659.2	14.2	11.3	6.1

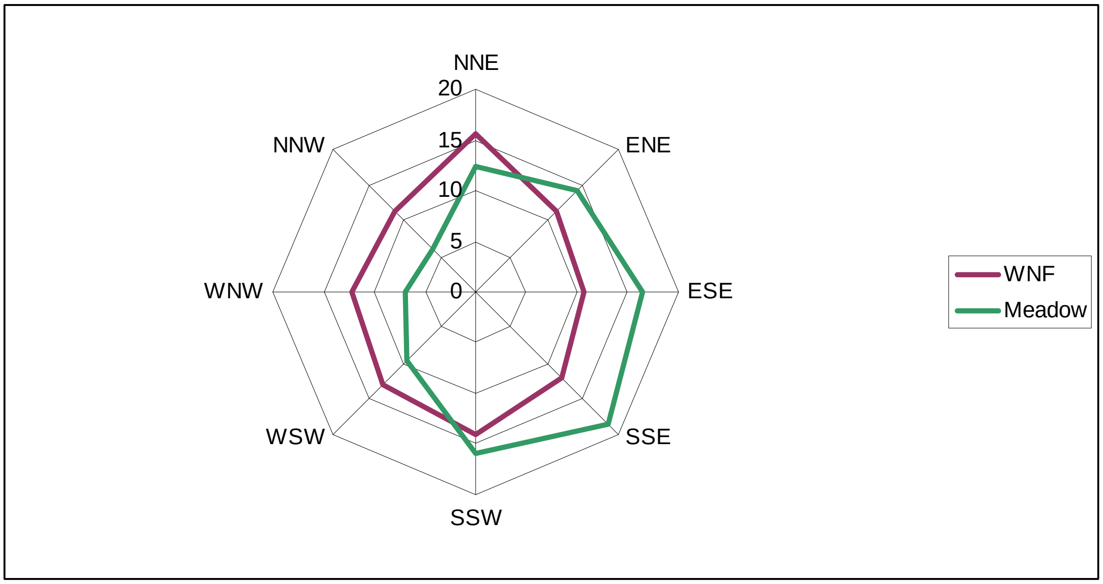


Figure 3.28. Distribution as percent of meadow class by aspect class and distribution as percent of the WNF by aspect class for the WNF-west extent.

In the WNF-east extent, areas classified as Meadow occurred most frequently on aspect class NNE (17%) followed by aspect classes SSW (16%), SSE (14%), WSW

(14%), ESE (13%), ENE (11%), WNW (10%), and NNW (5%). Meadow occurred more frequently than expected on aspect classes ENE, ESE, SSE, and SSW, and less frequently than expected on aspect classes NNE, WSW, WNW, and NNW (Table 3.17, Figure 3.29).

In the WNF-east extent, Meadow is slightly, but not significantly, concentrated on aspect classes ENE, ESE, SSE, and SSW relative to the frequency of these aspect classes in the WNF (Chi-squared = 12.12, 7 df, $p > 0.05$) (Table 3.17).

Table 3.17. Area and percent of WNF and meadow class per aspect range for the WNF-east extent.

Cardinal Direction	Area (km^2)		% of total cover	
	WNF	Meadow	WNF	Meadow
NNE	477.2	27.0	18.5	17.0
ENE	238.3	17.7	9.3	11.0
ESE	204.1	21.3	7.9	13.3
SSE	232.6	22.7	9.0	14.1
SSW	352.3	25.9	13.7	16.1
WSW	419.5	22.3	16.3	13.9
WNW	392.5	15.5	15.3	9.7
NNW	256.3	8.2	10.0	5.1

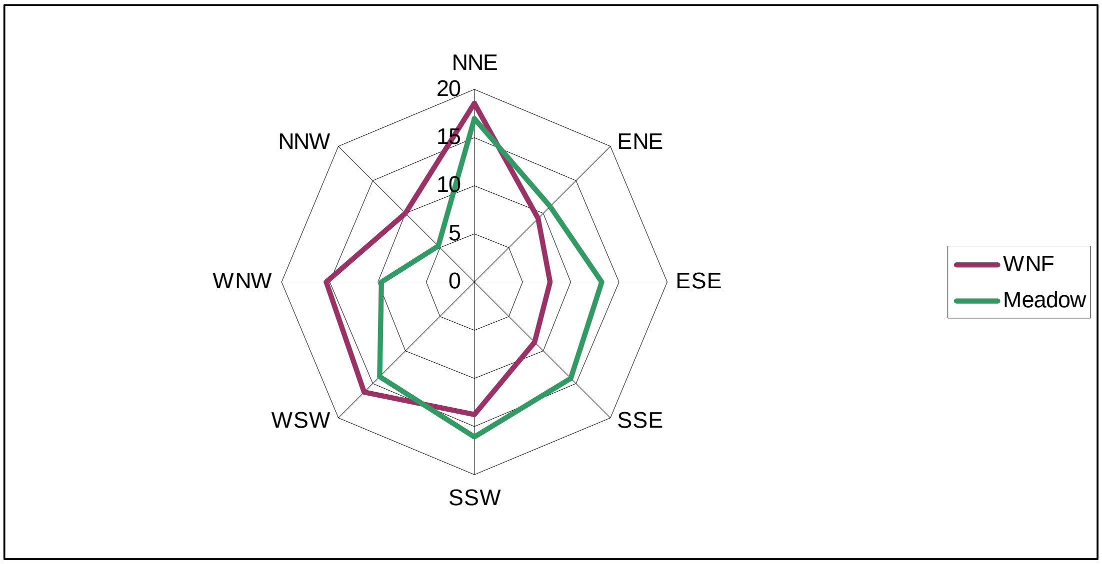


Figure 3.29. Distribution as percent of meadow class by aspect class and distribution as percent of the WNF by aspect class for the WNF-east extent.

3.5 Discussion

Through a combination of satellite remote sensing and GIS, the distribution of meadow cover over the WNF extent and physical geography can be generally identified and correlated. The image processing described in this chapter produced a classification that according to accuracy assessment procedures proves to be reasonably precise and useful to identify meadow land cover. GIS analysis provides the distribution of the meadows per terrain feature classes as modeled from 10 meter DEMs. The resulting data provides a consistent inventory of potential meadow habitats in the WNF appropriate to the scale of the data used in analysis.

The classification, though not grossly incorrect according to validation measures, could be improved by various means. The most dramatic improvement could be made by using a satellite image with finer spatial and spectral resolution. For example, the IKONOS sensor has an improved spatial resolution (0.82 meters at nadir) though its spectral resolution is not a significant improvement over Landsat ETM+. IKONOS also has greater geolocation accuracy than Landsat ETM+. However, the geolocation of the Landsat ETM+ could be improved by registering the imagery with source data with more precise spatial accuracy such as ortho-photos or digital topographic maps. The Hyperion hyperspectral sensor also has almost continuous spectral resolution with up to 220 bands but the same spatial resolution of Landsat ETM+ of 30 meters. Debinski et al. (2000) used 20 meter resolution, three band SPOT imagery to distinguish six different classes of meadows. Further study of the best sensor for differentiating between meadow, shrub, and tree would be useful to improve upon future meadow habitat classifications.

The classification showed a bias towards classifying a cell as less tree or shrub covered than the photo-interpretation revealed. This could be for a number of reasons including the coarse spatial resolution of the satellite imagery making meadow/tree transitions zones hard to define at fine scales. Additionally, the endmembers chosen may not have fully captured the land cover classes they were meant to identify. Endmembers defined on ortho-photographs may have captured Landsat ETM+ pixels that were shifted due to geolocation inaccuracy. Though efforts were made to leave a buffer around the endmember of the same land cover class as the endmember, small meadow and shrub areas sometimes prevented this. Also, the matched filter analysis assumes a linear spectral mixing of cover classes and does not account for the three dimensional effect of incident radiation being absorbed, transmitted, and reflected through multiple layers of vegetation.

The many approaches to remote sensing of vegetation produce varied results. In this chapter, the focus on identifying a small subset of cover classes translated into using an equally small number of spectral endmembers. For this reason, land cover types not included in the endmembers were often not classified or misclassified (i.e. water, rock, and ice). The 1988 Western Oregon Vegetation Classification was produced to target closed forest and did not capture meadows, though its overall accuracy (82%) was still acceptable (Cohen et al. 1995). Approaches other than those used in this chapter will produce different and potentially more accurate results and should be considered for future analysis. Examples of different techniques include combining a satellite image with LiDAR data (Light Detection and Ranging) to differentiate the texture of the vegetation cover. Another would be to use a software program, such as Ecognition, to generate habitat polygons using satellite images, aerial photographs, and texture derived from DEMs or LiDAR. Though many methods exist, cost and computing power may make them prohibitive. The technique described in this chapter produced an acceptable result at little cost with only moderate computing needs.

The GIS analysis used relatively coarse (10 meter) DEMs to model terrain features in order to determine the pattern, if any, of meadow distribution over those physical features. The results provided only two instances where the statistical measure of significance proved marked. In the WNF-west extent, meadow is significantly concentrated on ridges relative to the frequency of this hill slope position in the WNF (Chi-squared = 11.41, 3 df, $p < 0.01$). Also in the WNF-west extent, meadow is significantly concentrated in elevation bands 1000-1500m and 1500–2000m relative to the frequency of these elevation bands in the WNF (Chi-squared = 55.28, 3 df, $p < 0.0001$). Though the p-value is just below the threshold for significance, meadow in the WNF-west extent is concentrated on south and east facing aspects relative to the frequency of these aspect classes in the WNF (Chi-squared = 13.92, 7 df, $p = 0.0525$). Overall, meadows in the western extent are concentrated on ridges, between 1000-2000m elevation, on increasingly steep slopes, and on east and south facing slopes relative to the frequency of the physical features in that extent (Figures 3.22, 3.24, 3.26, and 3.28). Meadows in the eastern extent are concentrated in valleys, between 500-1000m elevation, on both gentle slopes and then after a threshold increasingly steep slopes, and on east and south facing slopes relative to the frequency of the physical features in that extent (Figures 3.23, 3.25, 3.27, and 3.29).

The occurrence of meadows is expected to be mostly on steep south facing slopes in the montane areas and on gentle slopes and ridges in the subalpine areas (Miller and Halpern, 1998). In both the west and east extents of the WNF, meadows occurred mostly on the mid-slope position (61% and 92% respectively) (Tables 3.10 and 3.11). Mid-slope is however a variable designation based on the inputs of the Zimmerman aml used (2000) and may capture ridge areas. Examination of Figure 3.16 shows the Grasshopper meadow extent by topographic position. Based on field observation and photographic interpretation, the mid-slope designation is considered adequate to capture the slopes transitioning from ridge lines to mid-slope and mid-slopes. More complex topographic modeling could result in refined meadow distribution results. Herzfeld and Higginson (1996) developed a method of geostatistical classification based on directional variograms that quantifies morphologic properties of the seafloor. This method could be applied to terrestrial topography to “characterize complex topographic features quantitatively” (Herzfeld and Higginson, 1996). It is unexpected that the WNF-east extent has a lower percentage of meadows on the ridge position compared to the WNF-west extent because the east extent contains more subalpine areas where meadows occur on ridges. The occurrence of most (75%) of the WNF-west meadows on slopes between 10-40% is expected (Table 3.14) as is the occurrence of WNF-east meadows to be predominantly (68%) on more gentle 0-10% slopes (Table 3.15). Expectedly, a majority (65%) of the WNF-west meadows is on slopes facing ESE, SSE, SSW, and WSW (Table 3.16) but the WNF-east meadows are almost evenly distributed across aspects with 46% on NNE, ENE, WNW, and NNW slopes (Table 3.17).

The distribution of meadows in relation to slope, aspect, and topographic position may be confounded by the vegetation classification’s inability to distinguish between regenerating clear-cuts, burns, and talus slopes from meadow openings. The disturbance data only tracks clear-cuts between 1972 and 2004 and does not capture partial cuts or older clear-cuts. It is possible some clear cuts older than 1972 could be so slow to regenerate that they appear similar to meadows spectrally. Partial cuts and talus slopes may also appear similar to meadows spectrally. If a significant number of pre-1972 clear-cuts, partial cuts, and talus slopes are classified as meadows, meadow distribution calculations may be skewed and not reflect a statistically significant concentration of meadows on steep south facing slopes and ridges.

Further analysis distinguishing meadow type could provide valuable added information. If moisture regimes and general vegetative classes were identified, and the analysis performed on each distinct meadow type separately, a correlation to physical features could have been identified statistically. Moisture regimes can potentially be modeled by investigating soils, terrain concavity and convexity, or through other remote sensing methods such as seasonal change detection (Debinksi et al, 2000). In addition, incident solar radiation modeling could help predict dry areas. This extent of further analysis was, however, not in the scope of this project.

Overall, some patterns of meadow distribution have been identified and could be refined through additional analysis. Improved classification can be obtained through using more spectrally and spatially precise satellite imagery and incorporation of LiDAR and remote sensing methods that better capture the spectral and textural differences in montane vegetation. The same GIS analysis could be applied to the improved classification to reveal refined distribution patterns.

4 Change in the Chucksney-Grasshopper Meadow Complex, 1947-2005

4.1 Introduction and Objectives

The objective of this analysis was to quantify change in meadow extent and factors associated with tree encroachment from 1947 to 2005 in the Chucksney-Grasshopper meadow complex (122º 9’ 39” W, 43º 54’ 19” N), using historical aerial photographs and GIS. By detecting patterns of invasion and their relationship to slope, aspect, and proximity to trees, meadows could be classified by risk factors for invasion and priority ranked for restoration and maintenance activities.

4.2 Study Area

The Chucksney Mountain-Grasshopper Ridge meadow complex is contained by the Chucksney Mountain roadless area and comprised of approximately 8 distinct meadows located 27 kilometers northeast of Oakridge in the WNF (Salix, 2005). (See Figure 4.1). (Meadow designations 1 though 8 are adopted from Salix Associates (2005).) Meadow study areas 1 through 6 ranged from as little as 2.5 to as much as 119 ha in 1947 (Table 4.1). Meadow study areas 7 and 8 were together approximately 54 ha in 1972 (Table 4.1). The meadows occur on N, S, E and W oriented slopes near the ridgeline between Chucksney and Grasshopper Mountains. Elevation ranges from about 975 to 1768 meters (WNF, 2006).

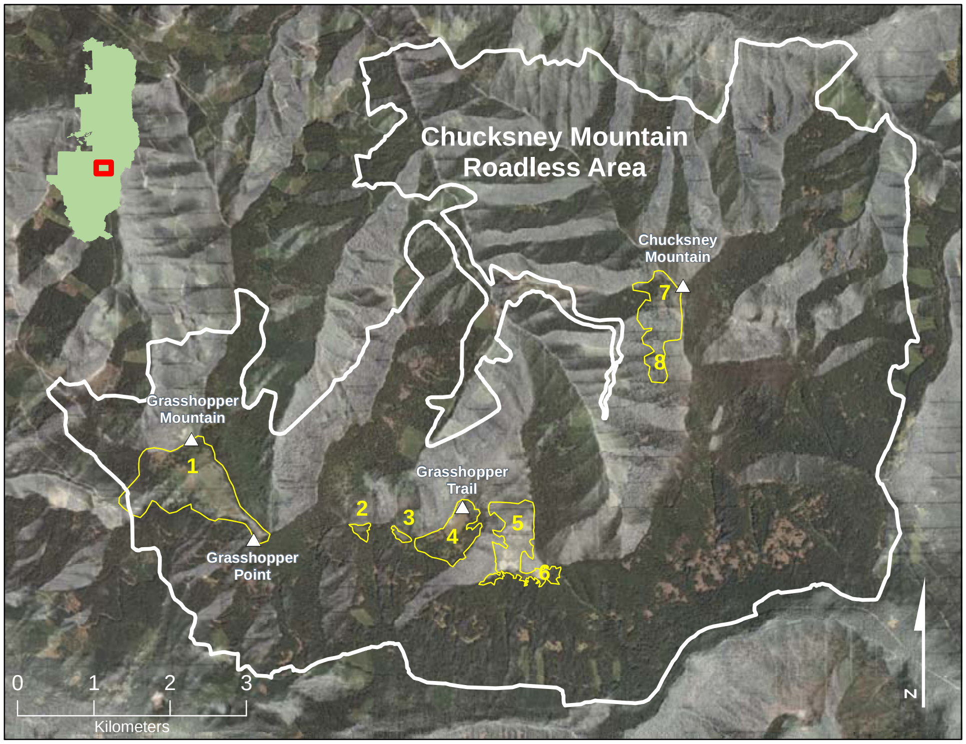


Figure 4.1. Location of the Chucksney – Grasshopper complex within the Chucksney Mountain Roadless Area.

Table 4.1. Approximate bounding coordinates and area of Meadows 1 through 6 in 1947 and Meadows 7 and 8 in 1972. Coordinate system: UTM, NAD83, Zone 10, meters.

Meadow	Min. x coordinate	Min. y coordinate	Max. x coordinate	Max. y coordinate	Area (ha)
1	563573	4860773	565556	4862184	118.99
2	566594	4860790	566875	4861042	3.63
3	567117	4860753	567455	4861021	2.53
4	567454	4860468	568340	4861350	37.76
5 & 6	568283	4860150	569304	4861370	58.60
7& 8	570311	4862877	570962	4864349	54.14

4.2.1 Geology

The geology of the study area reflects the volcanic and erosional history of the western Cascade Range. Most of the complex lies upon ridge-capping basalt and basaltic andesite of the Pliocene and upper Miocene. Meadow 1 has a small area of upper and middle Miocene basaltic and andesite rock as well (Figure 4.2) (WNF-GIS, 1991). The landscape is steep and well dissected.

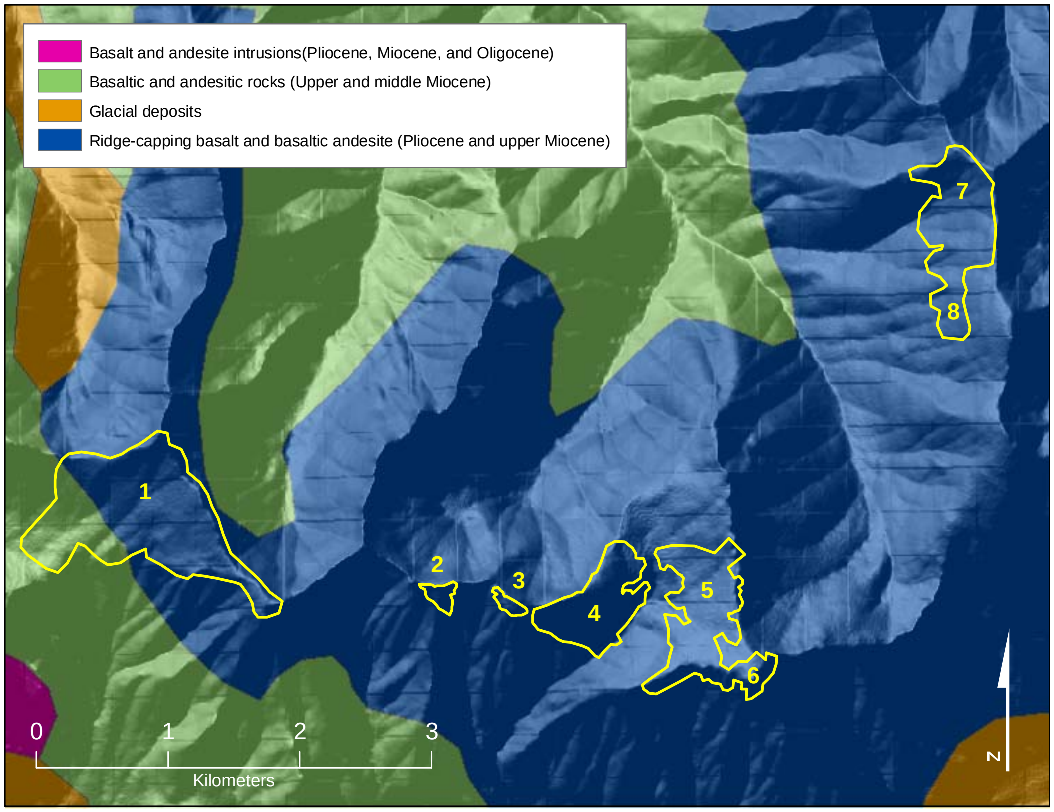


Figure 4.2. Geology of the Chucksney-Grasshopper meadow complex.

4.2.2 Climate

The climate is a marine west coast climate characteristic of the western Cascade Range, but no climate stations occur at the study site. According to precipitation and temperature information modeled using data from monitoring stations throughout the western Cascade Range over the period 1971 and 2000 by the PRISM Group at Oregon State University, the complex receives an average of 1,700 mm of rainfall per year. The majority of precipitation falls between the months of November and April with a total average of about 1248 mm. Only about 432 mm of precipitation occur from May through October. The minimum average daily temperature for the month of January is approximately -3.5 ºC with a range of -5.1 to -1.2 ºC and the mean average maximum daily temperature during the month of July is approximately 22.6 ºC with a range of about 19.2 to 27.1 ºC.

4.2.3 Soils

Soils in the study area are formed on igneous and pyroclastic parent materials. Meadows 1, 2, and 3 contain a soil unit that is shallow to moderately deep with less than 30% rock outcrop. (Rock outcrops were not observed in the field and can not be detected in the aerial photographs.) Meadows 4 and 6 include the same soil unit of Meadows 1-3, but also a unit of rock outcrop and talus with highly variable depth and moisture content. An area of rock outcrop outside the western boundary of Meadow 4 was observed in the field and through aerial photograph interpretation appears to be approximately 0.7 ha in size. Meadows 7 and 8 are comprised of this latter type of soil unit. (Rock outcrops were not observed in the field and can not be detected in the aerial photographs.) . Meadow 5 is almost entirely comprised of shallow to moderately deep sandy loams and loams with bedrock usually within 3-6 feet (WNF-GIS, 1992).

4.2.4 Rivers/Basins

The meadow complex lies within the Middle Fork Willamette and McKenzie sub-basins (Figure 4.3). Meadow 1 straddles the ridge between Upper Christy Creek and North Fork of the Middle Fork Willamette River – Devils Canyon sub-watersheds. Meadows 2-6 drain into the Fisher Creek sub-watershed of the North Fork of the Middle Fork Willamette River, and Meadows 7 and 8 drain into the Augusta Creek sub-watershed of the South Fork McKenzie River (OR GeoSpatial – GIS, 2001).

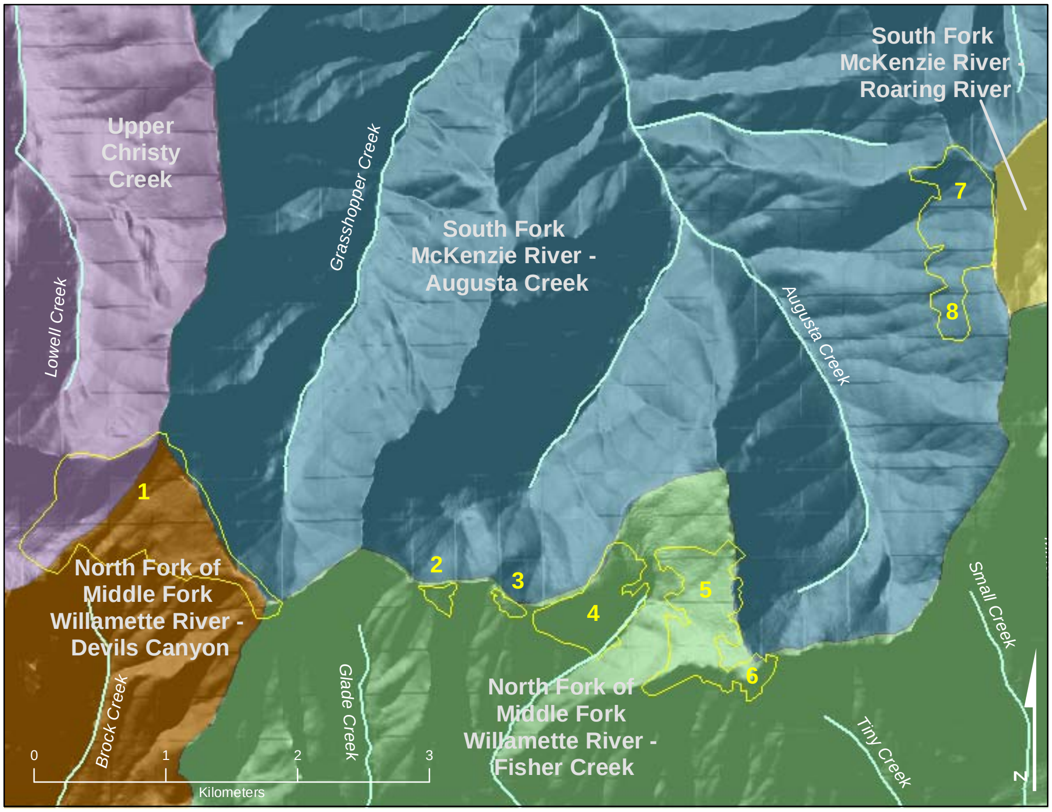


Figure 4.3. Sub-watersheds of the Chucksney-Grasshopper meadow complex area.

4.2.5 Vegetation

The meadows within the complex support a mixture of dry and mesic plant communities for the most part. Meadow 1 has a wide variety of cover from open and rocky, to dry grass and sedge dominated, to wetter forbs, and a fen. Meadow 2 consists of dry and mesic plant communities with a small rock garden on the east side. Meadow 3 is mostly a dry meadow with distantly spaced conifers and a rock garden community in the southwest. A complex of dry meadow, mesic forest-meadow, and rock garden community describes the cover of Meadow 4. Meadow 5 is a mixture of dry meadow and open conifer forest. Dry meadows, rock gardens, and forest opening constitute Meadow 6. Meadow 7 is a dry meadow. Meadow 8 is a combination of dry and mesic meadows, shrub, and rock garden (Salix, 2005).

4.2.6 Fauna

Meadow habitat supports a variety of wildlife and insect species. Salix Associates (2005) informally recorded sightings of wildlife in the meadow complex in 2004. They noted sightings of or signs of black bear, black-tailed deer, cougar, Roosevelt elk, Douglas' squirrel, mountain beaver, snowshoe hare, and Townsend's chipmunk. They also noted bird sightings in Meadow 1: violet-green swallow, western tanager, white-crowned sparrow, Wilson's warbler, winter wren, and yellow-rumped warbler. In addition, 31 species of common butterflies were identified (Salix, 2005).

4.2.7 Land Use and Management History

The meadow complex has a long history of use by humans. Artifacts such as obsidian flints, trails, and rock cairns used for vision quests give evidence for use by Native Americans. More recent evidence of historical use by white settlers is found as shepherds' cabins, livestock trails, and old bottles and cans. The area was used for sheep grazing until 1939 and cattle grazing until 1968 (Matarrese, 1992). Large erosion ditches caused by livestock travel were observed in the field at Meadow 4 and Meadow 1.

Historic management has primarily focused on maintaining forage for large game and recreational opportunities. Two primary methods were used for this purpose: mechanical cutting and prescribed fire. USFS records pertaining to the Chucksney roadless area dating back to 1964 were reviewed and the documented management actions and assessments are described below in chronological order.

In 1964, the Chucksney Mountain Cattle allotment located at T19S R5E, sections 24 and 25 and T19S R5½E, sections 20, 21, 28, and 29, totaling 87 acres, was mechanically treated to remove encroaching conifers. This area is coincident with the extent of Meadow 4. Encroachment was estimated to be from 0 to 1000 stems per acre. Slash was left on the ground with some of it placed in an erosion gully caused by livestock to stabilize the soil. The gully was measured at 2-3 feet wide by 800 feet long (US Government, 1964). A 1965 District Ranger memo noted that the slash in the gullies seemed to have stabilized the soil. Also, the herbaceous vegetation under the felled trees throughout the meadow seemed to be “more advanced and succulent” than vegetation found elsewhere (USFS, 1964).

The 1979 Chucksney Mountain Roadless Recreation management plan describes the conditions and management of the meadow complex. In 1979, approximately 600 of the 9500 acres of the area were covered by meadow. However, 450 acres were covered by lodgepole pine that had invaded since the late 1800s (USFS, 1981). It was suggested that the entire area would be 100% timber cover were it not for the past fire occurrences. An addendum to the wildlife management plan describes the first recorded prescribed fire being used in the meadow complex: a helicopter burn occurring on 12/21/1981 on the Shepherd’s Paradise and Middle Prairie (Meadow 5) meadows. (The Shepherd’s Paradise meadow appears to be almost entirely lost to conifer encroachment and is not in the Salix inventory or the scope of this chapter.) These burns were considered unsuccessful due to the excessive moisture at the time. It was suggested that the Shepherd’s Paradise meadow be mechanically cut in strips 15 feet wide spaced 25 feet apart and then burned the following year. It was proposed that the Middle Prairie meadow be 100% mechanically cut. No records were found to indicate if the proposed treatments were done. However, records indicate that Shepherd’s Paradise was being encroached by lodgepole pine, some infected with western gall rust (*Peridermium harknessii).* Middle Prairie was host to a much more varied set of invaders including lodgepole pine, mountain hemlock, western hemlock, subalpine fir, noble fir, pacific silver fir, and white pine (USFS, 1981). The management plan discusses seeding the meadows after prescribed burns. It was indicated that native species should be given priority but does not rule out the use of non-native species (USFS, 1981).

Management goals of the meadow complex remained essentially the same under the 1994 Northwest Forest Plan Management Act (Matarrese, 1992). Recreation and wildlife were primary management objectives with a bit less emphasis on game hunting. Specifically, the goals were “to provide for the conservation of unique geographic and topographic features and biological and ecological processes, as well as significant scenic, wildlife and recreation values" (Matarrese, 1992). The desired future condition goals included isolation from the sights and sounds of human activity and habitat for a wide range of plant and animal species. Matarrese (1992) proposed that without management through fire and/or mechanical cutting, meadows would be lost to conifer encroachment within 30 to 50 years and habitat for most species, with the exception of owls and small mammals, would be eliminated.

The Chucksney meadows located at T19S R5½E sections 10 and 15 (Meadows 7 and 8) were intentionally burned in September of 1994. The meadows were described as having lodgepole pine and true fir seedlings encroaching from the edges. The size of the burn was described in various documents as either 60 or 100 acres. Meadows 7 and 8 are a Heritage resource site containing a historic cabin and rock cairns used for Native American vision quests.

The West Middle Prairie meadow (Meadow 4) located at T19S R5½E section 20 had 80 acres broadcast burned on October 9, 1996. An unpublished document, Chucksney Mountain Meadow Restoration (Ford et al., 1998), describes the post-fire conditions of this meadow. Species targeted in this burn were lodgepole pine and grand fir. Mortality was about 73% for trees varying with diameter - the larger the tree, the greater the mortality rate. Average mortality for seedlings was approximately 66% and was greater for the taller stems. Mortality also depended on site-specific conditions. The herbaceous species occurring in or near the tree island areas were replaced by fire pioneer species.

Soil productivity appeared to be enhanced by fire as evidenced by the lush vegetation in burned areas. The Ford report suggested that prescribed burns every 5-20 years would maintain the meadows.

The Grasshopper/Chucksney Meadow Complex Field Reconnaissance report (Seitz and Martinez, 2003) briefly describes the condition of several meadows within the complex. Grasshopper meadow (Meadow 1) had 12 to 15-year old conifers encroaching from the edges and exhibited gopher activity. All meadows showed signs of encroachment and the West Middle Prairie (Meadow 4) showed lodgepole pine growth that appeared to have been stimulated by the 1996 burn.

A 2006 USFS memo titled Chucksney and Grasshopper Meadow Restoration Project proposed restoring meadow habitats where “the natural disturbance mechanism, fire, has been excluded”. The project area included 280 acres in Meadows 1, 7, and 8. Methods suggested included girdling and cutting small trees and leaving slash on site in the summer of 2006 followed by a burn in the fall of 2007. Mortality rates were targeted at 10-20%. Native seeds were to be collected before the burn for seeding post-burn. These actions were carried out and completed in October 2007.

Meadow 1 was burned October 2, 2007. Figures 4.4 though 4.7 provide photographic evidence of the post-fire condition. Some of the tree islands remained unburned and the fire was patchy in herbaceous areas as well. The fire burned the trees that were felled in

2006 and uncovered the historic grazing ditches previously hidden by vegetative cover. Seeding occurred on October 10, 2007 using stock gathered in the area prior to the burn. Seeding was focused on the areas that burned the hottest and had greater potential for seed bank loss.

Figure 4.4. Photograph of the Grasshopper Meadow (Meadow 1) after the fall 2007 burn. (Photo courtesy Sam Swetland, USFS.)

Figure 4.5. Photograph of historic grazing trenches that were revealed in Meadow 1 when 2007 fire removed vegetative cover. (Photo courtesy Sam Swetland, USFS.)

Figure 4.6. Photograph of trees in Meadow 1 that were felled in 2006 and burned in 2007. (Photo courtesy Sam Swetland, USFS.)

Figure 4.7. Photograph of patchy 2007 burn in Meadow 1 with historic water trough at center. (Photo courtesy Sam Swetland, USFS.)

4.2.8 Current Land Use

The Chucksney and Grasshopper meadows complex is subject to the WNF Land and Resource Management Plan. The study area lies within an area designated as Dispersed Recreation Semi-Private Non-motorized Use. It is actively managed for recreation and wildlife by the McKenzie and Middle Fork Ranger Districts (WNF, 2006). Meadow restoration and maintenance are high priority and activity is as recent as October 2007 as described in section 4.1.7.

4.3 Methods

4.3.1 Data Description

Historical aerial photographs for the years 1947 and 1972 were obtained from the University of Oregon Knight Library. These photographs were scanned at 1200 dpi and 24-bit color and saved in TIFF format. The Grasshopper Ridge meadows 1 through 6 are covered in the 1947 and 1972 photos. However, the Chucksney Mountain meadows 7 and 8 are not covered by the 1947 photos and the eastern edge of Meadow 8 is marginally cut off by the extent of the 1972 photo. No other photos of comparable years available at Knight Library covered the Chucksney Mountain meadows. The 2005 NAIP aerial photographs described in Chapter 3 were used to determine current meadow extent.

4.3.2 Image Processing

Geo-referencing

The historic photographs were processed to convert them into the UTM Zone 10 Datum NAD 83 coordinate system. Subsets of the scanned images were selected to include only the extent of the meadows being studied. These subsets were geo-referenced in ArcGIS using first order polynomial transformation using the ortho-rectified 2005 NAIP photographs to identify control points and coordinates. Georeferencing RMS errors ranged from 4 to 16 meters (Table 4.2).

Table 4.2. Geo-referencing RMS errors in meters by photo year and meadow designation.

Meadow	**Year 1947**	**Year 1972**
1	12.29	4.19
2	5.56	4.64
3	4.37	5.93
4	7.40	15.57
5 & 6	7.24	4.75
7 & 8	n/a	13.05

Classification

Each photograph was analyzed to determine the land cover per cell. An unsupervised ISODATA classification was performed in ENVI to extract two land cover classes: tree or non-tree, based on brightness values of grey scale images for the 1947 photographs and RGB images for the 1972 and 2005 photographs. The classification resulted in rasterized binary images for which each cell had a value of 1 for meadow cover or 0 for tree cover. These binary images were then used in subsequent GIS analysis.

4.3.3 GIS Analysis

Encroachment Modeling

GIS analysis was used to detect the change in meadow extent over time. The 1947 meadow study area extent was designated as the base extent and the geo-referenced 1947 photographs were used to visually determine the boundaries of Meadows 1-6. Because 1947 photographs were not available for Meadows 7 and 8, 1972 photographs were used to determine the boundaries of the base extent for those meadow study areas.

The base meadow extents were used to create an analysis extent. Polygons were drawn around meadows using the historic photographs. The polygons were then converted to rasters in ArcInfo. These extent rasters were used to subset the cells of the binary rasters described in section 4.3.2.

Land cover analysis was used to create an encroachment classification. Encroachment per cell was determined by combining the classification results of the historic and 2005 photos. The rasters were attributed so that a value of zero indicated tree cover and a value one indicated herbaceous or shrub cover. The rasters were combined in ArcInfo GRID and reclassified to indicate if an area that was previously meadow had changed to tree in subsequent classifications.

Due to the differing spatial resolution and georeferencing accuracy between years, the GIS analysis produced a seemingly contradictory sequence of values for some cells. For example, a cell may have been classified as tree in 1947, then meadow in 1972 though no efforts had been made to eradicate trees between those years. Decision rules were made in order to produce a consistent encroachment status. It was assumed the 2005 photograph is the most accurate and if the 2005 classification was meadow and a previous classification was tree, the spatial accuracy limitations of the previous classifications resulted in an incorrect result. Though Takaoka and Swanson (2006) determined that some meadows expand, visual inspection of several examples of such incongruous classification sequences show that it is more likely the different registration of the photographs. The actual breakdown of possible combinations and final encroachment classification are found below (Tables 4.3 and 4.4).

Table 4.3. Possible encroachment class combinations and outcomes for Meadows 1-6.

1947	1972	2005	Final code	Description
0	0	0	0	Always tree
1	0	0	1	Encroached
0	1	0	0	Always tree
0	0	1	2	Always meadow
1	1	0	1	Encroached
0	1	1	2	Always meadow
1	1	1	2	Always meadow
1	0	1	2	Always meadow
1	1	0	1	Encroached

Table 4.4. Possible encroachment class combinations and outcomes for Meadows 7-8.

1972	2005	Final Code	Description
0	0	0	Always tree
1	0	1	Encroached
0	1	2	Always meadow
1	1	2	Always meadow

For each meadow a raster was created with a value of zero for always in tree cover from the year the oldest photo was available, a value of 1 for encroachment occurring, and a value of 2 for always in meadow cover from the year of the oldest photo available.

Distance to Tree

Distance to tree was modeled using a Euclidian Distance function in ArcGIS. It was used to determine the distance of the center of each cell in the meadow extent to the nearest cell classified as tree using the oldest historic photograph available (1947 for all meadows except 7 and 8, whose earliest date was 1972). The Euclidian Distance output raster was designated with a one meter cell size. However, the resolution and geo-referenced accuracy of the oldest photographs may lend to inaccuracies in the classification and distort true distance to edge values. The distance to edge raster was combined in ArcInfo GRID with the encroachment classification raster. The distance from each cell classified as encroached to the nearest cell classified as tree (using the oldest photograph available) could then be measured. Distance categories were determined by applying a Jenks natural breaks function to Meadow 1 (0-5m, 5-20m, 20-40m, and 40-76m). The natural breaks for Meadow 1 were then applied to the remaining meadows.

Slope

Degree of slope data derived previously from 10 meter DEMs and described in Chapter 3 was used to characterize the meadows further. The degree of slope raster was combined with the distance to edge and encroachment classification raster in ArcInfo GRID. The range of slope for all the meadows was 0 to 77 degrees and categories were based on three virtually equal intervals (0-25º, 25-50º, and 50-77º).

Aspect

The aspect data, derived from the 10 meter DEMS and described in Chapter 3, were used in the encroachment analysis. It was combined with the slope, distance to edge, and encroachment classification rasters in ArcInfo GRID to create the final encroachment analysis raster dataset. Aspect values were divided into 4 categories reflecting four quadrants of a compass (0-90º, 90-180º, 180-270º, and 270-360º).

Chi-squared statistics were calculated to compare the percentage of each meadow's percent encroachment per respective category to the total area of each meadow per category. If fewer than 8 cells in the data fell into one of the categories described above, that category was not used in analysis. If only one category remained when those with too few cells were removed, a Chi-squared value was not calculated for that meadow because it requires at least one degree of freedom. Meadow 2 and 3 were not analyzed in the distance-to-tree section because too few cells fell in three categories for each meadow. Meadow 3 was also not analyzed in the slope section due to too few cells occurring in two categories. All the meadows contained sufficient cells in at least two aspect categories and were therefore all included in this analysis.

4.4 Results

4.4.1 Results of Image Processing

Percent Cover

The results of the photo classification method are consistent with visual inspection of the photographs. Between 1947 and 1972, treeless area decrease was relatively little except in Meadow 4, where approximately 33% of meadow area was encroached by trees. Between 1972 and 2005, trees encroached into meadow as little as 6% (Meadow 4) to as much as 56% (Meadows 5 and 6) (Table 4.5). Relative to the 1947-1972 period, encroachment rates in 1972-2005 accelerated in all meadows except Meadow 4, where encroachment declined, and Meadow 2 which saw a 6% increase in meadow cover that was probably due to geo-rectification error and misclassification of shade as tree.

Table 4.5. Beginning area, percent loss, and change in area of herbaceous cover per meadow per year.

	1947	1972		2005	
Meadow	Starting ha	% loss	Change in ha	% loss	Change in ha
1	69.58	-1.7	-1.2	-8.8	- 6.0
2	1.7	0	no change	+5.9	+ 0.1
3	1.4	+0.7	+ < 0.01	-7.1	- 0.1
4	21.2	-33.0	-7	-6.3	- 0.9
5 & 6	28.61	-6.3	-1.8	-55.6	-14.9
7& 8	n/a	n/a	(starting) 17.30	-23.1	- 4.0

Pattern

Encroachment occurred to varying degrees in each meadow. The encroachment in Meadow 1 occurs mostly in the western area with some occurring on the southern edge towards the east (Figure 4.8). In Meadow 2 trees became denser in the northeastern and southwestern areas from 1972-2005 (Figure 4.9). In Meadow 3 trees increased near the southwestern border (Figure 4.10). Tree cover increased in the southern half of Meadow 4 (Figure 4.11). In Meadows 5 and 6 trees encroachment spread from the northern boundary through the middle (Figure 4.12). In Meadows 7 and 8 tree encroachment occurred mostly in the center of the study area (Figure 4.13).

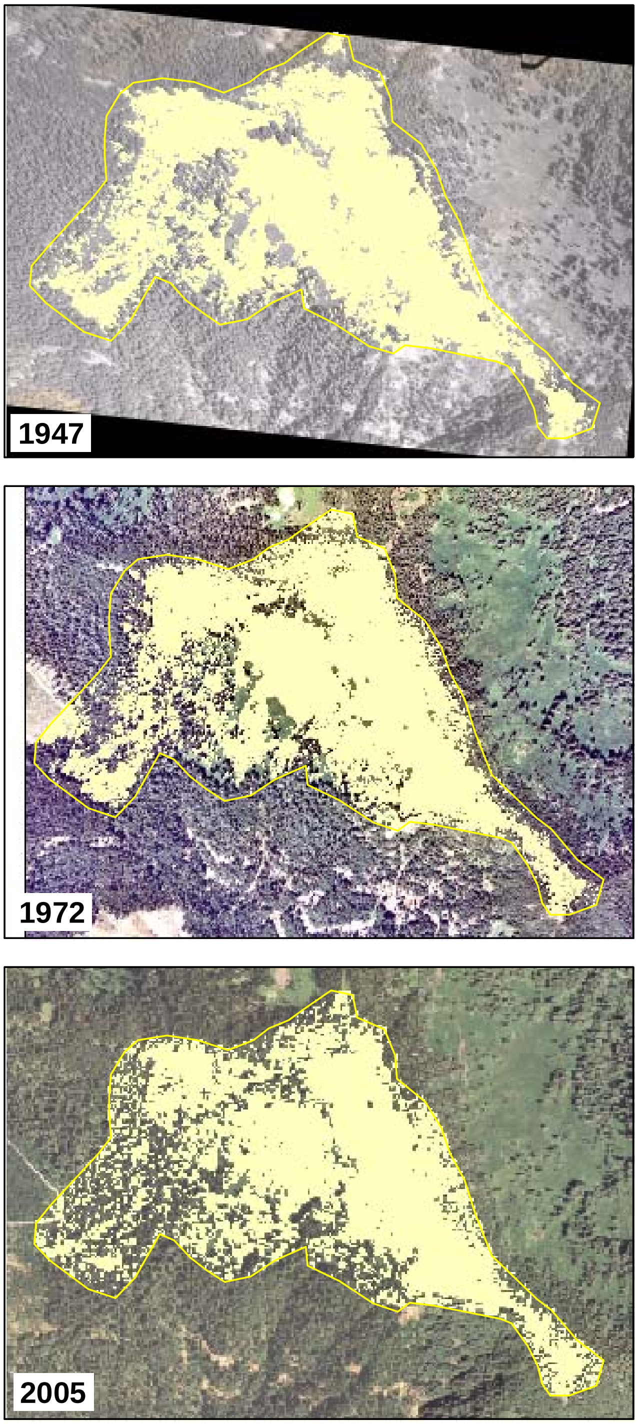


Figure 4.8. Extent of meadow/barren class (shown as pale yellow) in Meadow 1 over 1947, 1972, and 2005 photographs.

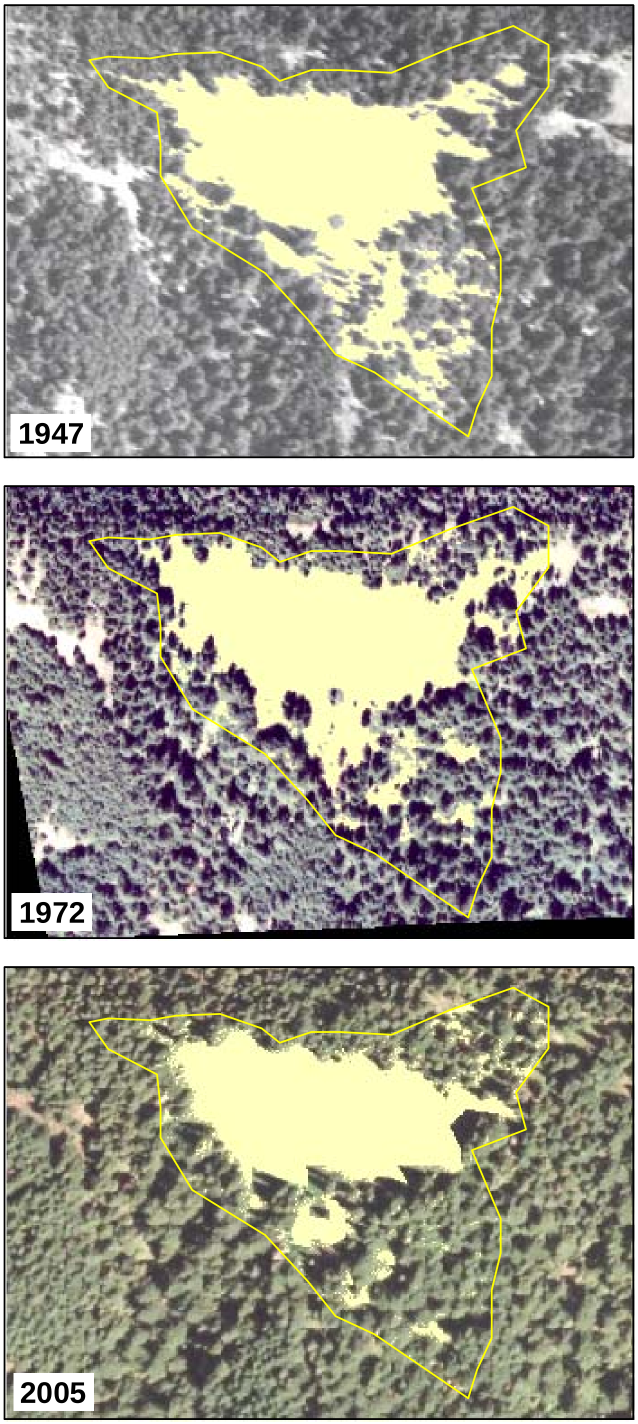


Figure 4.9. Extent of meadow/barren class (shown as pale yellow) in Meadow 2 over 1947, 1972, and 2005 photographs.

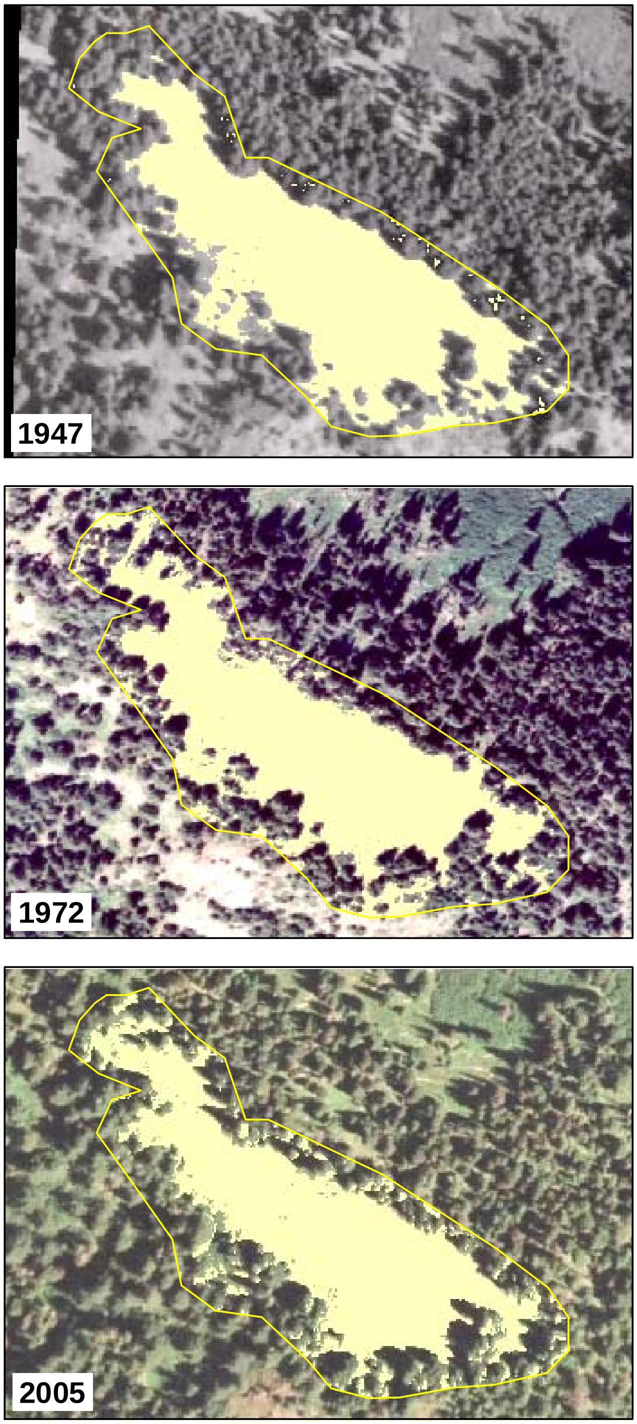


Figure 4.10. Extent of meadow/barren class (shown as pale yellow) in Meadow 3 over 1947, 1972, and 2005 photographs.

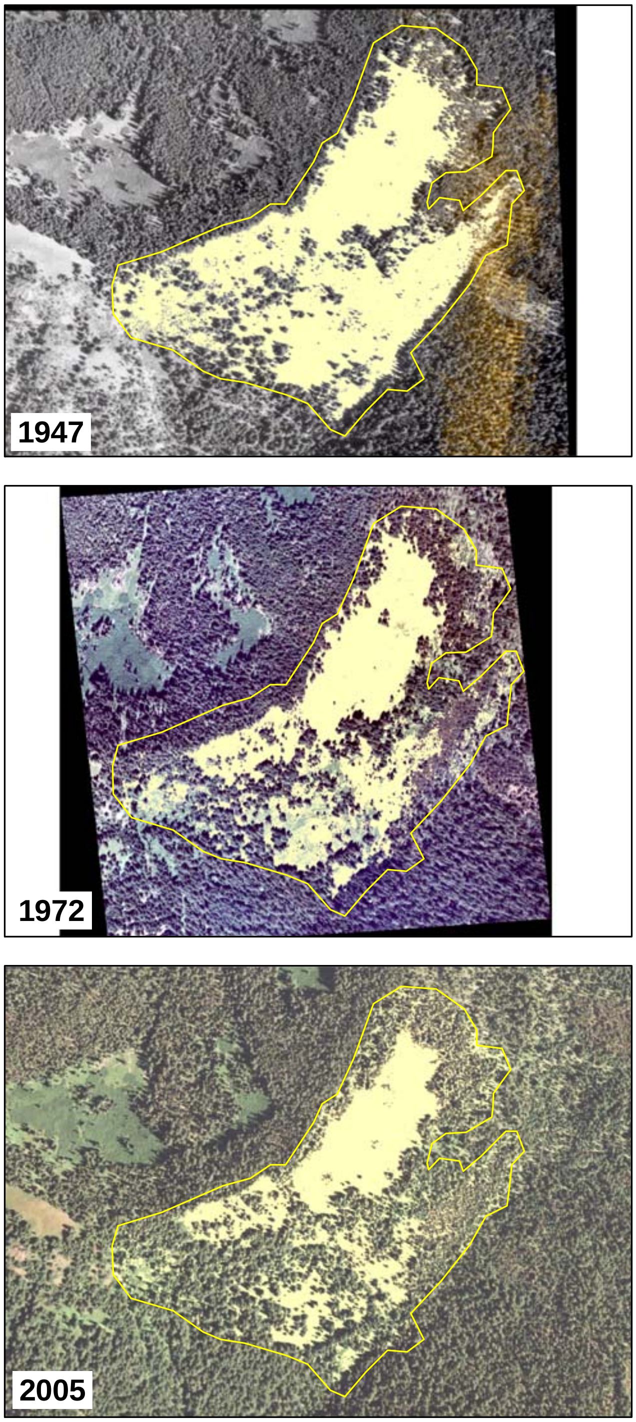


Figure 4.11. Extent of meadow/barren class (shown as pale yellow) in Meadow 4 over 1947, 1972, and 2005 photographs.

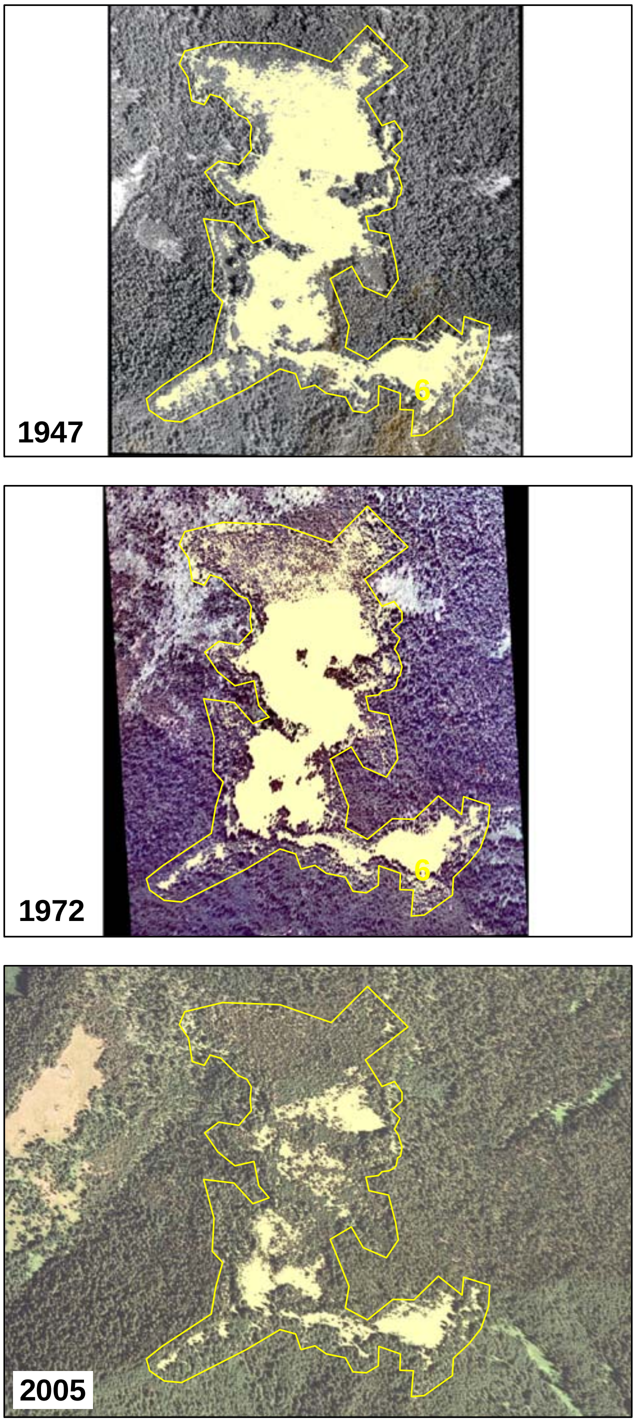


Figure 4.12. Extent of meadow/barren class (shown as pale yellow) in Meadows 5 and 6 over 1947, 1972, and 2005 photographs.

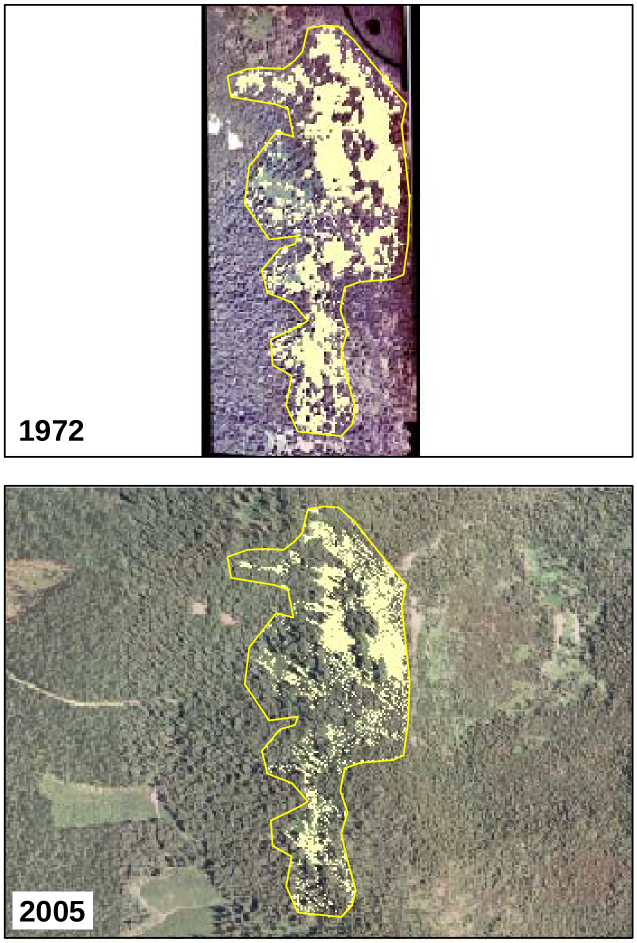


Figure 4.13. Extent of meadow/barren class (shown as pale yellow) in Meadows 7 and 8 over 1972 and 2005 photographs.

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4.4.2 Results of GIS Analysis

In Meadows 1, 2, 3, 7 and 8, more than 75% of cells that became tree cover by 2005 were within 5 m of trees in 1947 or in the case of Meadow 7 and 8, 1972 (Table 4.6). In Meadows 4, 5, and 6, 58 to 66% of cells that became tree cover by 2005 were within 5 m of trees in 1947, and over 90% occurred within 20 m (Table 4.6).

Table 4.6. Area and proportion of meadow-only that had/had not experienced encroachment by distance-to-tree category.

		Area (ha) of meadow per distance category				Percent of meadow per distance category			
Meadow	Total Area (ha)	0-5m	5-20m	20-40m	40-76m	0-5m	5-20m	20-40m	40-76m
M1									
Encroached since 1947	22.3	17.0	4.8	0.4	0.1	76.4	21.6	1.6	0.4
Not encroached	62.7	30.9	21.5	7.8	2.6	49.2	34.3	12.5	4.1
M2									
Encroached since 1947	0.6	0.5	< 0.1	0.0	0.0	92.9	7.1	0.0	0.0
Not encroached	1.4	0.6	0.5	0.3	0.0	43.1	36.5	20.4	0.0
M3									
Encroached since 1947	0.4	0.4	< 0.1	0.0	0.0	97.4	2.6	0.0	0.0
Not encroached	1.2	0.4	0.6	0.1	0.0	35.8	53.3	10.8	0.0
M4									
Encroached since 1947	11.0	7.3	3.5	0.2	0.0	66.4	31.7	1.9	0.0
Not encroached	13.2	5.9	5	2.1	0.2	44.4	38.1	15.6	1.8
M5 & M6									
Encroached since 1947	18.8	10.8	7.1	0.9	< 0.1	57.7	37.5	4.7	0.1
Not encroached	12.0	5.2	4.8	1.9	0.1	43.1	40.3	15.9	0.7
M7 & M8									
Encroached since 1972	10.9	8.6	2.1	0.2	0.0	78.9	19.4	1.6	0.0
Not encroached	13.5	9.6	3.2	0.7	0.0	71.2	24.0	4.8	0.0
All meadows combined									
Encroached since 1947 or 1972	63.9	44.6	17.5	1.6	0.1	69.9	27.4	2.6	0.2
Not encroached	104.0	52.5	35.7	12.9	2.9	50.5	34.3	12.4	2.8

In Meadows 2, 3, 4, 7 and 8, more than 70% of cells that became tree covered by 2005 were on slopes of 50 to 77 degrees (Table 4.7). In Meadows 1, 5, 6, more than 75% of cells that became tree covered by 2005 were on slopes greater than 25 degrees (Table 4.7).

Table 4.7. Area and proportion of meadow-only that had/had not experienced encroachment by slope category.

		Area (ha) of meadow per slope category			Percent of meadow per slope category		
Meadow	Total Area (ha)	0-25º	25-50º	50-77º	0-25º	25-50º	50-77º
M1							
Encroached since 1947	22.3	4.1	13.0	5.2	18.3	58.2	23.5
Not encroached	62.7	4.8	39.3	18.5	7.7	62.7	29.5
M2							
Encroached since 1947	0.6	0.0	0.1	0.5	0.0	19.6	80.4
Not encroached	1.4	< 0.1	0.8	0.6	1.5	55.5	43.1
M3							
Encroached since 1947	0.4	< 0.1	0.1	0.3	7.7	17.9	74.4
Not encroached	1.2	0.0	0.7	0.6	0.0	54.2	45.8
M4							
Encroached since 1947	11.0	0.5	2.7	7.8	4.3	24.9	70.8
Not encroached	13.2	2.2	5.5	5.6	16.4	41.4	42.2
M5 & M6							
Encroached since 1947	18.8	4.2	12.5	2.0	22.6	66.8	10.6
Not encroached	12.0	3.7	6.6	1.7	31.0	55.1	13.9
M7 & M8							
Encroached since 1972	10.9	0.1	1.8	9.0	0.5	16.7	82.8
Not encroached	13.5	0.1	2.4	11.1	0.4	17.6	82.0
All meadows combined							
Encroached since 1947 or 1972	63.9	8.9	30.2	24.8	13.9	47.3	38.7
Not encroached	104.0	10.8	55.2	38.0	10.4	53.1	36.5

All the meadows have overall mean aspects in the south facing 90 to 270 degree range (Table 4.8) The majority of encroachment for all meadows also falls within this range which consists of two categories (90-180º and 180-270º).

Table 4.8. Area and proportion of meadow-only that had/had not experienced encroachment by aspect category.

		Area (ha) of meadow per aspect category				Percent of meadow per aspect category			
Meadow	Total Area (ha)	0-90º	90-180º	180-270º	270-360º	0-90º	90-180º	180-270º	270-360º
M1									
Encroached since 1947	22.3	0.8	1.5	19.3	0.7	3.6	6.6	86.7	3.1
Not encroached	62.7	2.1	3.8	55.6	1.2	3.3	6.0	88.7	1.9
M2									
Encroached since 1947	0.6	0.0	0.4	0.2	0.0	0.0	62.5	37.5	0.0
Not encroached	1.4	0.0	0.5	0.9	0.0	0.0	35.8	64.2	0.0
M3									
Encroached since 1947	0.4	< 0.1	0.1	0.3	0.0	2.6	30.8	66.7	0.0
Not encroached	1.2	0.0	0.2	1.0	0.0	0.0	14.2	85.8	0.0
M4									
Encroached since 1947	11.0	1.0	8.7	1.3	< 0.1	9.0	79.1	11.5	0.4
Not encroached	13.2	3.7	8.7	0.7	0.2	27.8	65.8	5.0	1.4
M5 & M6									
Encroached since 1947	18.8	0.2	1.6	9.6	7.4	0.9	8.7	51.0	39.4
Not encroached	12.0	0.6	1.2	4.6	5.7	4.6	10.3	37.9	47.2
M7 & M8									
Encroached since 1972	10.9	< 0.1	0.1	6.9	3.9	0.4	0.8	63.2	35.6
Not encroached	13.5	< 0.1	< 0.1	9.3	4.2	0.3	0.1	68.6	30.9
All meadows combined									
Encroached since 1947 or 1972	63.9	2.0	12.3	37.5	12.0	3.1	19.3	58.8	18.8
Not encroached	104.0	6.3	14.4	72.0	11.3	6.1	13.8	69.3	10.8

Cells that became tree covered over the period 1947-2005 (1972-2005 for Meadows 7 and 8) on average were located 4 m from a cell classified as tree cover in 1947 (Table 4.9). The mean distance to trees regardless of encroachment status is relatively consistent over the meadows (8-9 meters) with the exception of Meadows 7 and 8 (5 meters). In Meadows 1 and 4, cells that were encroached upon by trees were significantly closer to existing tree cover than average (Chi-squared = 11.9, $p < 0.02$ and Chi-squared = 6.6, $p < 0.05$ respectively); no significant differences were found in the other meadows (Table 4.9).

Table 4.9. Mean distance to tree of portions of study areas that were encroached upon by tree cover compared to areas that remained meadow over the period 1947-2005 or 1972-2005 and Chi-squared and p-values describing relationship between the percent encroachment in each meadow per distance-to-tree category and the percent of meadow per category.

Meadow	Mean Distance to tree (m)			Chi-squared of encroachment area per distance category compared to meadow area per distance category		
	Encroached	Not Encroached	All	Chi-squared value	df	p-value
M1	5	11	9	11.9	3	< 0.02
M2	2	11	8	unable to calculate	0	n/a
M3	1	10	8	unable to calculate	0	n/a
M4	5	11	8	6.6	2	< 0.05
M5 & M6	7	10	8	2.2	2	> 0.1
M7 & M8	4	5	5	1.2	2	>0.25
All	4	10	8	n/a	n/a	n/a

The average slope of the meadows varies from 34 to 56 degrees (Table 4.10). Meadow 1 and Meadows 5 and 6 have the lowest slope overall and Meadow 2 and Meadows 7 and 8 are the steepest. On average, encroachment occurred on steeper than average slopes. However, in Meadow 1 encroachment occurred on less steep slopes than the average for that meadow, and in meadows 5,6,7,8 there was little difference in mean slope of areas that were encroached upon versus not encroached upon by trees. In meadows 2 and 4, encroachment occurred on significantly gentler slopes than the average slope for the meadow (Chi-squared = 21.2, $p < 0.0005$ and Chi-squared = 35.6, $p < 0.0005$ respectively); in other meadows encroachment was not significantly related to slope (Table 4.10).

Table 4.10. Mean degree slopes of portions of study areas that were encroached by tree cover compared to areas that remained meadow over the period 1947-2005 or 1972-2005 and Chi-squared and p-values describing relationship between the percent encroachment in each meadow per slope category and the percent of the meadow per category.

	Mean Degree Slope			Chi-squared of encroachment area per slope category compared to meadow area per slope category		
Meadow	Encroached	Not Encroached	All	Chi-squared value	df	p-value
M1	41	45	44	0.8	2	> 0.25
M2	60	49	52	21.2	1	< 0.0005
M3	54	48	50	unable to calculate	0	n/a
M4	53	44	48	35.6	2	< 0.0005
M5 & M6	35	34	34	0.5	2	> 0.25
M7& M8	56	55	56	< 0.1	1	> 0.25
All	50	46	47	n/a	n/a	n/a

Overall, all the meadows were on south facing slopes (orientations of 90 to 270 degrees) (Table 4.11). In Meadow 1 and Meadow 3 tree encroachment was more likely on relatively south facing slopes, compared to the average slope of the meadows. In Meadow 2 and Meadow 4 tree encroachment was more likely on relatively east facing slopes, compared to the average slope of the meadows. In Meadows 5 and 6 and Meadows 7 and 8 there was very little difference of aspect between the encroached and not encroached areas. In Meadow 2, encroachment occurred on significantly more east-facing slopes (Chi-squared = 13.9, p < 0.0005), and in Meadow 3, encroachment occurred on significantly more south-facing slopes (Chi-squared = 11.2, p < 0.001) compared to the average orientation of the meadows.

Table 4.11. Mean aspect of portions of study areas that were encroached by tree cover compared to areas that remained meadow over the period 1947-2005 or 1972 -2005 and Chi-squared and p-values describing relationship between the percent encroachment in each meadow per aspect category and the percent of the meadow per category.

Meadow	Mean Aspect			Chi-squared of encroachment area per aspect category compared to meadow area per aspect category		
	Encroached	Not Encroached	All	Chi-squared value	df	p-value
M1	214	219	218	0.4	3	> 0.25
M2	176	189	185	13.9	1	< 0.0005
M3	199	210	208	11.2	1	< 0.001
M4	146	127	136	2.7	3	> 0.25
M5 & M6	252	251	252	0.8	3	> 0.25
M7& M8	257	254	255	0.6	2	> 0.25
All	207	208	201	n/a	n/a	n/a

4.5 Discussion

Encroachment has occurred at different rates and in different time periods for each meadow. Overall, encroachment rates increased during the 1972-2005 time period for all meadows except Meadow 4. Meadow 4 had the highest rate of encroachment compared to the other meadows in the 1947-1972 time period, however. (Rates for Meadow 7&8 were not determined for that time period.) Though records indicate mechanical tree removal occurred in Meadow 4 on 1964, they do not indicate the precise location of removal. It is possible that the encroachment occurred in areas where no tree removal took place. Meadows 2 and 3 are significantly smaller in area than the other meadows on the complex and appear to be the most stable with little or no encroachment over either time period.

Invasion is concentrated on steeper slopes in Meadows 2 and 4 and more east and more south-facing slopes in Meadow 2 and Meadow 3. These meadows all had average slopes greater than 45 degrees and had on average the most south and east facing slopes of all the meadows. This is consistent with the Miller and Halpern (1998) finding that steep south-facing slopes had increased seedling establishment during wetter periods. The wetter period between 1945 and 1985 described by Miller and Halpern (1998) may have contributed to favorable conditions for invasion on these otherwise dry slopes.

Meadow 5&6 lost the greatest area (16.7 ha) and greatest percent of herbaceous cover (58%) overall. It also has the lowest average slopes of all the meadows and with the exception of Meadow 7&8, is the most west facing on average. This would seem to contradict the Miller and Halpern (1998) findings described above. It may be related to decreased snowpack resulting in longer growing seasons instead of increased moisture. The 1947 and 1972 photographs clearly show large tree islands in the middle of Meadow 5&6 and early edge invasion to the north of the study area (Figure 4.12) which may also have had a role creating conditions favorable to invasion.

The concentration of invasion occurring within 5 m of existing trees is consistent with other published research (Coop and Givnish, 2007; Haugo and Halpern, 2007; Wearne and Morgan, 2001; Miller and Halpern, 1998; Takaoka and Swanson, 2006; Franklin et al., 1971) that describe the ameliorating effects of trees on surrounding soil conditions and microclimate. However, the meadows where this was statistically significant, Meadows 1 and 4, had undergone mechanical tree removal and prescribed burns that may have preferentially removed trees from non-edge areas, confounding the results of this analysis. Meadow 7&8 had an average distance to tree for all cells of only 5 meters (Table 4.9). Though the Chi-squared statistics for this meadow were not significant in this respect, the overall loss of 23% of the herbaceous cover over the 1947 to 2005 time period may be attributable to the alteration of the soil and microclimate by trees.

The limited temporal record of these meadows through aerial photography and lack of specific fire and grazing histories obscure the origin of these meadows and their encroachment histories. For example, an area that appears to be meadow in 1947 could have been opened by fire or grazing and subsequent invasion by trees in not a loss of meadow but a re-establishment of the recent past land cover. Those areas that seem stable and have not experienced encroachment after grazing ceased could have been under long standing meadow cover. Further study of fire regimes and vegetative cover could illuminate longer term histories of meadows to better understand invasion patterns.

As already mentioned, some meadows underwent mechanical tree removal and prescribed burning but natural fires that could have impacted the analysis were not accounted for. (Evidence of fire, natural or human caused, was not gathered but gleaned from USFS documents.) If historic fire regimes were better understood by charcoal collection and dating, a relationship between encroachment patterns and the frequency and intensity of fires may be established.

Species composition of the herbaceous cover was also not factored into this analysis. Haugo and Halpern (2007) and Lang and Halpern (2007) describe the species composition changes and transient nature of meadow species seed banks. By surveying the understory and meadow species, status of the progression of invasion may be quantified. Takaoka and Swanson (2006) also determined that meadows dominated by forbs tended to contract more than meadows dominated by shrub which may provide another variable in determining a meadow’s risk of invasion. Correlating herbaceous species composition to encroachment patterns may provide further insight into the mechanisms and fine scale temporal patterns of invasion.

Alteration of analysis techniques could also produce improved results. Improvement of the geo-rectification results may be possible with other meadows with better and more plentiful control points. For example, those areas that had seemingly illogical encroachment histories could be reduced or eliminated by more accurate co-registration of the images. An increase in sample size stratified by meadow characterization as described by Miller and Halpern (1998) and Takaoka and Swanson (2006) could provide more significant results. With stratification, it may be possible to determine differential impacts of the physical factors measured on different types of meadows. Finally, the categories chosen for which to calculate statistics were arbitrary. They were applied to all the meadows in the study area in order to compare them but may not have been suitable for individual meadows.

This analysis demonstrates a potentially new method to analyze encroachment using historic photos. Takaoka and Swanson (2006) used photo-interpretation of a series of historic photos to determine encroachment. This analysis is different in that the historic and current photos were classified into two values (tree and not tree) and analysis was based on the classification, not photo-interpretation. Change in meadow area and distance of encroachment to trees could then be measured in a systematic way with raster analysis. This method can aid in change detection and when combined with slope, aspect, and distance to tree analysis can help classify meadow types that experience encroachment.

Existing meadows can be evaluated for their risk of encroachment and targeted for active management based on that risk. With the characterization of meadows described above and further analysis based on vegetation, soils, improved fire history, and other physical and biological variables, a model can be built and validated and finally used to predict conifer encroachment risk of meadows. Any such model would have to be calibrated to the ecoregion and land use history to which it was applied. This would provide a quantifiable risk assessment index and aid in meadow maintenance and potentially restoration strategies.

5 Tree Invasion Along Forest-Meadow Transects in the Chucksney-Grasshopper Meadow Complex, Western Cascade Range of Oregon

5.1 Introduction and Objectives

The purpose of this study was to quantify the timing and fine-scale spatial patterns of individual conifer tree encroachment through field sampling. Meadow 4 of the Chucksney-Grasshopper complex was chosen as a field site because it exhibited encroachment along the forest-meadow edge and in tree islands and experienced mechanical tree removal and broadcast burning. One “edge” transect and one “tree island” transect were chosen because they were intentionally burned in 1996. The other edge and tree island transects were chosen because they were not burned in 1996 and showed no signs of char resulting from natural fires. If encroachment of a particular species can be related to fire history and proximity to forest edge or slope position, active management of meadows may be adjusted to better eradicate invaders based on their species and location within a meadow.

5.2 Background

A limited number of dominant species were found in Meadow 4: *Abies concolor, Abies grandis, Pinus contorta, Pseudotsuga menziesii, Thuja plicata, and Tsuga heterophylla.* Table 5.1 compares the relative tolerances of these species to shade and fire. Environmental adaptations and growing strategies are discussed further below.

Table 5.1. Relative tolerances of dominant species in Meadow 4 to shade and fire.

Species	**Shade**	**Fire**
Abies concolor var. lowiana	Moderately tolerant	Moderately tolerant
Abies grandis	Tolerant	Tolerant
Pinus contorta	Intolerant	Moderately tolerant
Pseudotsuga menziesii	Moderately tolerant	Tolerant
Thuja plicata	Tolerant	Intolerant
Tsuga heterophylla	Tolerant	Intolerant

5.2.1 Abies concolor var. lowiana

Abies concolor var. lowiana, California white fir, henceforth referred to as white fir, occupies a range from the Pacific coast to Colorado and from Oregon to Mexico. It grows at cold high elevations and warmer lower elevations with precipitation ranging from 890 to 1900 mm (Burns and Honkala, 1990). It can be found in an array of conditions and on soils developed from volcanic or sedimentary parent materials. Soil type is less important than soil moisture (Burns and Honkala, 1990).

White fir is sensitive to excess soil moisture and frost. It germinates immediately after snowmelt and usually in partial shade. It tends to establish near lodgepole pine which essentially dries out the soil with its uptake. Lodgepole also protects the fir from cold and often results in white fir establishment in a radial pattern around it. For both of these reasons, white fir tends to invade meadows by taking advantage of older lodgepole pines (Burns and Honkala, 1990).

Associations of white fir with grand fir, tanoak, incense-cedar, ponderosa pine, lodgepole pine, Jeffrey pine, Douglas-fir, and California black oak are common. White fir is a tolerant major climax species and is only succeeded by western hemlock and western redcedar on moist sites in Oregon (Burns and Honkala, 1990). It is more shade tolerant than pines and Douglas-fir but less so than other true firs. Its tolerance may be affected by crossing with grand fir which is a common occurrence (Burns and Honkala, 1990).

Fire has in the past kept white fir in control. Because it can survive in the understory suppressed for a long time and fire suppression has prevented its eradication in the understory, pure stands of white fir have increasingly established dominance. White fir becomes more fire resistant with age and size. This resistance is greater than the resistance of associated species at higher elevations and less than the associated species at lower elevations (Burns and Honkala, 1990).

5.2.2 Abies grandis

Abies grandis, grand fir, occurs is a wide range of conditions. Its geographic distribution is from 39º N to 51º N and 114º W to 125ºW. It grows from valleys to mountains and tolerates annual precipitation ranges from 510 to greater than 2500 mm. Its average growing season temperature ranges from 14º to 19º C. In Oregon it is found to grow in the rich alluvial soils of the Willamette Valley as well as the shallow, exposed soils of central and eastern Oregon (Burns and Honkala, 1990).

Grand fir is most often found in mixed conifer and hardwood stands. It can either be a seral or climax species depending on the forest type it is growing in. When water is readily available, it grows rapidly and competes with other species. On dry sites, it exists as a shade-tolerant understory and becomes dominant when climax conditions occur (Burns and Honkala, 1990).

Growth rates of grand fir vary depending on moisture regime. It germinates in the spring in cool moist conditions. Growth is delayed on dry sites until the tap root reaches ground water. Its growth rivals shade intolerant species like Douglas-fir and it out-competes tolerant species such as western redcedar and western hemlock. Its "adaptable root system" allows grand fir to grow in a variety of conditions (Burns and Honkala, 1990).

Grand fir has a fire resistance rating of medium. It is less resistant to fire than Douglas-fir but more resistant than western hemlock. Its root strategy based on conditions lend to its tolerance. For example, in moist areas its shallow root system makes it more vulnerable to fire compared to its deep root system on dry exposed sites where it is more tolerant (Burns and Honkala, 1990).

Subalpine fir (Abies lasiocarpa), white fir (*Abies concolor*) and Sierra white fir (*Abies lowiana*) cross with grand fir to form hybrids. In cases where grand fir crosses with white fir, species cannot be discriminated by visual examination (Burns and Honkala, 1990).

5.2.3 Pinus contorta

Pinus contorta, lodgepole pine, tolerates a wider range of environmental conditions compared to other North American conifers. It occurs from the Pacific coast to South Dakota and from Baja California to Canada. It grows in regions with average winter temperatures as low as -57º C and average summer temperatures as high as 38º C. It grows in areas with precipitation, mostly in the form of snow, ranging from 250 to 500 mm (Burns and Honkala, 1990). Lodgepole tolerates a wide range of soil types but usually does best on moist soils developed from granite, shale, and coarse grained lava. It tends to grow best on sites with poorly drained soils in the Cascade Range but can also be found on well drained sites above 1600 meters. It will often be the only tree species found on infertile soils (Burns and Honkala, 1990).

Lodgepole grows well in association with western conifers and as a pure stand. As a very shade intolerant species, it grows best in full sunlight. Site conditions and species competition determines what successional role it plays. In warm moist climates it plays the role of a minor seral species but is dominant seral in cooler dryer environments. It is a persistent species where it occurs in even-aged stands with no threat of being overgrown by shade tolerant species. Finally, it serves as a climax species when it is the only tree able to grow under certain conditions (Burns and Honkala, 1990).

Some trees produce serotinous cones. However in Oregon, the non-serotinous type is more common. Because seeds in serotinous cones are viable for many years, fire can make available a large number of seeds. However, very hot fires created by burning slash can damage even these fire adapted cones (Burns and Honkala, 1990).

Germination occurs after snowmelt if temperatures are high enough – usually between 8 and 26º C. Adequate soil moisture and full sunlight on mineral soil or disturbed duff provide the best conditions. Competition from other species, including grasses, reduces seedling germination and survival rates. Soils with poor moisture holding capacity create drought conditions that commonly kill seedlings. Shade, under these circumstances, may actually benefit the otherwise very shade intolerant species. Seedlings are also vulnerable to livestock trampling and foraging (Burns and Honkala, 1990).

Lodgepole pine grows best when it has full sunlight and no competition. Even though it is very shade intolerant, it can persist in dense stands for up to 100 years. However, when a lack of fire no longer eliminates competitors, more shade tolerant species such as subalpine fir become dominant. Lodgepole pine needs more water than Douglas-fir and less than subalpine fir and can out complete some species for water. It is also moderate in its sensitivity to temperatures (Burns and Honkala, 1990).

5.2.4 Pseudotsuga menziesii

Pseudotsuga menziesii is known by a number of common names including Oregon-pine, red-fir and Douglas-fir. It has been a large part of western North American forests for hundreds of thousands of years. Its range, from British Columbia to Mexico and from the Pacific Coast to Wyoming, is one of the broadest of North American conifers. Its wide geographic range corresponds to the wide climatic conditions under which it grows. In the Pacific Northwest Cascades it exists in temperatures as low as -9º C in January and as high as 30º C in July. In Oregon it tends to occur between 0 and 1520 meters and higher. In the north it tends to grow on south facing slopes and in the south on north facing slopes. At high elevations, however, it grows on south facing slopes (Burns and Honkala, 1990). It does best on deep, well aerated soils developed from a range of parent materials. However, it can grow on shallow soils occurring on steep slopes ranging from gravel sand to clay textures. It grows best in moderately acidic conditions (Burns and Honkala, 1990).

Depending on latitude and elevation, Douglas-fir is associated with a number of species. Depending on its range, it can be either a seral or climax species. In colder climates it is replaced by whitebark pine, true firs, Engelmann spruce, western white pine and lodgepole pine. Incense-cedar, Oregon white oak, California black oak, canyon live oak, and interior live oak replace it on drier sites. On poorly drained sites, it’s replaced by western redcedar, maples, red alder, and black cottonwood. In the fog belt on the

Pacific coast it is replaced by Sitka spruce, western hemlock, and western redcedar (Burns and Honkala, 1990).

Fire benefits Douglas-fir by eliminating the seed banks of competing species. The thick bark, quick growth, and long life span of Douglas-fir enable it to thrive as a dominant species in fire adapted environments (Burns and Honkala, 1990).

Douglas-fir has different tolerances to shade depending on its stage of life, though in general it is considered to have intermediate shade tolerance. In its interior range, its associated species of western larch, ponderosa pine, lodgepole pine, southwestern pine, and aspen are all less tolerant of shade (Burns and Honkala, 1990). Germination timing depends on climate; in warmer areas it occurs in mid March to early April, but in cooler areas it occurs as late as May.

5.2.5 Thuja plicata

The common names for *Thuja plicata* are Pacific redcedar and western redcedar. It grows on the Pacific coast from northern California to Alaska. Its interior range is as far east as western Montana. In Oregon its range of elevation is from sea level to 2290 meters (Burns and Honkala, 1990). It occurs on all types of landforms, parent materials and textures. It can also grow on soils low in nutrients. In good moisture and fertilized conditions, seedlings outgrow Douglas-fir, grand fir, and western hemlock, to name a few species (Burns and Honkala, 1990).

Thuja plicata is usually associated with several other species. These species include western hemlock, western white pine, Douglas-fir, grand fir, Pacific yew, white spruce, lodgepole pine, subalpine fir, western larch, Engelmann spruce and ponderosa pine (Burns and Honkala, 1990).

Germination occurs best on disturbed mineral soil. It can occur in autumn, winter, or spring. Though it does not always benefit from fire, slash burning can prepare a mineral soil surface and promote regeneration. Partial shade and adequate soil moisture also enable germination (Burns and Honkala, 1990).

Western redcedar is very shade tolerant. Only Pacific silver fir, western hemlock, and Pacific yew are more tolerant. Though it can occur as a pioneer and seral species, it is considered a climax or near climax species. Douglas-fir, grand fir, western hemlock, and western white pine usually occur in the overstory where western redcedar occupies the understory (Burns and Honkala, 1990).

Though western redcedar has few threats from insects, it is vulnerable in other ways. It is often severely damaged by fire but less so than western hemlock, for example. It is also browsed by game and rodents during its seedling and sapling stages (Burns and Honkala, 1990).

5.2.6 Tsuga heterophylla

Tsuga heterophylla, also known as Pacific hemlock, west coast hemlock, and western hemlock, occurs on the western and upper eastern slopes of the Cascade Range of Oregon and Washington as well as the western side of the northern Rocky Mountains. It grows best in mild, humid and super-humid climates but also occurs in sub-humid climates mostly on north facing slopes or stream bottoms. It grows in areas with precipitation as low as 380 mm and as high as 6650 mm. Minimum temperature can be as low as -47.8º C and maximum temperatures can be as high as 42.2º C depending on range. Its elevation range is from sea level to 2130 meters (Burns and Honkala, 1990). It grows on soils developed from any type of bedrock and with most textures. It grows better on moist soils but does not do well where there is a very high water table. It tends to grow poorly on drier soils. It is very dependent on the organic soils horizon for nutrients. However, mineral seedbeds are better for germination than organic seedbeds due to the tendency of organic material to dry out (Burns and Honkala, 1990).

Western hemlock is a climax species. It is very shade tolerant though its seedlings can grow in full sun. It can germinate at temperatures just above freezing but most effectively at around 20º C. Its associated climax species include western redcedar, Pacific silver fir, and subalpine fir but it can occur by itself as a climax species (Burns and Honkala, 1990). Germination timing depends on climate; in warmer areas it occurs in mid March to early April, but in cooler areas it occurs as late as May.

5.3 Study Area

Meadow 4, also known as West Middle Prairie, is the fourth largest meadow in the Chucksney-Grasshopper complex (Figure 5.1). Its historic (1947) extent runs approximately 875 meters north to south and 890 meters east to west and covered almost 38 hectares. Its northern boundary is formed by a ridge line and Fisher Creek runs along the southern boundary. Its slope is less than 20 degrees in the flatter and more herbaceous section in the north and north-east area and becomes steeper (40-60 degrees) as it slopes to the south towards the creek. Its aspect is predominantly south and south east facing.

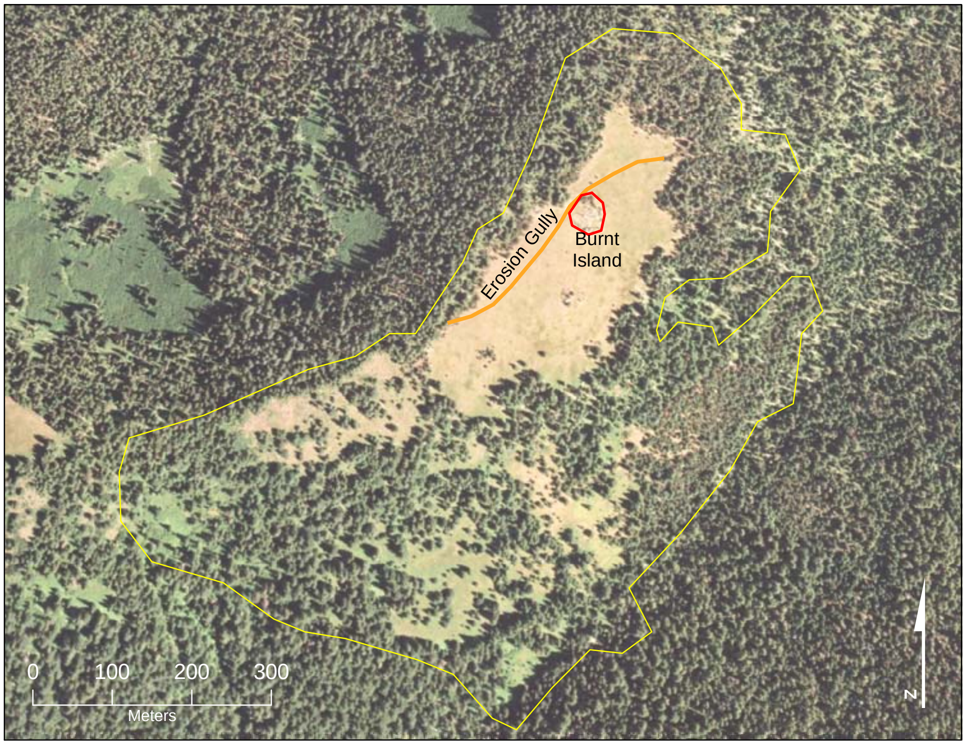

Figure 5.1. 2005 photograph of Meadow 4. 1947 meadow extent and study area outlined in yellow. The tree island burnt in 1996 is outlined in red and the erosion gully caused by livestock is delineated in orange.

Effects of historic land use management are evident in the meadow today. The meadow was used for cattle and sheep grazing until the 1960s and a large erosion gully can still be seen (Figure 5.1). Trees were mechanically removed in 1964 and the northeastern section was intentionally burned in 1996. A fire-scarred tree island can be found in the northeastern section of the herbaceous covered area (Figure 5.1).

A 2004 Salix Associates plant inventory (2005) describes the vegetation of a portion of the meadow. Areas that had already been heavily encroached were not surveyed. There is a rock garden at the western most end of the meadow with *Arctostaphylos nevadensis, Phlox diffusa and Penstemon procerus* as the dominant species. The dry meadows constituting the remaining open areas shown in the 2005 photograph tended to have low herbaceous species diversity. Dominant species in these areas include *Festuca virdula, Danthonia intermedia,* and *Carex inops*. The area towards the southern extent of the meadow that is partially open is described as a mesic meadow-forest mosaic with *Bromus Carinatus* and *Carex inops* as the dominant herbaceous species. *Abies grandis* was recorded as the dominant tree species. Some of the openings in the meadow-forest mosaic exhibited more diversity than the dry meadows described above. The mesic area is more heavily encroached by conifers and shrubs (Salix, 2005).

Photographic interpretation and field surveys reveal different patterns and levels of encroachment. (See Figure 4.11 in Chapter 4 for photographic interpretation.) The areas described as dry meadow in the Salix reports (2005) showed encroachment occurring along edges and from tree islands. The areas described as mesic meadow-forest mosaic showed higher levels of encroachment. Those areas not surveyed by Salix but analyzed in Chapter 4 exhibited high levels of encroachment as well. The primary invading tree species were *Pinus contorta* and *Abies grandis*. *Abies lasiocarpa* was also noted. Shrubs were common in the meadow-forest mosaic and other heavily encroached areas (Salix, 2005).

5.4 Methods

Four transects were identified based on history of encroachment and previous management status (Figure 5.2). Two examples where trees appeared to establish around existing trees in open areas (island encroachment) were chosen. One transect was laid out in the center of a tree island that had experienced a prescribed burn in 1996 (T1). Another transect was laid out in the center of a tree island that neither had a record of prescribed burn nor contained trees with char (T2). Two examples of edge encroachment were also chosen. Again, one had experienced a prescribed burn in 1996 (T3), and the other had no record of a prescribed burn or trees with char (T4).

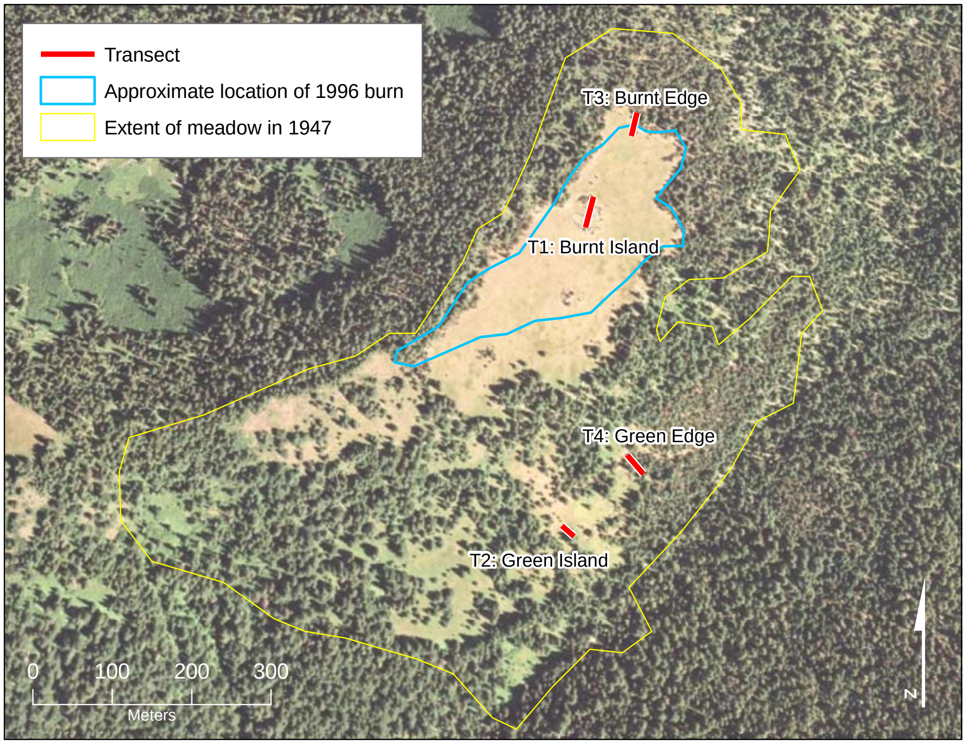

Figure 5.2. Location of survey transects within Meadow 4.

The length of transects was determined two ways. If the transect was located at an island, the entire length of the island was encompassed. If the transect was located at an edge, it extended roughly perpendicular from where the youngest tree occurred in the meadow to where trees were significantly larger and presumably older within the forest. The length of the transects were: T1 (40-m), T2 (20-m), T3 (30-m), T4 (30-m). The width of the transects were ten meters with the exception of Transect T2 which was 15 meters.

Transects were delineated in the field as a series of 5x5m blocks using a tape measure and survey flags. In each block, every live tree was counted and its species identified.

Trees less than 1.4 meters in height were not sampled. Trees greater than 1.4 meters in height were measured for diameter at breast height (dbh) size class. Size classes were 0-5 cm, 5-10, 10-20, and continued in 10 cm increments. Snags were counted and size class noted. Species were not recorded for snags. Within each block, trees representative of each live species/size class combination were sampled at a rate of approximately one per block or 10%, whichever was greater. Basal sections were obtained for trees less than 5 cm dbh. Increment cores were obtained for trees greater than 5 cm dbh and these cores were mounted in the field. Cores and basal sections were sanded using a 220 grain paper and rings were counted using a 40x magnification binocular microscope. When possible, cross dating was used to increase the accuracy of the ages recorded. Some trees were not cored due to lack of access, wasp nests, or the size limitation of the incremental borer used.

5.5 Results

Transect T1: Burnt Island

Transect T1 is oriented SSW to NNE with a bearing of 14 degrees (Figure 5.3). The 5x5 meter blocks are labeled and correspond to the data table below (Table 5.2). Species, applicable to all transects, with corresponding scientific and common names are found in Table 5.3. Transect T1 lies within a relatively flat area that was burnt in 1996 and contains several burnt snags and fallen trees. Seedlings seem to have established near the snags but not the fallen trees. This may be due to the mineral soils resulting from a hotter fire that also caused the trees to fall in this area (Jones, 2007). At the NNE end of the transect, the end closest to the forest, a nearly straight narrow line of trees appears to run perpendicular to the transect and may originate from the edge of the meadow to the northeast.

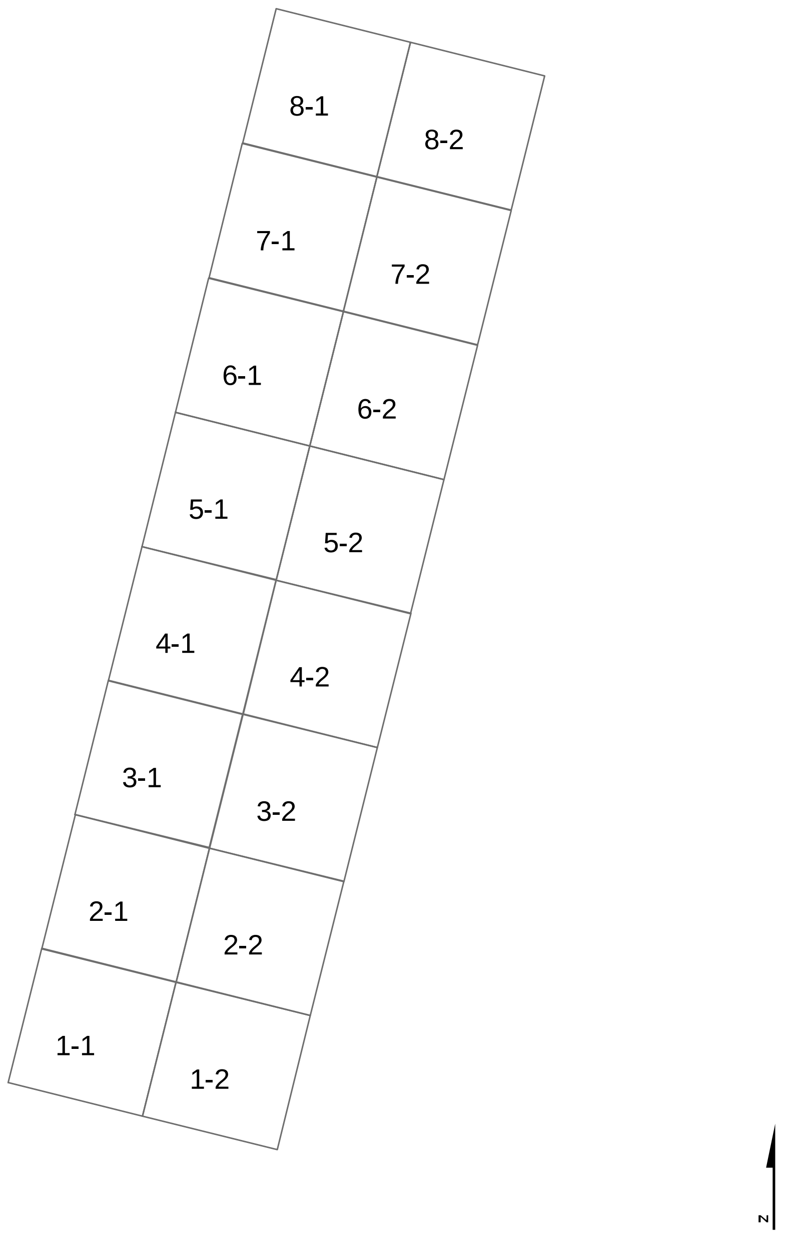

Figure 5.3. Orientation and designation of survey blocks for Transect T1.

Table 5.2. Transect T1 field data by survey block. Survey Block designation corresponds to Figure 5.3. Species codes are found in Table 5.3. The count column refers to all the occurrences of that species by size class per survey block. The dbh size class pertains to all occurrences and the sample dbh and age pertain to just the subset of trees sampled.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
1-1	*Pinus contorta*	3	seedling	X	X
1-1	*Abies grandis*	5	seedling	X	X
1-1	burnt snag	3	40-50	X	X
1-1	burnt snag	1	70-80	X	X
1-2	*Pinus contorta*	2	0-5	2.6	9
1-2	*Pinus contorta*	3	seedling	X	X
1-2	*Abies grandis*	7	seedling	X	X
1-2	burnt snag	5	30-40	X	X
2-1	*Abies grandis*	2	seedling	X	X
2-2	*Pinus contorta*	3	0-5	1.7	6
2-2	*Pinus contorta*	3	seedling	X	X
2-2	*Abies grandis*	10	seedling	X	X
2-2	*Abies concolor*	4	seedling	X	X
2-2	burnt snag	1	20-30	X	X
3-1	burnt and fallen	0	X	X	X
3-2	burnt and fallen	0	X	X	X
4-1	burnt and fallen	0	X	X	X
4-2	burnt and fallen	0	X	X	X
5-1	burnt snag	1	50-60	X	X
5-1	*Abies grandis*	2	seedling	X	X
5-2	*Pinus contorta*	1	seedling	X	X
5-2	*Pinus contorta*	1	0-5	2.7	8
5-2	burnt snag	4	10-20	X	X
6-1	nothing present	0	X	X	X
6-2	burnt snag	4	20-30	X	X
6-2	*Abies grandis*	9	seedling	X	X
6-2	*Abies concolor*	1	seedling	X	X
7-1	*Abies grandis*	5	seedling	X	X
7-1	burnt snag	2	20-30	X	X
7-1	*Abies concolor*	1	seedling	X	X
7-1	*Pinus contorta*	2	0-5	1.9	18
7-2	*Abies grandis*	2	seedling	X	X

Table 5.2 Continued. Transect T1 field data by survey block.

Survey Block	Species	Count	dbh size class (cm)	Sample dbh (cm)	Age (years)
7-2	burnt snag	1	20-30	X	X
8-1	*Pinus contorta*	6	10-20	12.8	22
8-1	*Pinus contorta*	8	0-5	1.7	24
8-1	*Pinus contorta*	2	5-10	9.95	20
8-2	*Pinus contorta*	3	10-20	10.5	20
8-2	*Abies concolor*	1	10-20	16.3	20
8-2	*Abies grandis*	1	10-20	11.1	18

Table 5.3. Species displayed in data tables with scientific and common names.

Scientific name	Common name
Abies concolor	white fir
Abies grandis	grand fir
Abies procera	noble fir
Pinus contorta	lodgepole pine
Pseudotsuga menziesii	Douglas-fir
Thuja plicata	western redcedar
Tsuga heterophylla	western hemlock

Species counted included 38 lodgepole pine, 43 grand fir, and 7 white fir (Table 5.2). Most trees were seedlings and the majority of the non-seedlings were lodgepole pine with only one white fir and one grand fir non-seedling. All of the trees older than ten years were located towards the north eastern end of the transect in blocks 8-1 and 8-2 aligned with a line of trees coming in from the edge (Figure 5.3). *Pinus contorta* were distributed throughout the transect and show a pattern of decreasing age with distance from the forested end of the transect (Figure 5.4). *Abies grandis* and *Abies concolor* were not distributed well enough to detect a pattern.

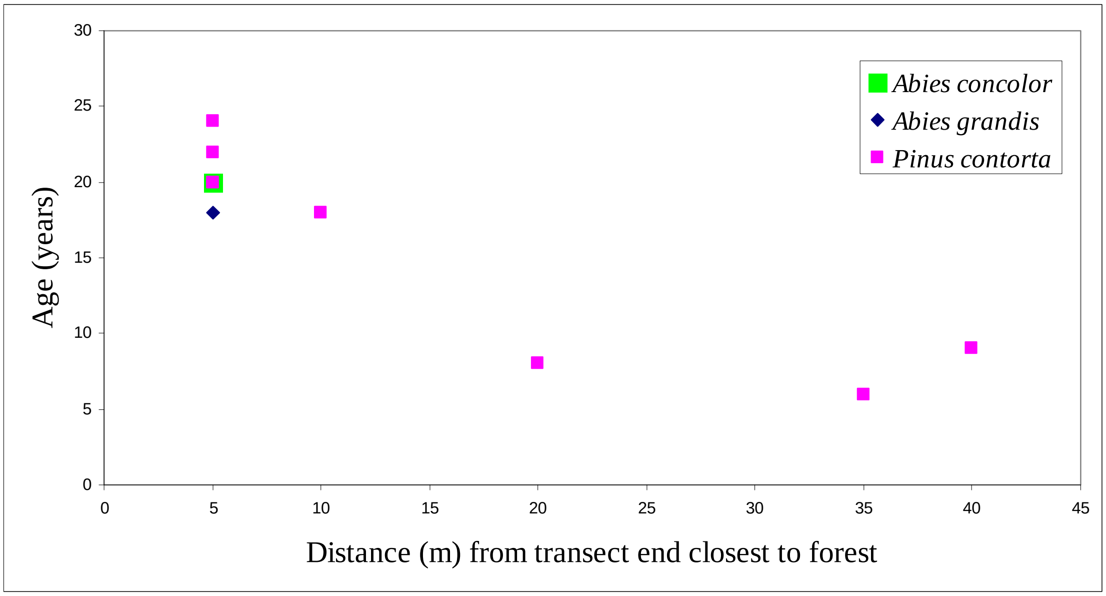

Figure 5.4. Age of trees by species in relation to the distance from the end of the transect closest to the forest in Transect 1.

Transect T2: Green Island

Transect T2 is oriented SE to NW with a bearing of 228 degrees (Figure 5.5). The 5x5 meter blocks are labeled and correspond to the data table below (Table 5.4). This transect is located on a steep slope with several other “tree islands” surrounded by open meadow. The entire extent of the island is encompassed by the field survey.

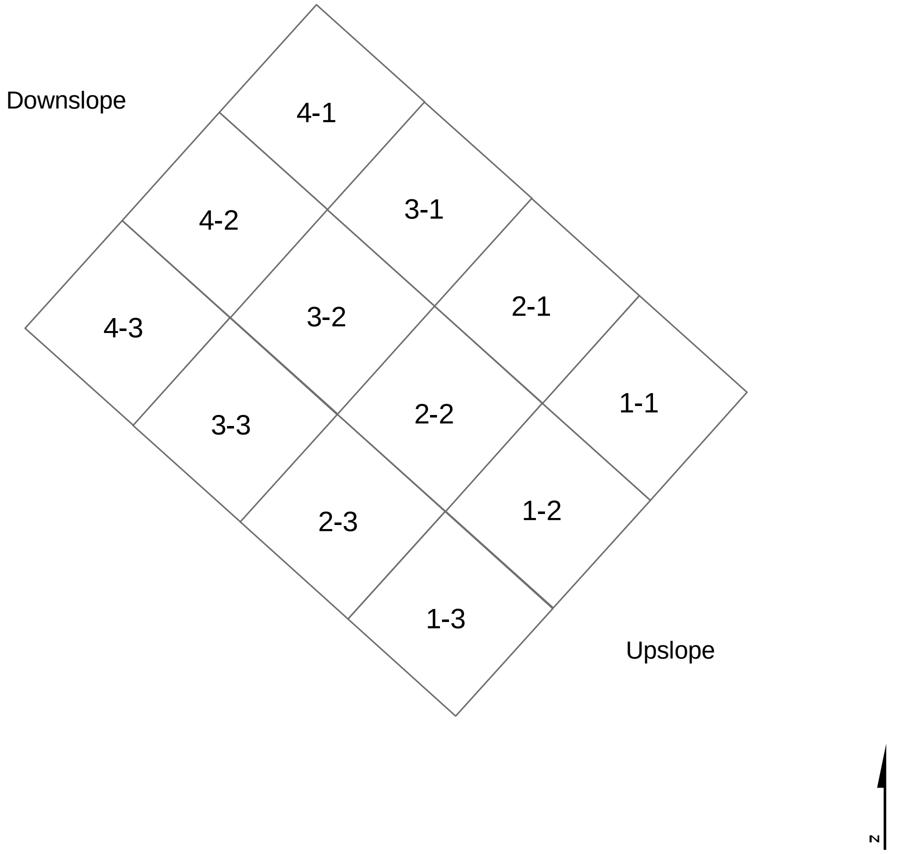

Figure 5.5. Orientation and designation of survey blocks for Transect T2.

Table 5.4. Transect T2 field data by survey block. Survey Block designation corresponds to Figure 5.5. Species codes are found in Table 5.3. The count column refers to all the occurrences of that species by size class per survey block. The dbh size class pertains to all occurrences and the sample dbh and age pertain to just the subset of trees sampled.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
1-1	*Abies grandis*	1	5-10	5.1	28
1-1	*Abies grandis*	1	0-5	2.3	28
1-1	*Abies grandis*	1	5-10	8.5	11
1-2	*Abies grandis*	7	seedling	X	X
1-2	*Abies grandis*	19	0-5	3.6	29
1-2	*Abies grandis*	9	5-10	7.0	15
1-3	*Abies grandis*	8	seedling	X	X
1-3	*Abies grandis*	5	0-5	3.3	16
1-3	*Abies grandis*	1	5-10	6.7	12
2-1	*Thuja plicata*	1	seedling	X	X
2-1	*Abies grandis*	3	seedling	X	X
2-1	*Abies grandis*	3	0-5	1.7	33
2-1	*Abies grandis*	2	5-10	5.5	11
2-1	*Abies grandis*	1	20-30	21.9	25
2-2	*Abies grandis*	6	0-5	1.3	22
2-2	*Abies grandis*	7	seedling	X	X
2-2	*Tsuga heterophylla*	1	5-10	6.2	15
2-3	*Abies grandis or concolor*	1	seedling	X	X
2-3	*Thuja plicata*	1	10-20	9.7	12
2-3	*Abies grandis*	5	seedling	X	X
2-3	*Abies grandis*	12	0-5	2.4	16
2-3	*Abies grandis*	7	5-10	7.7	13
2-3	*Abies grandis*	1	10-20	10.4	17
2-3	*Abies concolor*	2	seedling	X	X
3-1	*Abies grandis*	1	seedling	X	X
3-1	*Abies grandis*	2	5-10	6.8	5
3-1	*Abies grandis*	2	20-30	22.5	29
3-1	*Pseudotsuga menziesii*	1	30-40	36.2	26
3-2	*Abies grandis*	4	10-20	11.2	24
3-2	*Abies grandis*	3	0-5	1.7	28
3-2	*Abies grandis*	10	seedling	X	X
3-2	*Abies grandis*	1	5-10	5.2	21
3-3	*Abies grandis*	1	60-70	X	X

Table 5.4 continued. Transect T2 field data by survey block.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
3-3	*Abies grandis*	6	seedling	X	X
3-3	*Pseudotsuga menziesii*	1	seedling	X	X
3-3	*Abies grandis or concolor*	1	5-10	8.4	16
3-3	*Abies grandis or concolor*	3	10-20	14.9	24
4-1	*Abies grandis*	2	seedling	X	X
4-1	*Pseudotsuga menziesii*	1	10-20	16.1	27
4-2	*Abies grandis*	1	5-10	5.8	22
4-2	*Abies grandis*	2	0-5	1.8	21
4-2	*Abies grandis or concolor*	1	80-90	X	X
4-3	*Pseudotsuga menziesii*	1	20-30	25.6	25

The species found in this transect are white fir, grand fir, Douglas-fir, western redcedar, and western hemlock. In a few instances, it was difficult to tell if a fir was actually grand fir or white fir and it is noted in Table 5.4. This difficulty arises from the fact that in Oregon, white fir and grand fir cross (Jensen and Ross, 2005). At the northwestern end of the transect, notably large grand fir (or white fir) trees were established with somewhat smaller Douglas-firs. Grand fir overwhelmingly dominated with 142 stems compared to two western redcedar seedlings, one western hemlock, and four Douglas-firs. *Pseudotsuga menziesii* were roughly the same ages but occurred mostly on the downlospe end of the transect (Figure 5.6). *Abies grandis* occurred throughout the transect but tended to be younger farther away from the downslope end with the older Pseudotsuga menziesii (Figure 5.6).

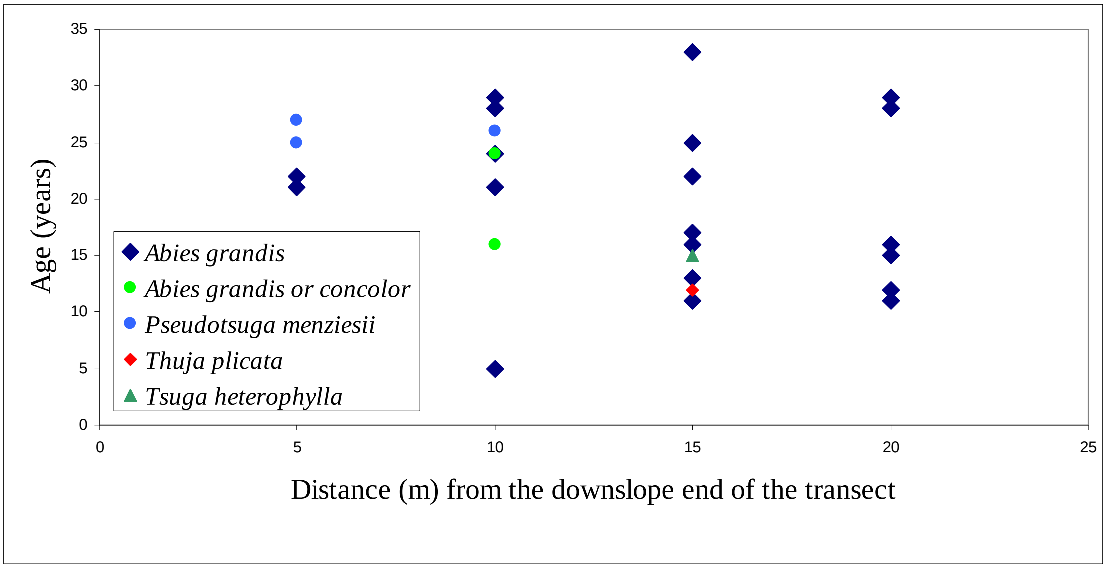

Figure 5.6. Age of trees by species in relation to the distance from the downslope end of Transect 2.

Transect T3: Burnt Edge

Transect T3 is oriented SSW to NNE with a bearing of 10 degrees (Figure 5.7). The meadow side of the transect occurs at the SSE end and the forest side occurs at the NNW end. The 5x5 meter blocks are labeled and correspond to the data table below (Table 5.5). This transect is located on a relatively flat area on the northeastern edge of the meadow. Though this area was burned in 1996, fire scars could not be found within the transect.

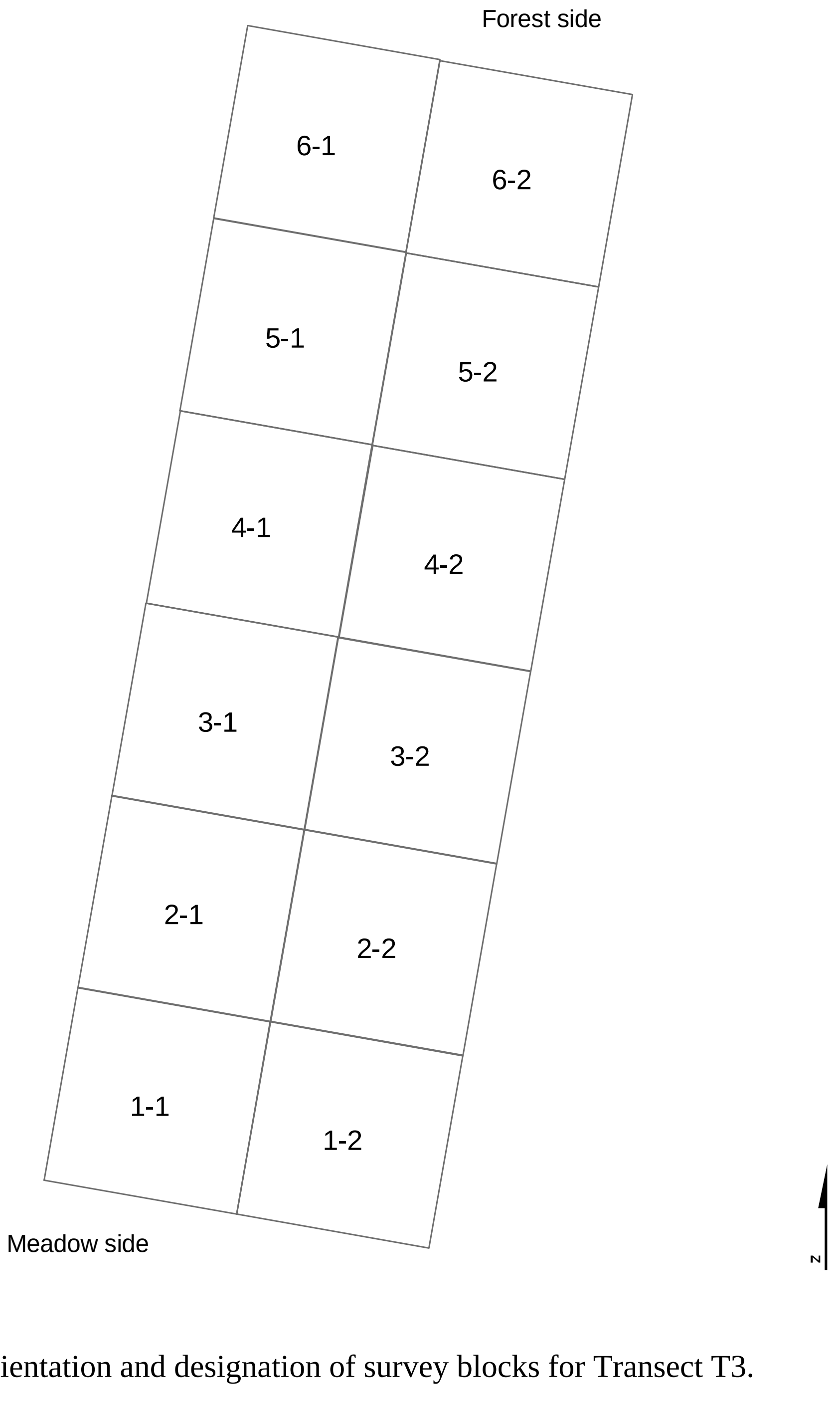

Figure 5.7. Orientation and designation of survey blocks for Transect T3.

Table 5.5. Transect T3 field data by survey block. Survey Block designation corresponds to Figure 5.7. Species codes are found in Table 5.3. The count column refers to all the occurrences of that species by size class per survey block. The dbh size class pertains to all occurrences and the sample dbh and age pertain to just the subset of trees sampled.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
1-1	*Pinus contorta*	8	seedling	X	X
1-2	*Pinus contorta*	2	10-20	10.5	12
1-2	*Pinus contorta*	3	seedling	X	X
2-1	*Pinus contorta*	5	seedling	X	X
2-2	*Pinus contorta*	1	10-20	12.1	19
2-2	*Pinus contorta*	13	seedling	X	X
3-1	*Pinus contorta*	3	5-10	5.2	14
3-1	*Pinus contorta*	13	10-20	12.2	22
3-1	*Pinus contorta*	3	seedling	X	X
3-2	*Pinus contorta*	3	seedling	X	X
4-1	*Pinus contorta*	7	5-10	9.4	14
4-1	*Pinus contorta*	4	10-20	16.5	23
4-1	*Tsuga heterophylla*	1	5-10	2.7	19
4-2	*Pinus contorta*	2	5-10	2.7	21
4-2	*Pinus contorta*	10	10-20	10.2	17
5-1	*Pinus contorta*	1	0-5	2.5	22
5-1	*Abies grandis*	2	10-20	16.6	42
5-1	*Abies grandis*	1	30-40	28.3	33
5-1	*Pseudotsuga menziesii*	1	30-40	X	X
5-1	*Pseudotsuga menziesii*	1	20-30	21.2	46
5-1	*Tsuga heterophylla*	1	10-20	10.6	23
5-1	*Abies grandis*	1	5-10	9	34
5-1	*Pinus contorta*	1	20-30	21.8	31
5-2	*Pinus contorta*	1	20- 30	26.4	22
5-2	*Pinus contorta*	1	0-5	1.3	12
5-2	*Pinus contorta*	1	seedling	X	X
5-2	*Abies grandis*	2	10-20	10.8	25
5-2	*Abies grandis*	1	20-30	21.8	29
6-1	*Pseudotsuga menziesii*	1	30-40	30.6	44
6-1	*Pseudotsuga menziesii*	1	10-20	15.8	30
6-1	*Pseudotsuga menziesii*	2	40-50	X	X
6-1	*Abies grandis*	2	0-5	3.1	23

Table 5.5 continued. Transect T3 field data by survey block.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
6-1	*Abies grandis*	1	10-20	12.3	17
6-1	*Pseudotsuga menziesii*	1	0-5	2.6	20
6-2	*Abies grandis*	1	10-20	10.2	23
6-2	*Tsuga heterophylla*	1	0-5	1.5	17
6-2	*Tsuga heterophylla*	1	20-30	25.4	27
6-2	*Pinus contorta*	1	10-20	15.2	42

The species found in this transect are grand fir, lodgepole pine, Douglas-fir, and western hemlock and are recorded in the Table 5.5. The southwestern end of the transect contained only lodgepole pine. Lodgepole then diminished almost entirely towards the northeastern end where western hemlock, Douglas-fir, and grand fir were established. One older lodgepole (42 yrs) occurred at the very northeastern end of the transect. Seven Douglas-fir trees constituted the majority of the trees greater than 30 cm dbh. Eleven grand fir, mostly over 10 cm dbh, and four western hemlock of various size classes occurred towards the northeastern end of the transect. *Pinus contorta* occurred throughout the transect but tended to be younger with increased distance from the transect's forested end (Figure 5.8). *Pseudotsuga menziesii*, *Abies grandis*, and *Tsuga heterophylla* did not occur in survey blocks further than 20 meters from the transect's forested end (Figure 5.8).

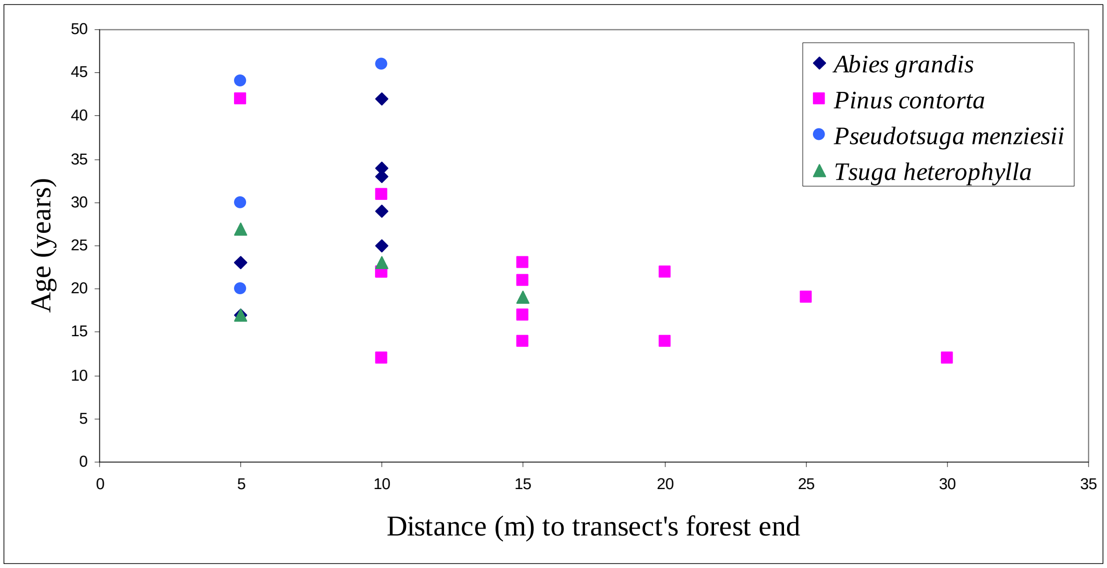

Figure 5.8. Age of trees by species in relation to the distance from the forested end of Transect 3.

Transect T4: Green Edge

Transect T4 is oriented NW to SE with a bearing of 139 degrees (Figure 5.9). The 5x5 meter blocks are labeled and correspond to the data table below (Table 5.6). This transect is located on a moderately steep slope with the forest side of the transect terminating a few meters from Fisher Creek.

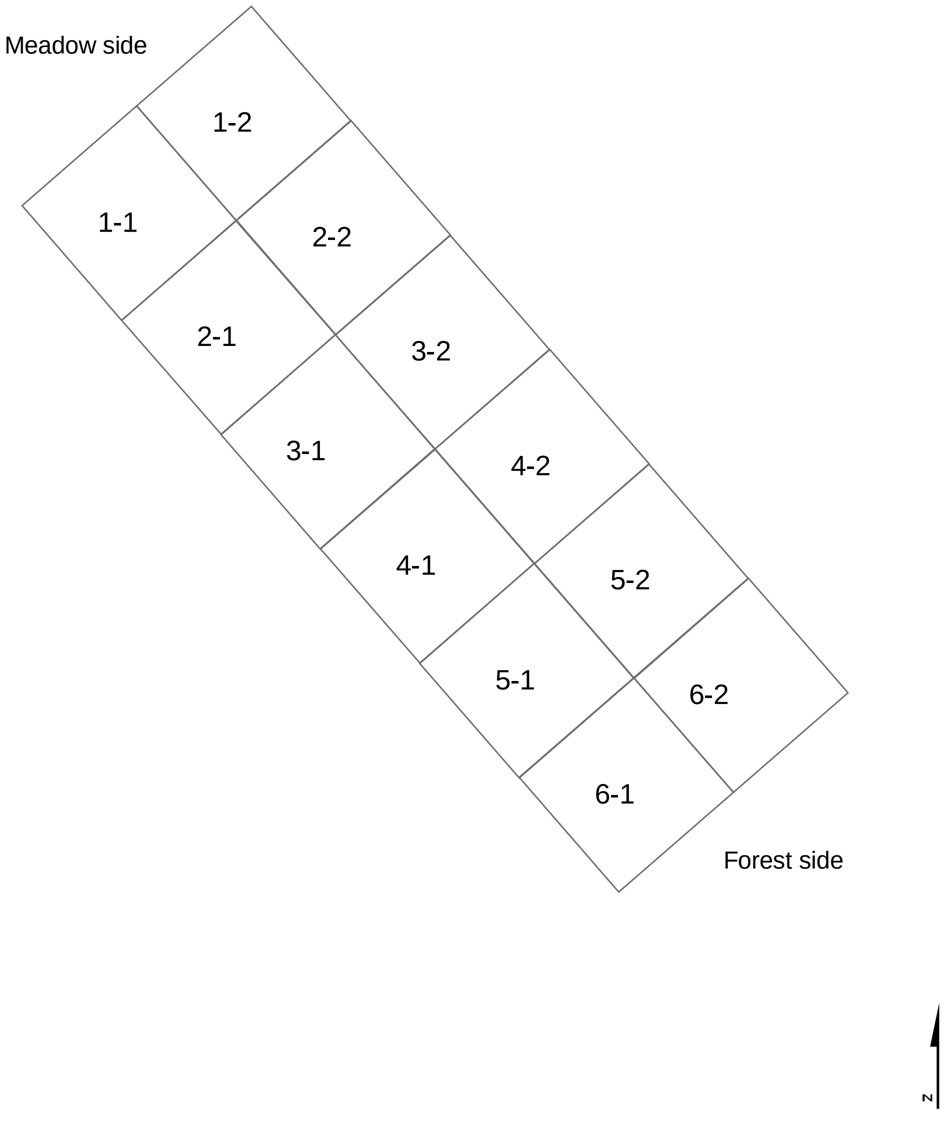

Figure 5.9. Orientation and designation of survey blocks for Transect T4.

Table 5.6. Transect T4 field data by survey block. Survey Block designation corresponds to Figure 5.9. Species codes are found in Table 5.3. The count column refers to all the occurrences of that species by size class per survey block. The dbh size class pertains to all occurrences and the sample dbh and age pertain to just the subset of trees sampled.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
1-1	*Abies grandis*	3	seedling	X	X
1-1	*Abies grandis*	1	0-5	4.3	32
1-1	*Tsuga heterophylla*	2	20-30	22.1	39
1-1	*Pseudotsuga menziesii*	1	5-10	8.3	15
1-1	*Pinus contorta*	2	10-20	15.7	29
1-1	*Abies grandis*	5	seedling	X	X
1-1	*Pseudotsuga menziesii*	1	0-5	1.7	28
1-1	*Tsuga heterophylla*	1	5-10	5.6	21
1-1	*Abies grandis*	2	0-5	2.4	19
1-1	*Pinus contorta*	1	20-30	29.2	42
1-2	*Abies grandis*	4	seedling	X	X
1-2	*Abies grandis*	3	0-5	1.8	31
1-2	*Pseudotsuga menziesii*	1	10-20	19.2	41
1-2	*Pinus contorta*	2	10-20	12.8	37
1-2	*Abies grandis*	2	10-20	13.1	23
2-1	*Abies grandis*	5	seedling	X	X
2-1	*Tsuga heterophylla*	2	seedling	X	X
2-1	*Abies grandis*	1	0-5	1.4	20
2-1	*Abies grandis*	1	5-10	7.1	17
2-1	*Pinus contorta*	1	20-30	23.3	X
2-1	*Tsuga heterophylla*	3	0-5	2.8	27
2-1	*Tsuga heterophylla*	1	5-10	7.2	21
2-2	*Pseudotsuga menziesii*	4	10-20	15.4	22
2-2	*Tsuga heterophylla*	2	seedling	X	X
3-1	*Pseudotsuga menziesii*	3	5-10	9.9	35
3-1	*Pseudotsuga menziesii*	1	0-5	1.2	20
3-1	snag	1	10-20	X	X

Table 5.6 continued. Transect T4 field data by survey block.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
3-1	snag	1	0-5	X	X
3-1	*Pseudotsuga menziesii*	2	30-40	38.1	55
3-2	*Abies grandis*	1	5-10	5.6	27
3-2	snag	1	0-5	X	X
3-2	snag	2	10-20	X	X
3-2	*Tsuga heterophylla*	2	seedling	X	X
3-2	*Abies grandis*	1	seedling	X	X
3-2	*Pseudotsuga menziesii*	1	0-5	2.6	28
3-2	*Pseudotsuga menziesii*	1	10-20	18.1	39
4-1	*Pseudotsuga menziesii*	7	0-5	4.4	25
4-1	*Thuja plicata*	3	10-20	12.5	35
4-1	snag	1	30-40	X	X
4-1	*Thuja plicata*	1	20-30	26.1	76
4-1	*Pseudotsuga menziesii*	4	10-20	8.1	36
4-1	snag	2	10-20	X	X
4-1	snag	1	20-30	X	X
4-1	snag	1	20-30	X	X
4-1	*Pseudotsuga menziesii*	1	30-40	36.4	46
4-1	*Abies grandis*	3	10-20	12.1	25
4-1	*Abies grandis*	3	5-10	6.7	36
4-1	*Abies grandis*	1	0-5	1.8	26
4-2	*Abies grandis*	1	0-5	1.7	21
4-2	*Tsuga heterophylla*	3	seedling	X	
4-2	*Pseudotsuga menziesii*	4	5-10	5.9	X
4-2	*Pseudotsuga menziesii*	1	20-30	29.7	37
5-1	*Pseudotsuga menziesii*	4	0-5	3.8	40
5-1	*Pseudotsuga menziesii*	2	seedling	X	X
5-1	snag	2	5-10	X	X
5-1	snag	2	20-30	X	X

Table 5.6 continued. Transect T4 field data by survey block.

Survey Block	**Species**	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
5-1	*Pseudotsuga menziesii*	3	10-20	14.1	31
5-1	*Abies grandis*	2	0-5	1.5	20
5-1	*Abies grandis*	2	10-20	19.1	17
5-1	*Abies grandis*	2	seedling	X	X
5-1	*Tsuga heterophylla*	2	seedling	X	X
5-1	*Pseudotsuga menziesii*	2	seedling	X	X
5-1	*Tsuga heterophylla*	1	0-5	2.7	30
5-1	*Abies procera*	1	30-40	32.0	44
5-1	*Thuja plicata*	4	10-20	10.7	57
5-2	*Pseudotsuga menziesii*	2	5-10	5.6	42
5-2	*Pseudotsuga menziesii*	4	10-20	16.1	37
5-2	*Thuja plicata*	2	10-20	16.9	43
5-2	*Tsuga heterophylla*	1	seedling	X	X
5-2	*Abies grandis*	1	seedling	X	X
5-2	*Pseudotsuga menziesii*	2	0-5	2.9	X
6-1	*Abies grandis*	3	seedling	X	X
6-1	*Tsuga heterophylla*	1	seedling	X	X
6-1	*Tsuga heterophylla*	1	5-10	5.8	43
6-1	*Pseudotsuga menziesii*	1	30-40	38.6	83
6-1	*Tsuga heterophylla*	1	5-10	7.3	25
6-1	*Abies grandis*	2	seedling	X	X
6-1	*Tsuga heterophylla*	3	seedling	X	X
6-1	*Tsuga heterophylla*	1	0-5	3.7	33
6-1	*Tsuga heterophylla*	1	10-20	14.4	41
6-2	*Abies procera*	1	5-10	7.1	42

Table 5.6 continued. Transect T4 field data by survey block.

Survey Block	***Species***	**Count**	**dbh size class (cm)**	**Sample dbh (cm)**	**Age (years)**
6-2	*Tsuga heterophylla*	4	seedling	X	X
6-2	*Abies procera*	2	seedling	X	X
6-2	*Pseudotsuga menziesii*	1	20-Oct	13.7	34
6-2	*Tsuga heterophylla*	3	10-May	4.6	32
6-2	snag	1	40-50	X	X
6-2	*Tsuga heterophylla*	2	seedling	X	X
6-2	*Abies grandis*	4	seedling	X	X
6-2	*Tsuga heterophylla*	1	10-May	7.9	39
6-2	*Pseudotsuga menziesii*	1	70-80	76.5	94
6-2	snag	1	20-30	X	X
6-2	*Pseudotsuga menziesii*	1	40-50	42.5	66

The species found in this transect include white fir, grand fir, noble fir, lodgepole pine, Douglas-fir, western hemlock, and western redcedar (Table 5.6). The dominant species in this transect are grand fir and Douglas-fir. Western hemlock was also prevalent. Only a handful of lodgepole pine, noble fir, and western redcedar were present. Sixteen snags of various sizes were counted. The largest and oldest trees appeared to be the Douglas-fir. Overall, the sizes of the trees increased towards the southeastern end of the transect (that is, moving toward the forest edge). Lodgepole pine was only found towards the northwestern end of the transect (i.e., farthest from the forest edge). *Pseudotsuga menziesii* occurred throughout the transect but were older the closer to the transect's forested end (Figure 5.10). *Pinus contorta* only occurred 30 meters or more away from the forested end while *Thuja plicata* did not occur further than 15 meters from the forested end (Figure 5.10). *Abies grandis* and *Tsuga heterophylla* occurred throughout the transect and did not show a particular relationship between distance for forested end and age (Figure 5.10). *Abies procera* occurred only within 10 meters from the forested end (Figure 5.10).

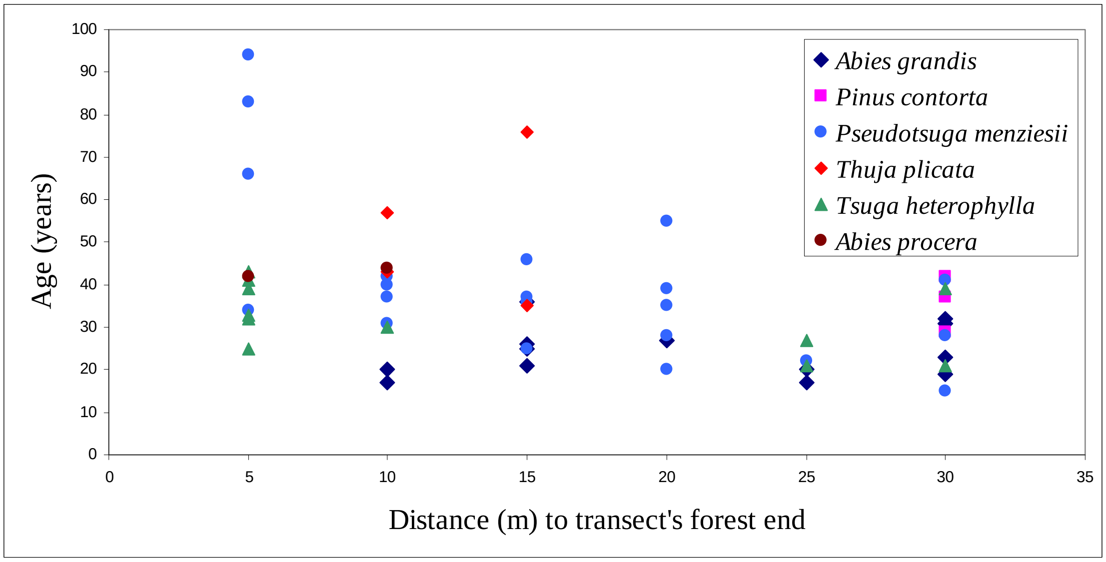

Figure 5.10. Age of trees by species in relation to the distance from the forested end of Transect 4.

5.5.2 Comparison of dbh and age

For all *Abies grandis* samples, there appears to be no relationship between age and dbh (R^2 = 0.04) (Figure 5.11). The same is true when looking at age and dbh in Transect 2 (R^2 = 0.002) (Figure 5.12), Transect 3 (R^2 = 0.0.18) (Figure 5.13), and Transect 4 (R^2 = 0.04) (Figure 5.14). (There was only one Abies grandis in Transect 1.)

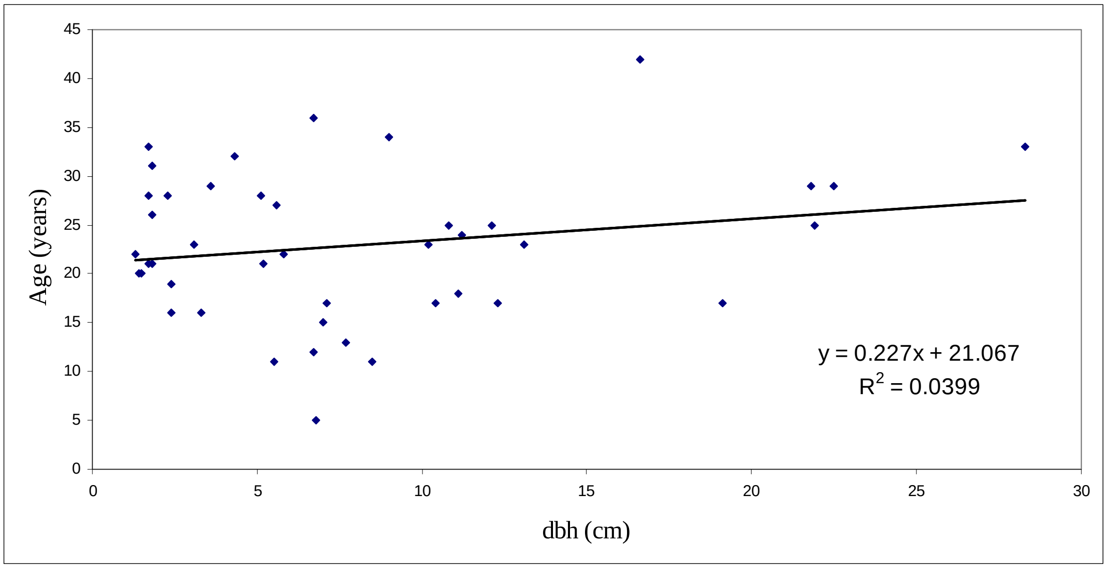

Figure 5.11. Plot of relationship between age and dbh (cm) for all *Abies grandis* samples.

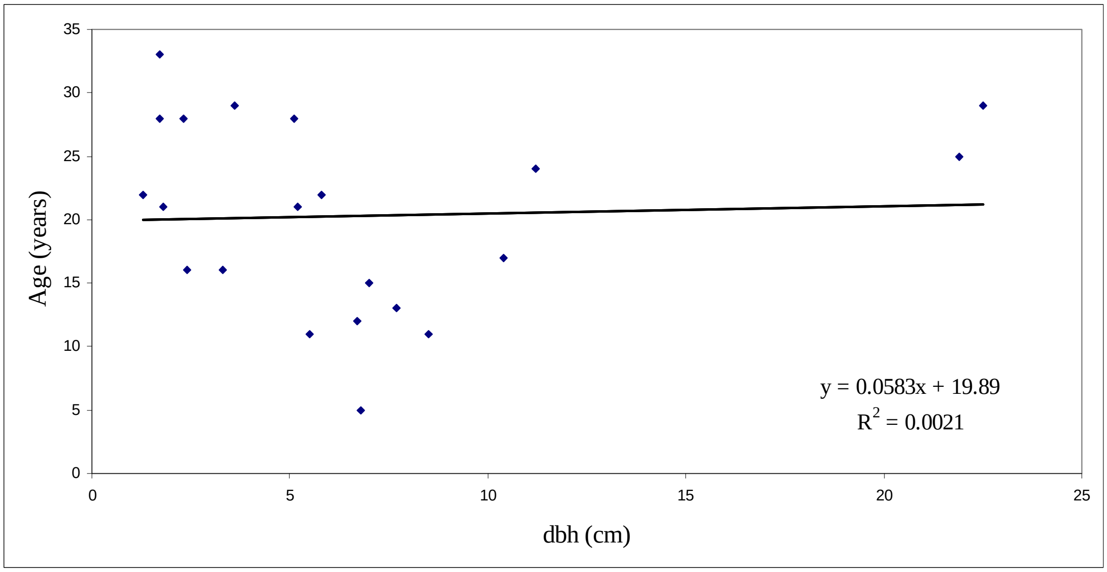

Figure 5.12. Plot of relationship between age and dbh (cm) for *Abies grandis* samples taken from Transect 2.

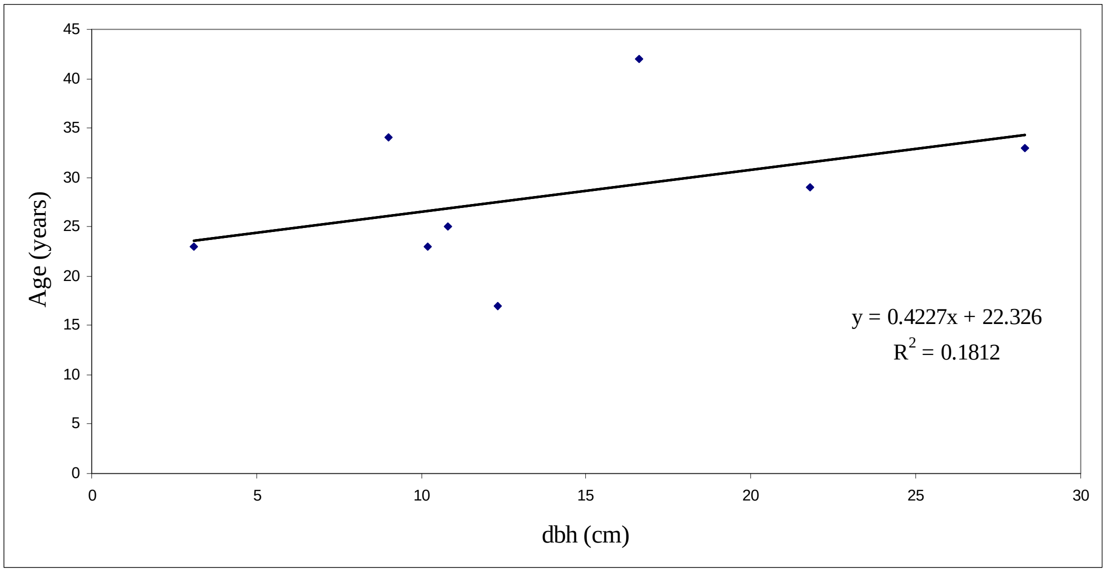

Figure 5.13. Plot of relationship between age and dbh (cm) for *Abies grandis* samples taken from Transect 3. R^2 was not calculated due to the small sample size.

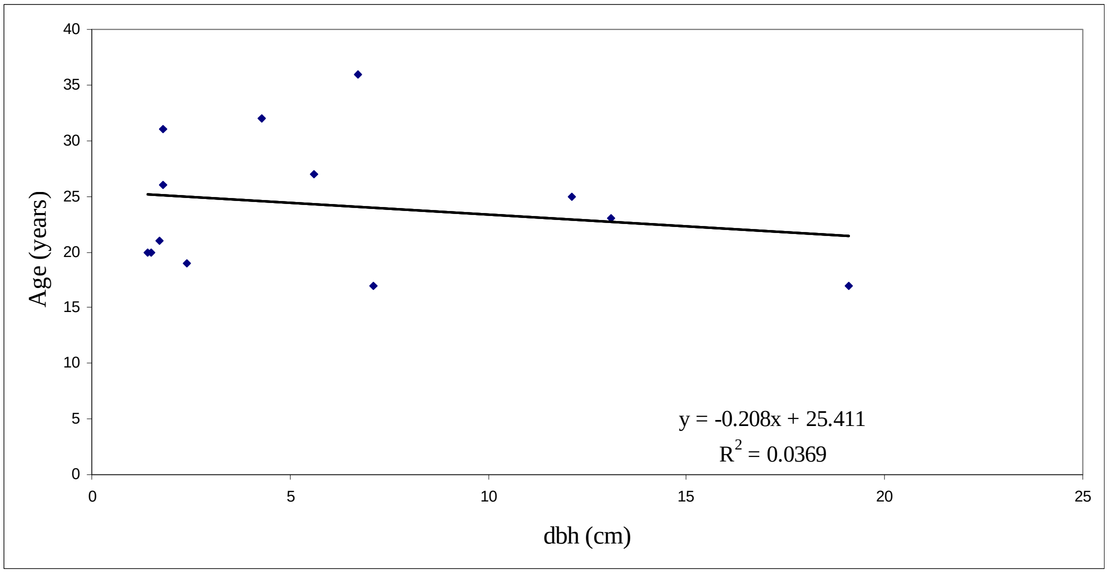

Figure 5.14. Plot of relationship between age and dbh (cm) for *Abies grandis* samples taken from Transect 4.

For species *Pinus contorta* in all transects, dbh is only marginally explained by tree age ($R^2 = 0.4$) (Figure 5.15). When comparing age and dbh in Transects 1 and 3, this relationship weakens even further (Figures 5.16 and 5.17). There were no *Pinus contorta* in Transect 2 and only two in Transect 4.

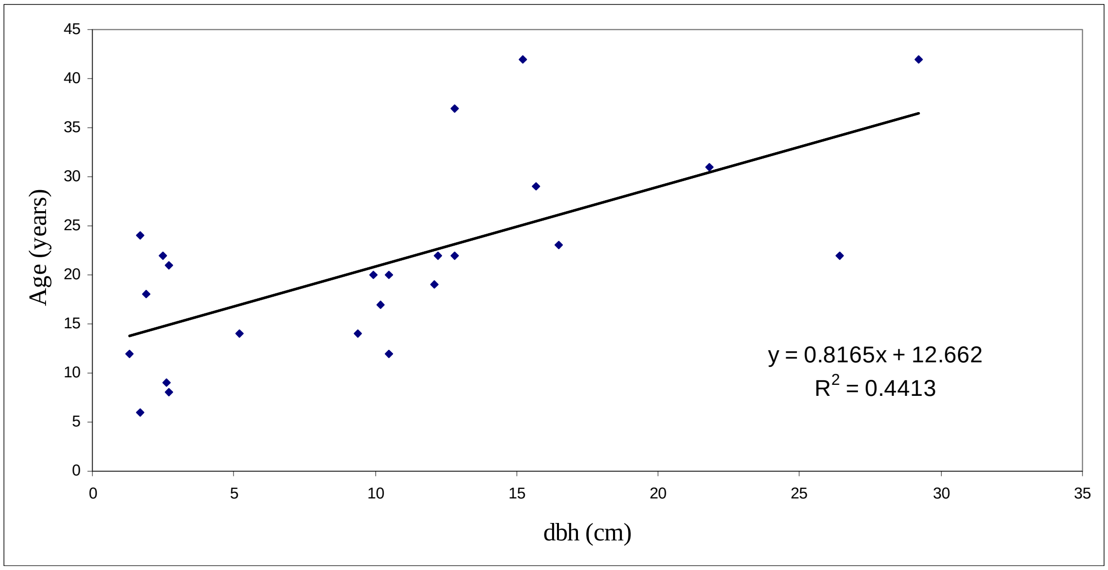

Figure 5.15. Plot of relationship between age and dbh (cm) for all *Pinus contorta* samples taken.

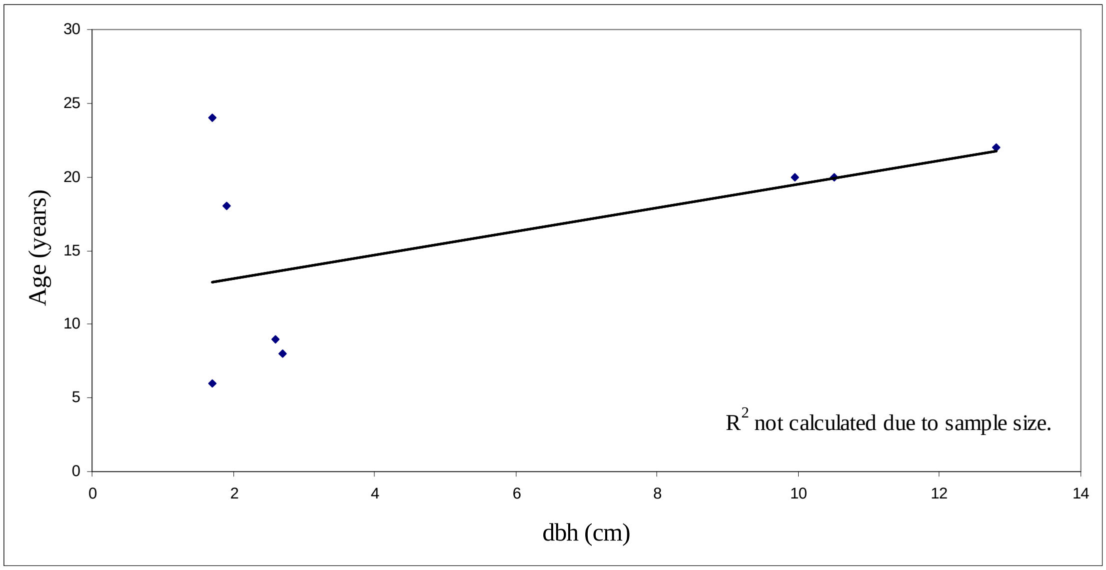

Figure 5.16. Plot of relationship between age and dbh (cm) for *Pinus contorta* samples taken in Transect 1. R^2 was not calculated due to the small sample size.

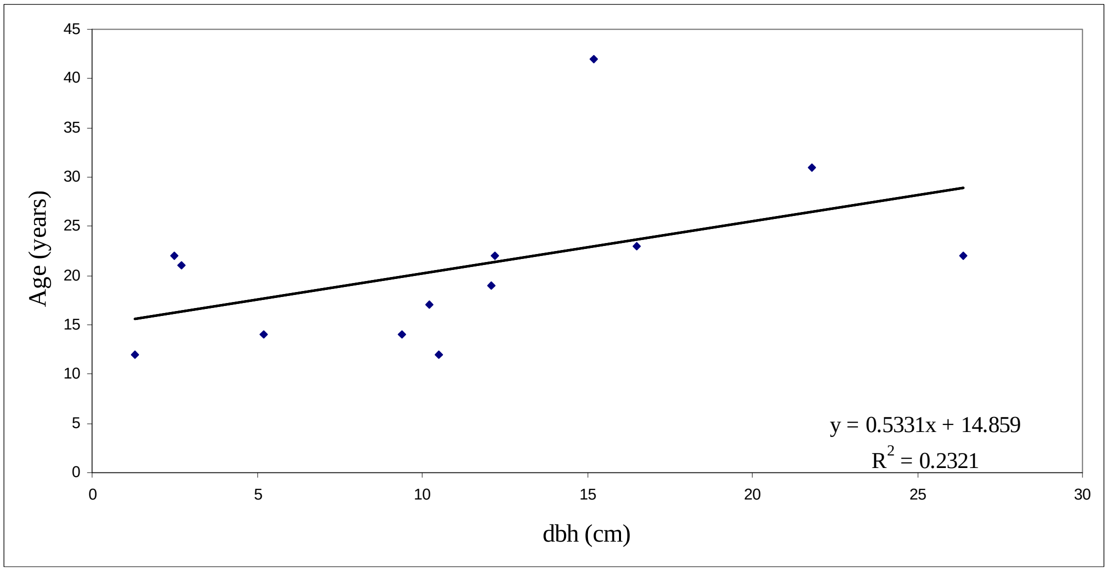

Figure 5.17. Plot of relationship between age and dbh (cm) for *Pinus contorta* samples taken in Transect 3.

For all *Pseudotsuga menziesii* sampled, the relationship between age and dbh is moderately correlated ($R^2 = 0.6$) (Figure 5.18). This relationship becomes stronger in Transect 3 (Figure 5.19) and Transect 4 (Figure 5.20) where average growth rate is almost 1 cm dbh per year in both transects. There were no *Pseudotsuga menziesii* in Transect 1 and only two in Transect 2.

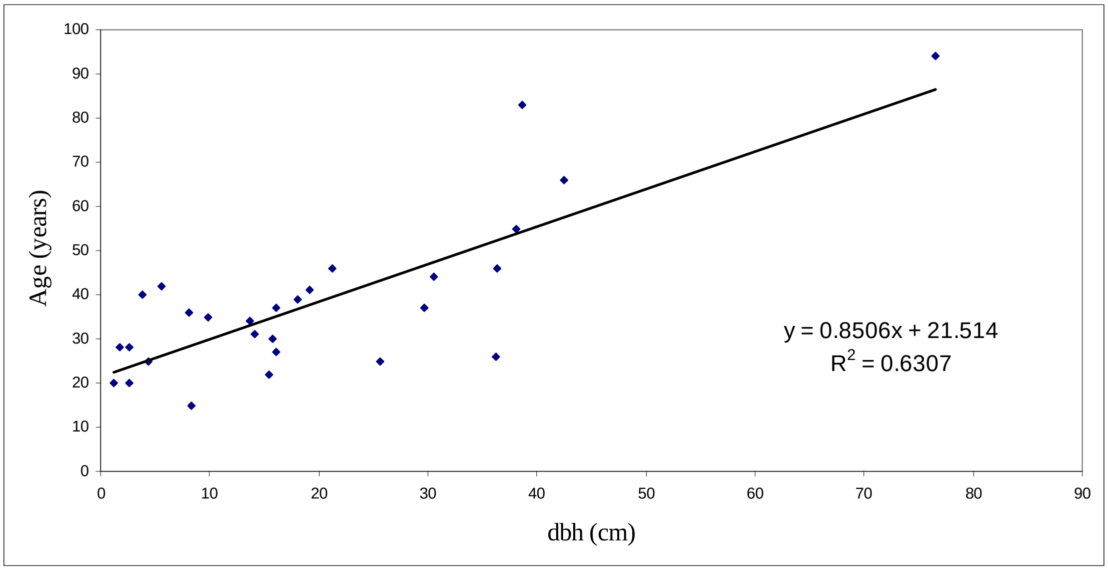

Figure 5.18. Plot of relationship between age and dbh (cm) for all *Pseudotsuga menziesii* samples taken.

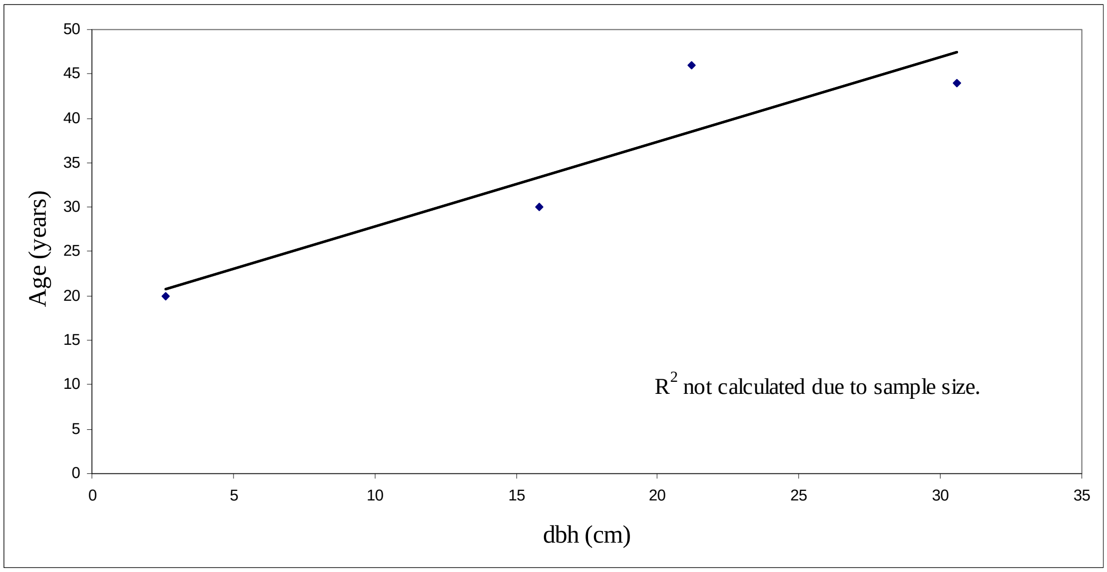

Figure 5.19. Plot of relationship between age and dbh (cm) for *Pseudotsuga menziesii* samples taken in Transect 3. R^2 was not calculated due to the small sample size.

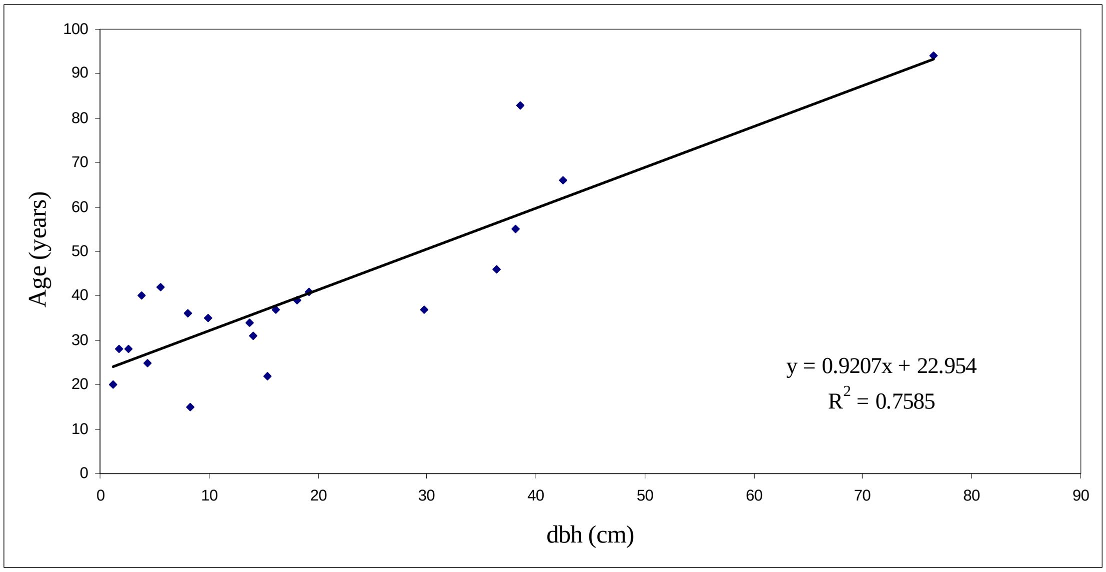

Figure 5.20. Plot of relationship between age and dbh (cm) for *Pseudotsuga menziesii* samples taken in Transect 4.

The five *Thuja plicata* sampled in all transects show a moderately strong relationship between age and dbh (Figure 5.21). No *Thuja plicata* occurred in Transects 1 or 3. One occurred in Transect 2 and the remaining 4 occurred in

Transect 4.

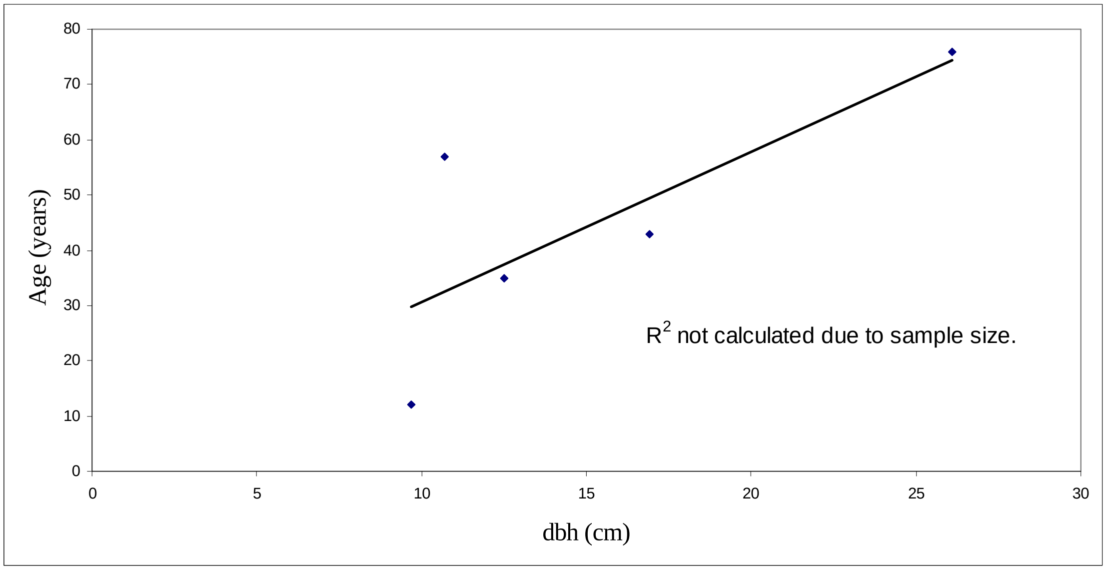

Figure 5.21. Plot of relationship between age and dbh (cm) for all *Thuja plicata* samples taken. R^2 was not calculated due to the small sample size.

The relationship between age and dbh for all of the *Tsuga heterophylla* is

Very weak ($R^2 = 0.1$) (Figure 5.22). However, this relationship appears quite strong when looking only at data collected in Transect 3 (Figure 5.23) with an average growth rate of 0.4 cm dbh per year. The relationship is weak in Transect 4 ($R^2 = 0.2$) (Figure 5.24). There are no Tsuga heterophylla in Transect 1 and only one in Transect 2.

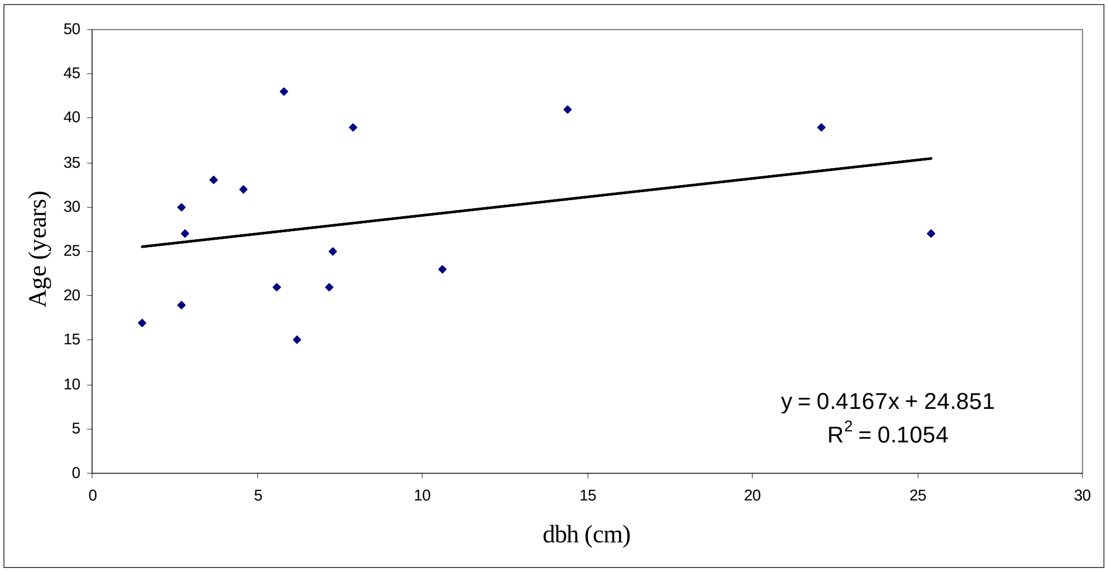

Figure 5.22. Plot of relationship between age and dbh (cm) for all *Tsuga heterophylla* samples taken.

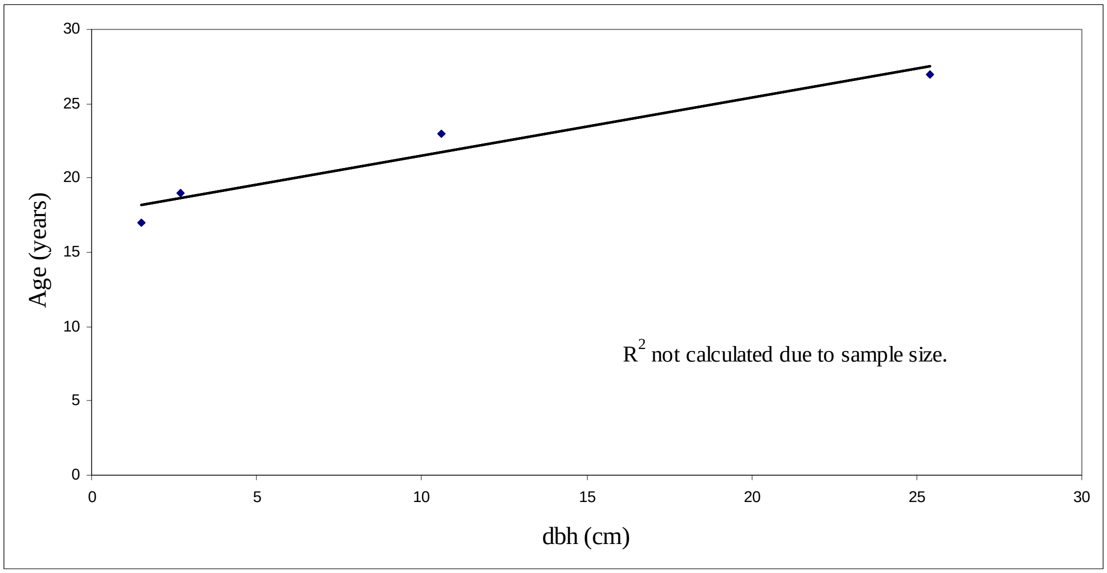

Figure 5.23. Plot of relationship between age and dbh (cm) for *Tsuga heterophylla* samples taken in Transect 3. R^2 was not calculated due to the small sample size.

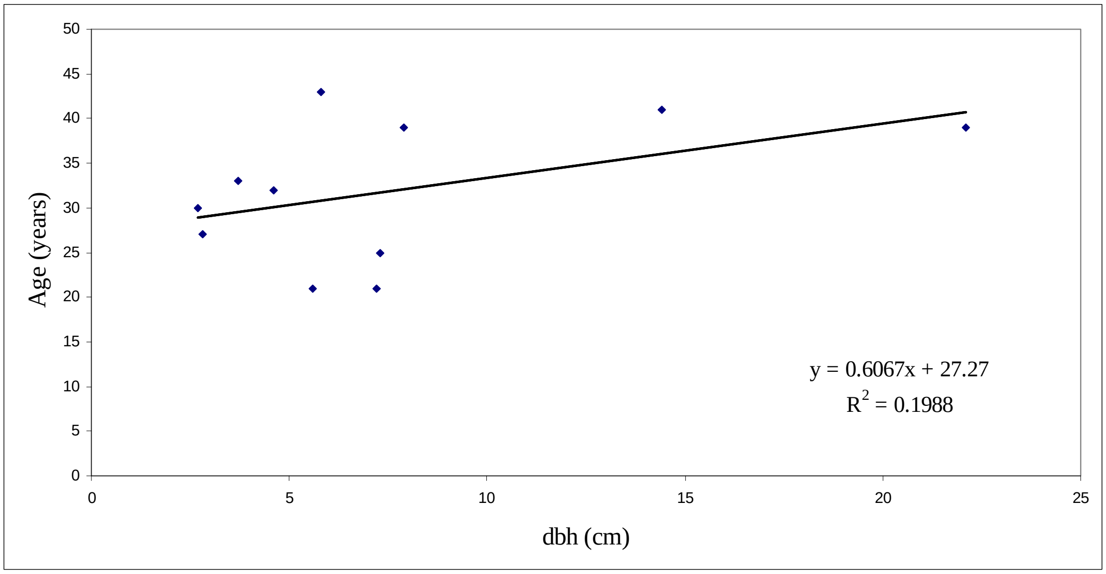

Figure 5.24. Plot of relationship between age and dbh (cm) for *Tsuga heterophylla* samples taken in Transect 4.

5.5.3 Snag size in Transect 4 relative to forest edge

Only two Transects (T1: Burnt Island and T4: Green Edge) contained snags. The snags in T1 were 10-80 cm dbh (Table 5.2) and had burned in 1996. There is no way of knowing if they died previous to or because of the fire. The snags in T4 were 0-50 cm dbh (Table 5.6) and were not burned indicating they may have died from stem exclusion or disease. There is a slight pattern of the larger snags occurring closer to the forested end of Transect 4 (Figure 5.25).

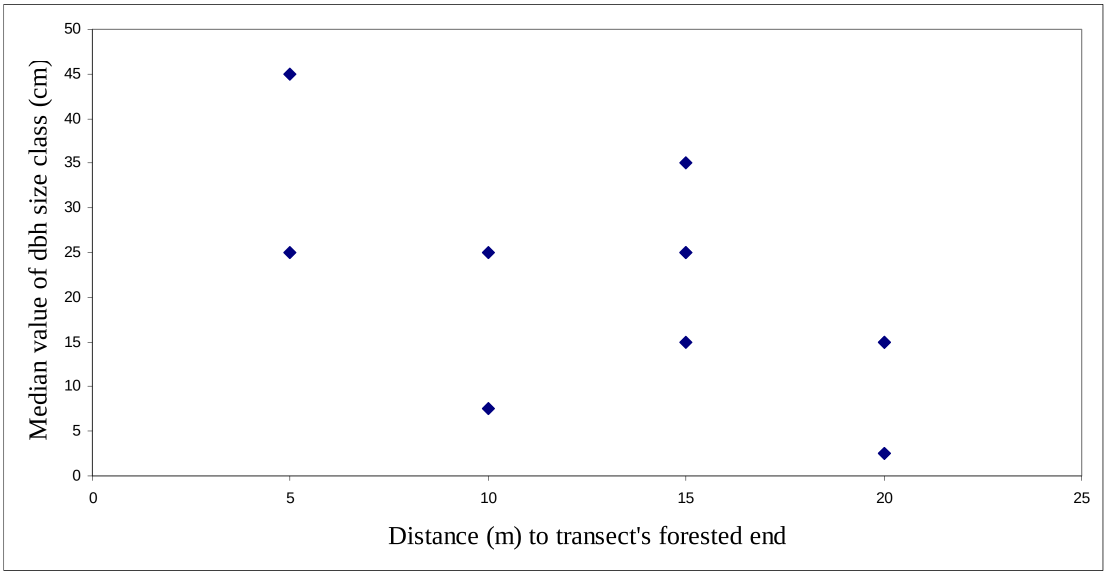

Figure 5.25. Plot of relationship between snag size and distance from forested end of Transect 4.

5.5.4 Relationship between seedling occurrence and location in transect

In Transect 1, *Abies concolor* and *Abies grandis* seedlings occur throughout most of the transect except in the survey block closest to the forest edge (Figure 5.26). *Pinus contorta* seedlings only occur in the survey blocks at least 20 meters from the end of the transect that is closest to the forest edge (Figure 5.26).

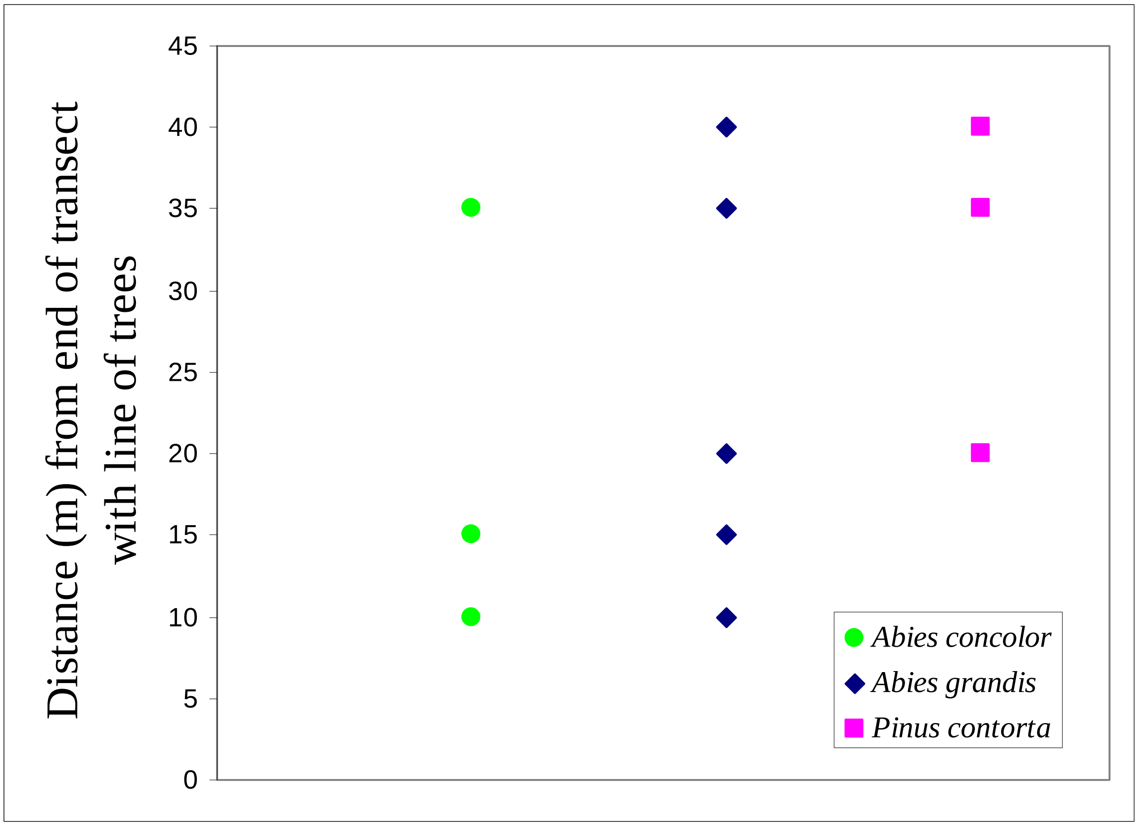

Figure 5.26 Plot of relationship between seedling occurrence and distance to end of Transect 1 closest to forest edge.

In transect 2, *Abies grandis* seedlings occurs throughout the transect while *Abies concolor*, and *Thuja plicata* seedlings occur closer to the upslope end of the transect (Figure 5.27). *Pseudotsuga menziesii* seedlings occur in the approximate middle of the transect (Figure 5.27).

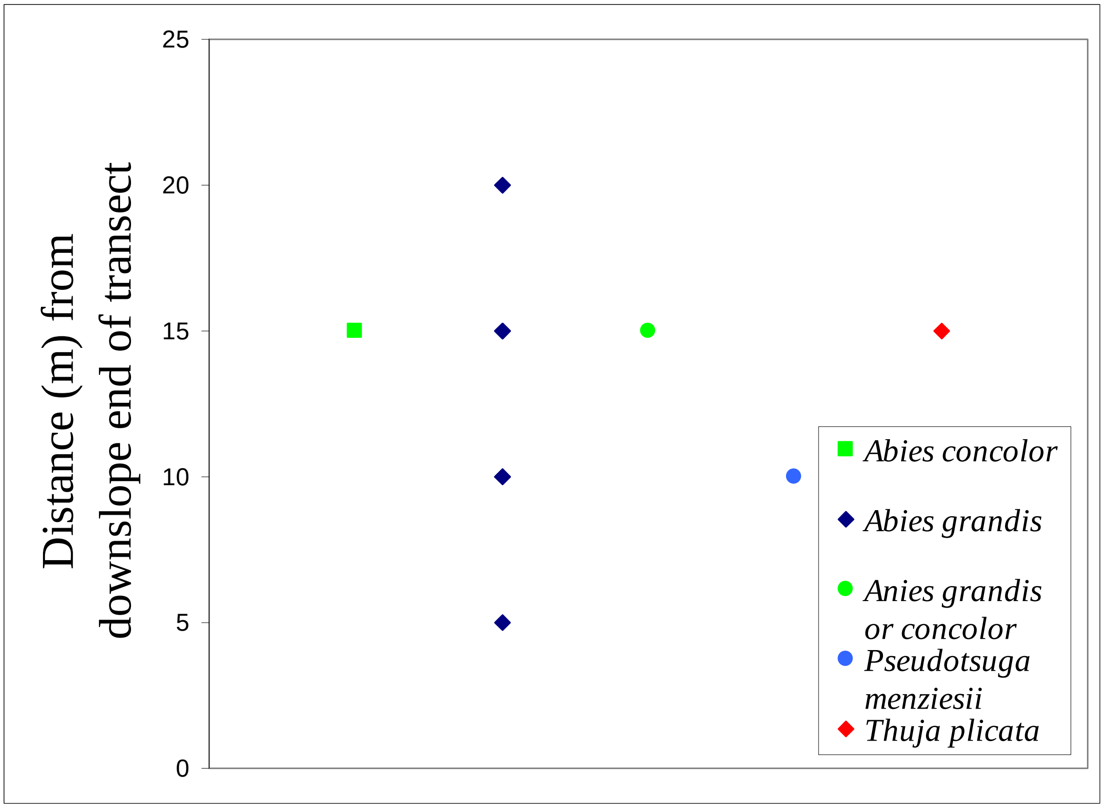

Figure 5.27 Plot of relationship between seedling occurrence and distance to downslope end of Transect 2.

Pinus contorta are the only seedlings counted in Transect 3 and occur more often the further from the forested end of the transect (Figure 5.28).

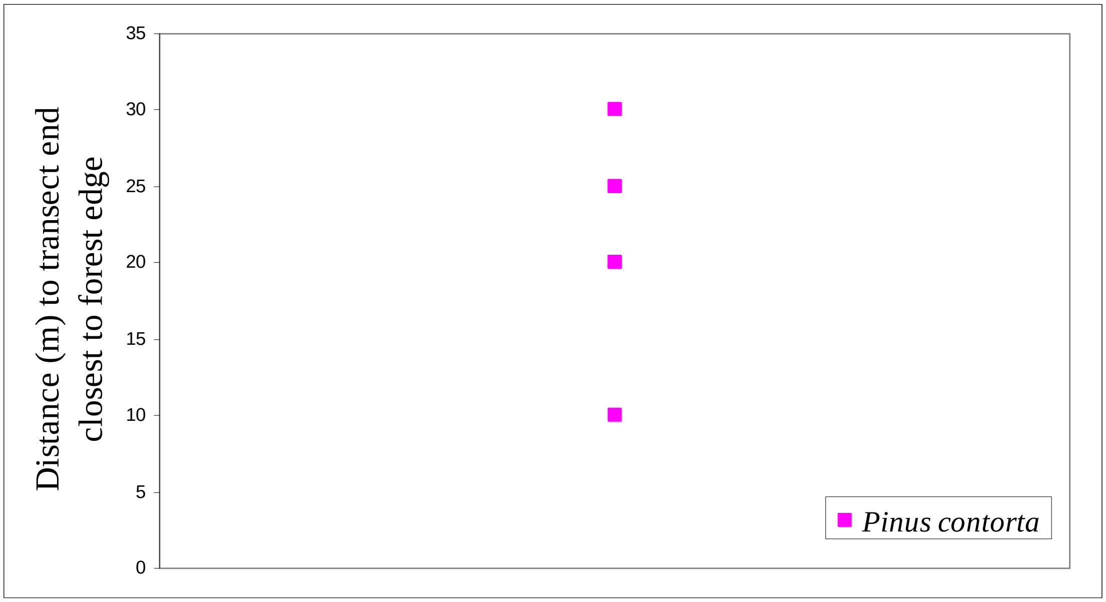

Figure 5.28 Plot of relationship between seedling occurrence and distance to forested end of Transect 3.

In Transect 4, *Abies grandis* and *Tsuga heterophylla* seedlings occur throughout out the transect though *Tsuga heterophylla* does not occur in the survey block closest to the meadow edge (Figure 5.29). *Abies procera* and *Pseudotsuga menziesii* seedlings occur within 10 meters of the forested end of the transect (Figure 5.29).

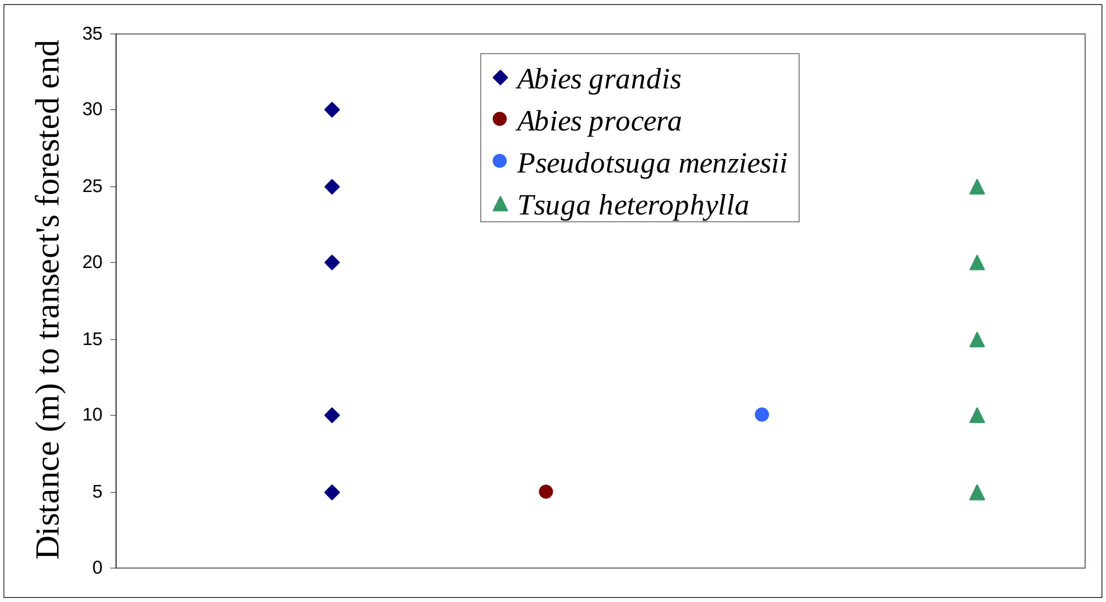

Figure 5.29 Plot of relationship between seedling occurrence and distance to forested end of Transect 4.

5.6 Discussion

The survey provides a pattern of species establishment and dominance. Though not every tree was sampled, there were obvious trends in the transects that could be understood through each species' tolerances to fire and shade. Site characteristics and land management also provide clues to invasion timing and patterns.

The T1 and T3 Transects were burned in 1996 and both contain a large number of *Pinus contorta* seedlings that are not found in T2 or as prevalent in T4. Though Burns and Honkala (1990) state that serotinous cones are not prevalent in Oregon, this large number of seedlings may indicate this is a case where they do occur and the previous management caused this species to proliferate. The mineralization of the soil in this area from the prescribed burn may have been good seed bed preparation, contributing to the large number of seedlings established after the fire. Future management should consider the intensity required to eradicate specific species under various age and density conditions and balance it with the undesirable impacts of such an intensity (i.e. soil mineralization promotes seedling establishment). In the case of Transects 1 and 3, continued tree removal or burning needs to occur to remove post-fire invasion of *Pinus contorta.*

Transects 3 and 4 are “edge” transects where invasion occurs from the historic forest edge. Similar to what Jakubos and Romme (1993) observed in their study area, overall trees became younger the further they were form the forested end of the transect. However, when looking at just *Abies grandis* and *Tsuga heterophylla* in Transect 4 (Figure 5.10), the ages appear to be roughly the same suggesting seedlings established all at once in a band similar to what Lepofsky (2003) found. If seedlings are establishing progressively, it may be because with each new seedling, the soil conditions and microclimate are becoming more favorable for subsequent seedling establishment. Establishment all at once in a band may indicate the ameliorating effects of the previously established trees have a certain range of influence reflected by the band’s width. In either case, this indicates eradication of the early invaders may tide the flow of subsequent invaders. Transect 3, the burnt island, doesn’t have a forested end but one end is closer to the forest than the other and the Pinus contorta show a linear decrease in age with distance to forest relationship. Transect 4 reflects an invasion pattern similar to the “leap and fill” patterns described by Norman and Taylor (2005) and Franklin et al. (1971).

The T2 encroachment pattern may be explained by the ameliorating effects of established trees and potential reduced snow pack (Lepofsky et al., 2003). The largest and presumably oldest tree, an 80-90 cm dbh *Abies grandis* or *Abies concolor* (or a cross between the two), was too large to core with available equipment. The surrounding trees were mostly between 25-30 years old and significantly smaller in girth. The single large tree may have provided favorable conditions for the younger trees to establish. The relatively uniform age of most of the non-seedlings may also indicate that reduced snowpack since 1970 (as suggested by Lepofsky et al. (2003)) on the steep south facing slope allowed for a greater growing season and encouraged conifer germination. This area was also heavily grazed and the cessation of grazing may be a contributing factor to invasion.

The burnt edge, T3, occurs at the margin of a dry meadow community (Salix, 2005). Shade from the older (30-46 years) Douglas-fir that occurs on the forested end of the transect may have facilitated establishment of shade tolerant western redcedar and western hemlock. The presence of western hemlock aged 17-27 years indicates that the prescribed fire of 1996 probably was of very low intensity. The co-dominance of grand fir with lodgepole pine may be a reflection of the moderate fire resistance of grand fir or its ability to tolerate more sun than the western hemlock or western redcedar.

Transect T4, the green edge, is within the mesic meadow community identified by Salix (2005). It is most shaded of all the transects and terminates at a creek. Lodgepole pine occurs only at the meadow end of the transect, suggesting that heavy shade further precludes its establishment there. Grand fir and Douglas-fir dominate, shading their even more shade tolerant associate western hemlock. Perhaps the small amount of western redcedar present is due to heavy browsing by deer and elk. There were many scat signs and game trails in this area. This transect was unique in that it had many small diameter snags with no evidence of char so presumably not killed by fire. These small snags may have been killed during the stem exclusion phase of this forest's establishment.

The pattern of encroachment in T4 reflects an upslope creep from forested to previously open areas. The ages of the trees become younger as the meadow edge is approached. Even more so than the green island, a pattern of "leap and fill" can be found in this area: the meadow side of this transect is being encroached from all sides and is nearly gone. Like all the other transects, this is a steep, south facing slope that was once heavily grazed by sheep. Therefore, increased wet periods between 1945 and 1985 (Miller and Halpern, 1998) and grazing may also be responsible for the timing of invasion in this transect.

Generally certain expected patterns were found. Shade intolerant *Pinus contorta* occurred in open areas and edges and shade tolerant *Thuja plicata* and *Tsuga heterophylla* occurred closer to the shaded forested end of transects. The latter were not found in areas that had burned owing to their fire intolerance. The distribution of seedlings demonstrated no patterns but the sample size was too small to consider this significant.

Though a subset of trees were destructively sampled and their age determined by counting rings, strong correlation between age and dbh could be made only for *Pseudotsuga menziesii*. This suggests that for future fine-scale encroachment studies that intend to relate specific fire, climate, or land use events to encroachment, all trees should be aged for best results.

6. Conclusion

This purpose of this study was to determine the distribution of meadows within the Willamette National Forest, identify conifer encroachment patterns into meadows within the Chucksney-Grasshopper meadow complex, and understand fine scale encroachment in one meadow. Three methods of analysis at three scales were used to achieve this: satellite remote sensing, historic photographic interpretation, and field surveys. The context of this study is the increased management and restoration of meadow habitat by agencies, such as the US Forest Service, in light of the decrease of its areal extent.

A land cover classification dataset was created that identifies meadow cover in the Willamette National Forest. It fills the data gap created by the previous focus of forest management on timber resources. The meadow classification was combined with data derived from digital elevation models to characterize the distribution of meadows in the western and high Cascades of Oregon. In the western Cascades, meadows are concentrated on steep, south and east facing ridges between 1000 and 2000m in elevation. In the high Cascades, meadows are concentrated in valleys between 500 and 1000 meters in elevation and occur on both gentle and steep east and south facing slopes.

Historic photographic interpretation in combination with GIS analysis revealed different encroachment pattern in the Chucksney-Grasshopper complex. All meadows demonstrated encroachment occurred closer to existing trees than further from them. Encroachment was significant on steep, south and east facing slopes in some meadows, but also on gentle, west facing slopes in other meadows. Vegetation cover, land use history, and fire history, and climate effects may be factors in these differing patterns. This preliminary analysis lays the groundwork for a potential invasion risk tool. The multiple factors affecting invasion that were analyzed or identified can be combined with invasion patterns to create a risk model that can be used by land managers to assess and prioritize maintenance and restoration activities.

The results of the field sampling and analysis of meadow 4 in the Chucksney-Grasshopper complex provide insight to how invasion occurs at a fine scale and potentially how to thwart it. It appears as though the prescribed burns conducted in 1996 promoted *Pinus contorta* invasion suggesting a review and revision of current burning methods. Management methods may also be revised based on encroachment patterns found in the field transects. Whether seedlings establish all at once in a band or progressively from older trees or forest edges, they facilitate the subsequent establishment of other seedlings suggesting early eradication prevents increased rates of invasion.

This study provides some guidance to managers but a large body of work by multidisciplinary researchers provides a greater context for management. If the purpose of management is to mitigate conifer invasion into meadows, then the drivers of invasion must be considered. Three dominant drivers are grazing practices, changes in fire regime, and climate changes. The impact of grazing cessation in the 1960s has occurred and is likely irreversible. The effect of tree establishment on soil conditions and the transient nature of meadow species in the seed bank prevents meadow species from re-establishing (Haugo and Halpern, 2007; Lang and Halpern, 2007). Meadows in the WNF may have been artificially maintained through fire by Native Americans until the mid-19th century (Boyd, 1999; French, 1999; Robbins, 1999; Whitlock, 2004, Lepofsky, 2003) and natural fire regimes have been altered by subsequent land management or through climate change (Westerling, et al., 2006). Regardless of the cause of the changes in fire regimes, fire has a role in the maintenance of meadows. Researchers Swanson, Cissel, and Halpern, among others, are involved in on-going studies that look at the effects of alternative fire management strategies on soil and vegetation. Lessons learned from these studies will enable managers to determine the severity and frequency of fires needed to maintain or restore meadow habitat without promoting the establishment of fire adapted tree species such as *Pinus contorta* or fire adapted ruderals that will outcompete native meadow vegetation. Finally, climate change has an impact on meadows in multiple ways. On steep dry slopes, increased precipitation can favor conifer seedling establishment while on cold north slopes, increased temperatures can reduce snowpack and lengthen the growing season facilitating conifer invasion (Miller and Halpern, 1998). Increased temperatures have also resulted in drought conditions which have been correlated to more frequent and longer lasting wildfires in the western US (Westerling et al., 2006). This change in fire regime may impact meadows by mineralizing soils for conifer seedling establishment and destroying meadow species' seed banks. The role of managers is to understand what drivers are impacting particular meadow habitat and develop maintenance and restoration strategies accordingly. Managers should also consider that meadows and forests have formed a shifting mosaic since the mid-Holocene (Jakubos and Romme, 1993) and that some drivers of invasion, such as climate change, cannot be mitigated.

Literature Cited

Agee, J.K., 1993. Fire ecology of Pacific Northwest Forests, Island press. Washington, D.C.

Boardman, J. W., Kruse, F. A., and Green, R. O., 1995, Mapping target signatures via partial unmixing of AVIRIS data: in Summaries, Fifth JPL Airborne Earth Science Workshop, JPL Publication 95-1, v. 1, pp. 23-26.

Boyd, R., 1999. Introduction and Strategies of Indian Burning in the Willamette Valley in Indians, Fire, and the Land in the Pacific Northwest. R. Boyd ed. Oregon State University Press, Corvallis, Oregon.

Burke, C.J., 1980. Historic fires in the central Western Cascades, Oregon. Thesis, Oregon State University, Corvallis, Oregon.

Burns, R.M., and B.H. Honkala, 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. USDA FS Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p.

Cohen, W.B., T.A. Spies, T.K. Maiersperger, and D.R. Oetter – GIS, 1988. Land Cover of Western Oregon raster format data. Obtained from LARSE January 2007 (http://www.fsl.orst.edu/larse/wov/88wov.html).

Cohen, W.B., M. Fiorella, J. Gray, E. Helmer, and K. Anderson, 1998. The efficient and accurate method for mapping forest clear cuts in the Pacific Northwest using Landsat imagery. Photogrammetric engineering and remote sensing, v. 64, no. 4, p. 293-300.

Cohen, W.B., T.A. Spies, and M. Fiorella, 1995. Estimating the age and structure of forests in a multi-ownership landscape of western Oregon, U.S.A. *International Journal of Remote Sensing*, v. 16, no. 4: 721-746.

Cohen, W.B., T.A. Spies, R.J. Alig, D.R. Oetter, T.K. Maiersperger, and M. Fiorella, 2002. Characterizing 23 Years (1972-1995) of Stand Replacement Disturbance in Western Oregon Forests with Landsat Imagery. *Ecosystems* 5: 122-137.

Cohen, W.B. and S. Lennartz - GIS, 2004. 1972-2004 Western Oregon Stand Replacement Disturbance Map. ESRI GRID format. Oregon. http://www.fsl.orst.edu/larse/

Coop, J.D. and T.J. Givnish, 2007. Spatial and temporal patterns of recent forest encroachment in montane grasslands of the Valles Caldera, New Mexico, USA. *Journal of Biogeography*, v. 34: 914-927.

Coops, N, P. Ryan, A. Loughhead, B. Mackey, J. Gallant, I. Mullen, and M. Austin, 1998. Developing and Testing Procedures to Predict Topographic Position from Digital Elevation Models (DEM) for Species Mapping (Phase I). CSIRO Forestry and Forest Products: Client Report No: 271, http://www.ffp.csiro.au/nfm/mdp/topo/topo_home.htm (Accessed May 2007.)

Courtney, S.P., J.A. Blakesley, R.E. Bigley, J.P. Dumbacher, R.C. Fleisher, A.B. Franklin, J.F. Franklin, R.J. Gutierrez, J.M. Marzluff, L. Sztukowksi, 2004. Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute, Portland, Oregon. http://www.sei.org/owl/finalreport/finalreport.htm

Crippen, R.E., 1988. The dangers of underestimating the importance of data adjustments in band ratioing. *International Journal of Remote Sensing*, v. 9, no. 4, p. 767-776.

Debinksi, D.M. M.E. Jakubauskas, and K.Kindscher, 2000. *Environmental Monitoring and Assessment*, 64: 213-225.

Dunwiddie, P.W., 1977. Recent tree invasion of subalpine meadows in the wind river mountains, Wyoming, *Arctic and Alpine Research*, v 9, no. 4, p393-399.

ENVI, v. 4.2. Help Documentation.

Evans, R.D. and R.W. Fonda, 1990. The influence of snow on subalpine meadow community pattern, North Cascades, Washington. *Canadian Journal of Botany*, v. 68.

Ford, P., J. Kertis, J. Philips, R. Seitz, S. Swetland, and J. Cisel, 1998. Chucksney Mountain Meadow Restoration, USFS report, dated March 10, 1998. Unpublished.

Franklin, J.F. W.H. Moir, G.W. Douglas, and C. Wiberg, 1971. Invasion of subalpine meadows by trees in the Cascade Range, Washington and Oregon. *Arctic and Alpine Research*, v. 3, no. 3: 215-224.

Franklin, J.F. and C.T. Dyrness, 1988. Natural vegetation of Oregon and Washington. Corvallis, OR: Oregon State University Press.

French, D., 1999. Aboriginal Control of Huckleberry Yield in Indians, Fire, and the Land in the Pacific Northwest. R. Boyd ed. Oregon State University Press, Corvallis, Oregon.

Hadjimitsis, D.G., C.R.I. Clayton, and V.S. Hope, 2004. An assessment of the effectiveness of atmospheric correction algorithms through the remote sensing of some reservoirs. *International Journal of Remote Sensing*, v. 25, no. 18, p. 3651-3674.

Haugo, R.D. and C.B. Halpern, 2007. Vegetation responses to conifer encroachment in a western Cascade meadow: a chronosequence approach. *Canadian Journal of Botany*, v. 85: 285-298.

Herzfeld, U.C. and C.A. Higginson, 1996. Automated geostatistical seafloor classification – Principles, parameters, feature vectors, and discrimination criteria. Computers & Geosciences, v. 22, no.1: 35-52.

Idaho Forest Products Commission. http://www.idahoforests.org/ (Accessed March, 2007)

Jakubos, B. and W.H. Romme, 1993. Invasion of Subalpine Meadows by Lodgepole Pine in Yellowstone National Park, Wyoming, U.S.A. *Arctic and Alpine Research*, v 25, no. 4, p 382-390.

Jensen, J.R., 2005. *Introductory Digital Imaging Processing, A remote Sensing Perspective, third edition.* Pearson Prentice Hall, Upper Saddle River, New Jersey.

Jensen, E.C. and C.R. Ross, 2005. *Trees to Know in Oregon.* Oregon State University Extension Service, Corvallis, Oregon.

Jones, J.A., and G.E. Grant, 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. *Water Resources Research*, v. 32, no. 4: 959-974.

Jones, J.A., 2007. Personal communication, July, 2007.

Laboratory for Applications in Remote Sensing in Ecology (LARSE). http://www.fsl.orst.edu/larse/ (Accessed October, 2006.)

Lang, N.L. and C.B. Halpern, 2007. The soil seed bank of a montane meadow: consequences of conifer encroachment and implications for restoration. *Canadian Journal of Botany*, v. 85: 557-569.

Lennartz, S., 2005. Oregon Land Change Mapping. Conference paper: Pecora 16 “Global Priorities in Land Remote Sensing”, October 23-27, 2005, Sioux Falls, South Dakota.

Lepofsky, D., E.K. Heyerdahl, K. Lertzman, D. Schaepe, and B. Mierendorf, 2003. Historical meadow dynamics in southwest British Columbia: a multidisciplinary analysis. *Conservation Ecology*, v 7(3): 5.

Nolin, A., 2007. Personal communication, May 2007.

Norman, S.P. and A.H. Taylor, 2005. Pine forest expansion along a forest-meadow ecotone in northeastern California, USA. *Forest Ecology and Management*, 215: 51-68.

Norton, H.H., R. Boyd, and W. Hunn, 1999. The Klikitat Trail of South-central Washington in Indians, Fire, and the Land in the Pacific Northwest. R. Boyd ed. Oregon State University Press, Corvallis, Oregon.

Matarrese, M. 1992. Maintenance of Seral Meadow Ecosystems in the Chucksney Mountain Roadless Area, a unpublished paper presented for completion of requirements for Technical Fire Management, Willamette National Forest.

McKnight, T.L., 1999. *Physical Geography, A Landscape Appreciation, Sixth Edition*. Upper Saddle River, NJ: Prentice Hall.

Oregon Geospatial Enterprise Office - GIS, 2001. http://gis.oregon.gov/DAS/EISPD/GEO/sdlibrary.shtml River Reach data. (Accessed March, 2007.)

Orr, W.N. and E.L. Orr. 2002. *Geology of the Pacific Northwest, Second Edition.* New York, NY: McGraw Hill p.73-112.

Miller, E.A. and C.B. Halpern, 1998. Effects of environment and grazing disturbance on tree establishment in meadows of the central Cascade Range, Oregon, USA. *Journal of Vegetation Science*, v. 9: 265-282.

Oregon Department of Fish and Wildlife (ODFW), 2006. Oregon Conservation Strategy. http://www.dfw.state.or.us/conservationstrategy/document_pdf/b-eco_wc.pdf (Accessed March, 2007.)

PRISM Group - GIS, Oregon State University, 2004. http://www.prismclimate.org (Accessed May, 2007.)

Rakestraw, L. and M. Rakestraw, 1991. History of the Willamette National Forest. USDA Forest Service, Willamette National Forest, Eugene Oregon.

Robbins, W.G., 1999. Landscape and Environment in Indians, Fire, and the Land in the Pacific Northwest. R. Boyd ed. Oregon State University Press, Corvallis, Oregon.

Salix Associates, 2005. Grasshopper Mountain to Chucksney Mountain: 8-Meadow Plant and Wildlife Inventory and Mapping Project. Report for the Willamette National Forest.

Seitz, R., A. Martinez, 2003. Grasshopper/Chucksney Meadow Complex Field Reconnaissance USFS report dated September 2, 2003. Unpublished.

Strahler, A. and A. Strahler, 2002. *Physical Geography – Science and Systems of the Human Environment, second edition.* John Wiley & Sons, Inc., New York, NY.

Takaoka, S. and F.J. Swanson, 2006. Change in extent of meadows and shrub fields in the central western Cascade Range, Oregon, U.S.A. Publish pending.

Taylor, A.H., 1990. Tree invasion in meadows of Lassen Volcanic National Park, California, *Professional Geographer*, 42(4), p 457-470.

Taylor, A.H., 2000. Fire regimes and forest changes in mid and upper montane forests of the southern Cascades, Lasses Volcanic National Park, California, U.S.A. *Journal of Biogeography*, v. 27, no. 1, p 87-104.

Thompson, J., 2007. Mountain meadows – Here today, gone tomorrow? Meadow science and restoration. *Science Findings*, USDA Pacific Northwest Research Station, Portland, OR USA.

USFS, 1964. District Ranger Memo: Chucksney Mt. Allotment (Lodgepole Pine Eradication Project) Dated November 17, 1964.

USFS, 1981. Chucksney Mountain Undeveloped Roadless Recreation Area Management Plan, unpublished.

USDA Forest Service. Ecological Subregions of the United States. Chapter 25, Section M242B, Western Cascades. http://www.fs.fed.us/land/pubs/ecoregions/ch25.html#M242B (Accessed March 2007.)

USDA Natural Resources Conservation Service, 2006. Keys to Soil Taxonomy, 10th edition.

Vale, T.R., 1981. Tree Invasion of Montane Meadows in Oregon. *American Midland Naturalist*, v. 105, no. 1: 61-69.

van der Meer, F. and S.M. de Jong, 2000. Improving the results of spectral unmixing of Landsat Thematic Mapper imagery by enhancing the orthogonality of end-members. *International Journal of Remote Sensing*, v. 21, no. 15, p. 2781-2797.

Wearne, L.J. and J.W. Morgan, 2001. Recent forest encroachment into subalpine grasslands near Mount Hotham, Victoria, Australia. *Arctic, Antarctic, and Alpine Research*, v. 33, no. 3: 369-377.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006. Warming and earlier spring increase western US forest wildfire activity. *Science*, v. 313.

Whitlock, C., 2004. Land management: Forests, fires and climate. *Nature*, 432:28-29.

Willamette National Forest. Home.
http://www.fs.fed.us/r6/willamette/forest/facts/index.html
(Accessed March 2007.)

Willamette National Forest - GIS, 1991.
http://www.fs.fed.us/r6/willamette/manage/gis/
GEOL layer last updated June 2006. (Accessed March 2007.)

Willamette National Forest - GIS, 2006.
SHABS layer obtained by request from Willamette National forest October, 2006.

Willamette National Forest - GIS, 1992.
http://www.fs.fed.us/r6/willamette/manage/gis/
SRI layer last updated 1992. (Accessed March 2007.)

Willamette National Forest, 2006. Decision Memo: Chucksney & Grasshopper Meadow Restoration. McKenzie River and Middle Fork Ranger Districts, Willamette national Forest.

Williams, G.W., 2006. The Forest Service: Fighting for Public Lands. Greenwood Press, Westport, CT.

Woods, A., S. Bryce, and J. Omernik, 2003. Level III and IV Ecoregions of Oregon. GIS Data: USEPA http://www.epa.gov/wed/pages/ecoregions.htm (Accessed May, 2007.)

Zimmerman, N. 2000. Topographic Position Mapping Routines. http://www.wsl.ch/staff/niklaus.zimmermann/programs/aml4_2.html (Accessed March 2007.)