AN ABSTRACT OF THE THESIS OF

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Abstract approved:

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There are currently more than 580 natural areas in Oregon and Washington managed by 20 federal, state, local, and private agencies and organizations. The natural areas network is unparalleled in its representation of diverse ecosystems found in the region and may be an excellent collection of sites for monitoring long-term ecological responses to climate change. The goal of this research was to build a framework for a climate change monitoring program for the Pacific Northwest based on natural areas. Objectives were to (1) describe strengths of the existing natural areas network for representing effects of climate change by conducting a proportionality assessment and (2) determine which subset of natural areas have the best potential to detect change over the long term. Findings show that natural areas were generally representative and proportional compared to the Pacific Northwest. Subsets of natural areas were prioritized for long-term monitoring efforts through bioclimatic modelling based on the current and projected (2020s, 2050s, 2080s) outputs from 13 future

climate models from ClimateWNA and the Random Forest approach. Projection consensus showed a substantial range increase in suitable climate for warmer adapted forest types coupled with a contraction in cooler forest types. The results highlight the potential stress of climate change on ecosystems across the region and the need for management strategies to adapt to this uncertainty.

ASSESSMENT OF THE VULNERABILITY OF OREGON AND WASHINGTON'S NATURAL AREAS TO CLIMATE CHANGE

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

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Margaret H. Massie, Author

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CONTRIBUTION OF AUTHORS

Dr. Todd Wilson and Dr. Anita Morzillo assisted with overall project development, broad scale relevance and natural areas applicability. Dr. Emilie Henderson assisted with the development of the modeling procedures and methods. All three were fundamental in the design, reporting and review of the thesis chapters.

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CHAPTER 1: INTRODUCTION

1.1 General Introduction

Climate change is influencing ecological systems throughout the world. There has been a global temperature increase of 0.1 °C to 0.16 °C over the last 50 years, more than double the observed rate over the last 100 years (IPPC 2007). Rising temperatures have resulted in snowpack declines and an earlier (1- 4 week) onset of spring stream flow (Folland et al. 2001, Mote et al. 2005, Stewart el al. 2005, Mote et al. 2008). Evapotranspiration has increased, and drought severity and frequency is expected to intensify as global temperatures increase (Chmura et al. 2011). Recent global warming has also been linked to changes in phenological regimes, range movement of both plants and animals and shifts to natural disturbance regimes (Cayan et al. 2001, Regonda et al. 2004; Stewart et al. 2005; Parmesan and Yohe, 2003, Parmesan 2006, Littell et al. 2011). These changes could lead to reduced structural and biological heterogeneity, as well as lowered ecosystem resistance and resilience (Dale et al. 2000, Walther et al. 2002, Millar et al. 2007, Kliejunas et al. 2011, Woods 2011). Some organisms may be able to tolerate or adapt to such shifting environmental conditions but the rapid rate at which the shifts are occurring could stress some species and ecosystems to the point of extirpation (Walther et al. 2002, Rehfeldt et al. 2006, Scholze et al. 2006).

The understanding of future effects of climate change is based primarily on current hypotheses and existing data. There is a need for future research to test current assumptions about temporal and spatial responses among ecosystems and distinguish between proximate and ultimate causes of climate change (Schellnhuber et al. 2006). A region-wide landscape monitoring program could address uncertainties in future ecological responses to climate change by improving our understanding of the range of variability and thresholds in ecosystem responses to climate change. Effective monitoring, and adaptive management strategies and decisions require integrated coordination between various groups and agencies, especially given the complexity of potential climate change effects on biotic and abiotic interactions across the landscape (Noss 1999, MTCC 2009). A robust and collaborative monitoring network for studying climate change can also measure and monitor key indicators of biodiversity across a wide range of ecosystems and may provide potential opportunities for adaptation and mitigation of effects.

1.2 Literature Review

Several networks, programs, and modeling strategies exist that could be used as a foundation for a long-term monitoring program for studying the ecological effects of climate change in the Pacific Northwest. A majority of the existing programs were established for inventory purposes, but have potential for being used for climate change monitoring. The following sections highlight strengths and limitations of some of the existing networks, programs and strategies, the integration of which could create a robust and comprehensive regional monitoring network.

1.2.1 Forest Inventory and Analysis

The USDA Forest Service Forest Inventory and Analysis (FIA) program is the only national-level standard, systematic assessment of forested land in the United States (US), and is the foundation for a diverse array of direct and modeled temporal and spatial studies of forest composition, structure, and health (Williams et al. 2006). Vegetation plots were systematically established every 2,428 hectares across forested lands of the US, and periodic inventories have been carried out since 1928. Starting in 1998, annual monitoring has been conducted on a rotational basis where 10% of the plots in the western US are assessed each year. Assessments are carried out across all ownerships of forested land (Vose et al. 2012). However, there is a lack of systematic sampling on non-forested land, and incomplete documentation of shrubs and herbaceous vegetation, weeds and exotic species on forested lands (Williams et al. 2006).

The limitations of the FIA national standard have resulted in development of supplementary techniques and protocols by other agencies that require further integration techniques for statistical robustness (Winter et al. 2011). For example, both the FIA and Bureau of Land Management (BLM) equate ≥10% stocked land as forest land but the FIA defines 10% stocked land as 5% canopy cover while the BLM uses 10% canopy cover (Williams et al. 2006). Variations in protocol for canopy cover measurements also exist between federal and local agencies. Studies have shown that larger viewing angles in canopy measurement increases cover estimates and stand-level variability decreases (Fiala et al. 2006). Incorporating and harmonizing data monitoring techniques from multiple inventories across all lands will be critical to an effective monitoring program.

1.2.2 Natural Area Network

Natural areas are lands designated to represent and protect the best possible examples of the diverse array of abiotic and biotic features, species and processes found across the US with minimal human influence (Franklin et al. 1972). They provide a reference for evaluating and monitoring sustainability as well as measuring effects that management practices have on similar ecosystem types. The Natural Areas Program in Oregon and Washington began with the establishment of the Metolius Research Natural Area in Oregon in 1931 (Greene et al. 1985, Evenden et al. 2001, Oregon 2010). This network is unparalleled in its representation of the diverse ecosystems found across the Pacific Northwest. The network consists of approximately 580 natural areas managed by 20 federal, state, local, and private agencies and organizations, ranging in size from less than two hectares to over 30,500 hectares and collectively covers approximately 600,000 hectares (Wilson et al. 2009). Minimal anthropogenic influences coupled with diverse representation of ecosystems suggests this network may be the best collection of sites for monitoring long-term responses to climate change (Evenden et al. 2001, MTCC 2009).

Although natural areas may be useful for studying the effects of climate change, there are a number of issues that currently limit their ability to fulfill this role. First, natural areas are commonly designated based on plant associations and the degree to which they represent other ecological gradients important for understanding climate change has not been explored. Second, natural areas have been designated across 20 different agencies and organizations with few standardized monitoring protocols used among them. Finally, it may be impractical to monitor all sites within the network so criteria are needed to help prioritize sites. These drawbacks, however, do not limit the future potential of the network as sites for monitoring and understanding climate change across diverse ecosystems. Using existing standards, programs, and region wide modelling strategies provide the opportunity for relativized assessments of the areas based on common classifications and can help characterize the network as a whole. It also facilitates the inference of future climate effects and stressors in the natural areas in relation to the broader landscape (Mackey 1988, Bourgeron 1995, Rust 2000).

A. GAP Analysis

The National Vegetation Classification Standard (NVCS) was adopted in 1997 by the Federal Geographic Data Committee **(**FDGC 1997). The standard was shaped by earlier land classification systems (Driscoll et al. 1984, UNESCO 1973, Mueller-Dombois and Ellenberg 1974) and is based on combining plant physical structure (physiognomic) and species composition characteristics (floristic) to designate and classify vegetation across landscapes (Jennings 1993, FDGC 1997). The NVCS fine-scaled floristic classification of plant associations and alliances (aggregation of associations) are commonly used for describing and designating natural areas (Whittaker 1962, FDGC 1997, Grossman et al. 1998). This classification is highly reliant on intensive field sampling and is useful in select conservation and management strategies. However, the alliances occur in small, indistinctive patches and regional mapping and assessments of alliances are limited in their accuracy and spatial precision. As a result, a collaborative effort by the USGS, GAP analyses Program (GAP), The Natural Conservancy, NatureServe, and Natural Heritage Network established a meso-scaled thematic mapping approach to compliment the NVCS standard and address the complications and complexity associated with mapping vegetation at such fine scales (Comer et al. 2003).

The primary classification units of the GAP program are ecological systems, groups of plant communities occurring under similar ecological constraints and environmental gradients (Jennings 1993, FDGC 1997, Comer et al. 2003). Western and central Oregon ecological systems were mapped based on Breiman's Random Forest (Grossmann et al. 2008). The Random Forest model is comprised of a set of classification trees which are built from randomized subsets of response (ecological systems) and explanatory data (environmental data; Breiman 2001). Eastern Oregon and Washington were mapped based on the decision tree classifier approach, a method similar to Random Forest (Kagan et al. 2008). Both methods incorporated ancillary plot and Landsat imagery to delineate ecological systems across the region.

B. Landscape Ecology, Modeling, Mapping & Analysis (LEMMA)

Species composition and structural information of forested landscapes was developed in Oregon and Washington by the Landscape Ecology, Modeling, Mapping and Analysis team (LEMMA). The LEMMA team used Canonical Correspondence Analysis (CCA) to quantify the relationship between vegetation at field plot locations and environmental variables (climate, topography, soils, and spectral reflectance from Landsat). Gradient Nearest Neighbor (GNN) interpolation method was then used for assigning and mapping locations lacking ground data and creating a continuous geographic map layer (Ohmann and Gregory 2002).

Field plot data for LEMMA was acquired from national and regional inventories including the FIA, Natural Resource Inventory (NRI) of the Bureau of Land Management, Current Vegetation Survey (CVS) and Old Growth Study (OGS) of the USDA Forest Service, Pacific Northwest Research Station (Spies and Franklin 1991, Ohmann and Gregory 2002). Landsat Thematic Mapper (TM) imagery was used to enhance the integration of plot and environmental data along with validation and identification of land use changes to account for field sampling across multiple years (1984-1997) (Ohmann and Gregory 2002). Climate data were derived from the precipitation-elevation regression on independent slopes model (PRISM). PRISM operates under the main basic assumption that elevation is the predominant control of temperature and precipitation (Daly et al. 2002, 2008). The program interpolates weather station data to a uniform 4 km grid (2.5 arc min) through distance weighting, elevation, clustering, and simple regression (Daly et al. 1994). Distance weighting is based on station proximity to another station, distance from a systematic grid point, elevation, coastal proximity, topographic facet and position, and terrain (Daly et al. 2002, 2007, 2008).

CCA is a direct gradient analysis and quantifies the relationship between field plot, vegetation data (response) and mapped environmental (explanatory) data. Field plots were ordinated in multidimensional space according to their values of the environmental variables and assigned a score based on this eight-dimensional environmental space (McCune and Grace 2002, Ohmann and Gregory 2002). A continuous ~30-square meter pixel grid was created out of this eight-dimensional space by assigning each pixel a score from the CCA analysis and then identifying its nearest distance (Euclidean) to an actual plot value. Plot attribute data was then imputed to the pixel with the nearest proximity. Pixels with long imputation distances and, thus not represented by field plot data (e.g. non-forest areas), were designated with an ecological systems classification from the GAP analysis program. Spatial precision of the GNN data does not support a stand level analysis but at a broader, landscape scale, it can provide insight of dominant species and structural diversity over Oregon and Washington (Ohmann and Gregory 2002).

1.2.3 Climate Envelope Modeling

Climate models have been developed to produce approximations of the effects of climate change on species and ecosystem distributions. Each strategy is shaped by the methods, emission scenarios, Global Circulation Models (GCMs), and the scale to which the strategy is applied (Caicco et al 1995, Pearson et al., 2002, Rehfeldt et al. 2012, Wang et al. 2012b).

The Intergovernmental Panel on Climate Change (IPCC) has been the foundation for a global, collaborative effort in educating the public and policy makers about the effects of climate change and modeling future trends though projecting relationships of future climate predictions and emission scenarios. The IPCC has published five reports, the most recent of which included new emission representative concentration pathways (RCPs), which will replace the fourth assessment's (AR4) Special Report on Emission Scenarios (SRES). However, additional analysis is still needed on the RCP's before region model recommendations can be made for the Pacific Northwest (Murdock and Spittlehouse 2011). The AR4 had approximately twenty different research centers independently developing predictions of future climate. The GCMs calculated sun, atmosphere and surface energy fluxes, and methods have more recently been incorporating ocean, land surface, and sea ice interactions (Mote et al. 2005). These circulation models were tied with emission scenarios (defined by current emission baselines, economic development, technological change, and global interaction; IPCC 2001). The primary emission scenarios used in the AR4 were the B1, A1B, and A2. The A2 scenario is driven by a highly self-reliant, heterogeneous interaction of societies, operating separately from one and other. A1 scenarios encompass technological developments which are grouped by fossil-fuel (A1F1) and non-fossil fueled (A1T) developments. The A1B is an amalgamation between the A1F1 and A1T. B1 scenarios are centered upon technological advances as well and global interaction on economic, social, and environmental sustainability and justice, but even these scenarios have output projections that suggest serious climate change shifts (Schellnhuber et al. 2006, Mote and Salathe 2009, Murdock and Spittlehouse 2011).

Consensus of future climate projections predicts an increase in temperatures beyond observed natural ranges of variability. However, the magnitude of uncertainty from the models makes development of management strategies based on their results difficult (Pearson and Dawson, 2003, Brook et al. 2009, Rehfeldt et al. 2012). Efforts to address the uncertainty include the development of high-resolution climate data and improving prediction accuracy specific to resource management (Spittlehouse et al. 2009, Wang et al. 2012b). For example, the climate modelling program ClimateWNA (Climate Western North America) is a computer based climate modelling program that provides spatially explicit historical and future climate data with specific emphasis on the topographically diverse region of Western North America. Similar to LEMMA, ClimateWNA relies on downscaling the 4-km (2.5 arc min) climate grid from PRISM for the baseline climate data (Daly et al. 1994, Wang et al. 2006, Daly 2007, Wang et al. 2012a), but further addresses inconsistencies in prediction accuracy over the mountainous regions of the Western North America (Wang et al., 2012a). The program standardizes climate data and uses bilinear interpolation (distance weighted average of the four nearest pixel values), and elevation adjustments (for temperature) to downscale the data to specific latitude and longitude coordinates. Program outputs include 36 directly-measured monthly variables along with 12 monthly, 16 seasonal, and 21 annual derived variables for historical, current and 20 future climate projections (Wang et al. 2012a).

The development of continuous, downscaled current and future climate data has led to developments in methods used to correlate and relate climate projections with the distribution of biotic variables. Methods such as mechanistic based models are defined by the physiological characteristics of a species or ecosystem and are considered superior for understanding the relationship between climate and distribution (Woodward & Rochefort, 1991, Prentice et al., 1992, Hijmans and Graham, 2006). Mechanistic modeling has resulted in significant progress in capturing vegetation and climate relationships (Woodward and Beering, 1997, Cramer et al. 2001, Pearson and Dawson 2003), but their complexity does not allow broad applicability and require in-depth physiological data for each individual species or focus unit, which is not available for most species (Pearson and Dawson, 2003, Hijmans and Graham, 2006).

Another approach is bioclimatic modeling, which evaluates the correlations between species distribution and climate. Bioclimate envelope modeling was developed from ecological niche theory where a species' climatic requirements limit the areas where it can survive and grow (Hutchinson 1957). This is based on the understanding that while local scale vegetation models are driven by micro-climatic, edaphic and topographic characteristics, broad patterns are climatically driven at the regional scale. Climate also modifies and regulates the outcome of competition and biotic interaction (Daubenmire 1978, Woodward 1987, Booth 1990, Prentice et al. 1992, Box et al. 1993, Iverson and Prasad, 1998, Ohmann and Spies 1998, Pearson and Dawson 2003, Rehfeldt et al., 2006). Simplified bioclimate models may be less precise but are sufficiently accurate to estimate the potential distribution of climatically suitable habitats and regions most at risk for climate change (Prentice et al. 1992, Berry et al. 2002, Hannah et al. 2002, Midgley et al. 2002, Pearson and Dawson 2003).

Many statistical methods and algorithms have been applied to bioclimatic modeling to correlate climate variables with vegetation distribution. Non-parametric learning algorithms have been developed and used as one of the primary tools for bioclimatic envelope modeling (Siroky 2009). Linear and logistic regression have also been widely used in parametric models however, they have several shortcomings (Strobl et al. 2009). Specifically, parametric approaches are not applicable when the number of classifying variables exceeds the sample size and have reduced accuracy when there are strong interactions between input variables (Cutler et al., 2007, Strobl et al. 2009). Non-parametric learning algorithms, such as classification and regression tree (CART), recursively partition data to classify and predict based on relationships between explanatory and response variables (Breiman et al., 1984; McCune and Grace, 2002). Later refinement to these algorithms of inductive learning constraints (Amit et al. 1999), random node split (Dietterick 1998), and random subset selection (Ho 1998) led to the development of Breiman's Random Forest method (Breiman 2001). Random Forest models avoid overfitting through internal cross-validation by randomly selecting a subset of the data along with a subset of predictor variables used for splitting nodes in the classification process (Breiman 2001, Rehfeldt et al. 2006, Siroky 2009). There is bias linked to the model with unbalanced data, especially seen in vegetation data, however, there are internal mechanisms within the model to help accommodate for this (Breiman 2001). Random Forest is considered one of the most accurate learning algorithms (Biau 2012) and is widely used in predictive vegetative mapping (Rehfeldt et al. 2006, Iverson et al. 2008, Siroky 2009, Mbogga et al. 2010, Rehfeldt et al., 2012).

1.2.4 Qualitative Risk Assessment

Natural disturbances are a necessary part of ecosystem health and function. However, interactions between climate shifts and disturbances are not well understood and multiple stressors could result in substantial changes to ecosystem dynamics

(Anderson et al. 2004, Millar et al 2007). Many interacting and confounding variables involved with disturbances make broad scale statistical inferences difficult but still must be taken under consideration qualitatively when evaluating ecosystem resilience and vulnerability in the face of climate change. It is generally assumed that climate change will increase tree stress through drought, heat, and hydrological shifts and exacerbate effects of many pathogens (Boland et al., 2004; Desprez-Loustau et al., 2007, Kliejunas et al. 2009, Klopfenstein et al., 2009, Sturrock 2007, Moore and Allard 2008, Sturrock et al., 2011, Woods et al., 2010, Kliejunas et al 2011). Projected increases in catastrophic wildfires are of special concern due to expected rising intensity and severity. Response of vegetation to climate is a slow process but may be abruptly accelerated by fire regimes influenced by shifting climate conditions (Stephens et al. 2013).

Aerial Detection Surveys (ADS) are a cooperative effort started in 1980 by the US Forest Service and state agencies, to monitor and provide a general footprint of forest disturbances. Survey methodology was developed by the USFS using geo-referenced, digital sketch maps generated during aerial surveys. Annual assessments are carried out with airplanes flying linear patterns over Oregon and Washington's forested lands with a two mile swath width. Two observers mark recently killed or defoliated trees with various codes defining the damaging agent (Dozic et al. 2012). This method lacks fine-scale precision, but it is useful in capturing broad trends, shifts, ranges, frequencies and severity of forest disturbances. The Monitoring Trends in

Burn Severity (MTBS) is also used as a data source for landscape disturbance. The MTBS project started in 1984 as a joint effort between the U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) and the U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center (RSAC), and primarily uses Landsat imagery to document and assess fires across all lands over 1000 acres (MTBS 2009).

Generally, patterns of insect, disease and fire throughout Oregon and Washington have been highly variable over time. In 2012, Oregon had its third consecutive year of overall decrease in area affected by insect outbreak. However, even with a 43% decline compared to 2011, tree mortality increased by approximately 88%, the highest level since 2009, increasing extreme fire risk (Flowers et al. 2012). There was an overall increase in pine beetle attacks in Washington in 2012 and numerous species had significant range expansions (Dozic et al. 2012). Washington also experienced an increase in the California fivespined *Ips*. This beetle is native to California and Oregon but was first detected in Washington in 2010. This range expansion resulted in increased ponderosa pine (*Pinus ponderosa)* mortality and is being closely monitored as new counties are showing population increases (Dozic et al. 2012).

Foliar diseases such as Sudden Oak Death (*Phytophthora ramorum)* and Swiss needle cast (*Phaeocryptopus gaeumannii)* and are under increased monitoring scrutiny because changes in climate could prove catastrophic for containment and eradication efforts (Manter et al. 2005, Stone et al. 2008, Lee et al. 2013). Sudden Oak Death (SOD) was first documented in southwest Oregon in 2001 and has since been detected at 172 sites around the region. SOD kills susceptible species such as tan oak (*Notholithocarpus densiflorus*), coast live oak (*Quercus agrifolia*), and California black oak (*Quercus kelloggii)* (Flowers et al. 2012). The disease spreads by runoff and wind during rainy periods. Swiss needle cast (SNC), although less fatal to susceptible tree species, reduces tree growth and survival. Aerial surveys recorded an all-time high in SNC detection in 2009 (519,000 acres; Flowers et al. 2012). Predictions of warmer and wetter winters and drier summers (Mote and Salathe 2010) may lead to the expansion and increased intensity of SNC in Oregon over the next century (Watt et al. 2011, Zhao et al. 2011). Washington has also seen an increase in SNC, especially along the coast (Dozic et al. 2012). Increases in other needle casts such as Larch Needle Cast (*Meria laricis* Vuill.) and Pine Needle Casts (*Dothistroma* spp., *Elytroderma* spp., *Lophodermella* spp.) also have been linked with above normal spring rainfall. Additionally, other foliar diseases such as *Marssonina* spp., *Melampsora* spp., *Septoria* spp. and *Venturia* spp. are affecting *Populus* spp. and are highly associated with cool, wet, spring weather patterns (Dozic et al. 2012).

Concern also is increasing over the expanding trends of the non-native white pine blister rust *(Cronartium ribicola Fisch.)*, which infects five needle pines, such as the whitebark pine (*Pinus albicaulis).* Whitebark pine also has heightened vulnerability that has resulted from previous land management practices (i.e. fire suppression) and general warming trends. Fire suppression has allowed shade tolerant species such as subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmanni*) to supplant whitebark pine over much of its former range. Increased interspecies competition coupled with recent warming trends and surge of mountain pine beetle numbers and blister rust infestations have resulted in the listing of whitbark pine as a eligible candidate species for protection under the federal Endangered Species Act (ESA) in 2011 (Arno 1986; Keane and Arno 1993, Tomback et al. 1995, Logan and Powell 2001, USFWS 2014).

1.3 Goal and Objectives

The goal of this research was to help build a climate change monitoring program for the Pacific Northwest based on natural areas. There were two specific objectives. The first objective was to better understand the suitability of the current natural areas network for representing effects of climate change in the Pacific Northwest by comparing measures of structure, composition, and elevation between natural areas and Oregon and Washington. A network that is representative and proportional would allow for the development of a robust monitoring program for the Pacific Northwest. A lack of representation would suggest the need for additional sites to be incorporated into the network and one that is disproportionate to the broader region would suggest caution in concluding broader inferences.

However, it is currently economically and operationally impractical to monitor all natural areas consistently or to the depth that may be required for rich understanding of climate change effects. Therefore, the second objective of this study was to assess the potential vulnerability of each natural area to climate change using climate modeling and history of recent disturbance as ways to help choose sites that have the best potential of detecting climate change effects. Use of a diverse range of climate prediction models (e.g., from relatively mild to severe scenarios) allows for choosing sites based on everything from model consensus (all models agree there will be change) to selecting individual or a subset of models based on perceived likelihood of model scenarios. Adding recent disturbance (e.g., fire, insect and disease) to site selection decisions may be important if vulnerability is assumed to increase when ecosystems are near ecological thresholds of change, and multiple stressors occur.

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CHAPTER 2 – MATERIAL AND METHODS

2.1 Study Area

This study was based on Oregon and Washington's natural areas (hereafter, Pacific Northwest [PNW]; Figure 1). PNW cover 124° to 116° west longitude to 41.9° to 48.9° north latitude and is characterized by 14 distinct ecoregions (Level III) spanning from sea level to approximately 4,390 meters in elevation. Temperature and precipitation trends are driven by topography and macroclimate circulation patterns (Ohmann and Spies, 1998, Ferguson 2001, USFWS 2011). Natural variations in the region's climate are primarily dependent upon the El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). ENSO fluctuates between warm (*El Niño)* and cold phases (*La Niña*) every 2 to 7 years and has the greatest effect on winter and spring temperatures, more so than precipitation (Mote et al. 1999). Every 10 to 30 years, the PDO oscillates cool, wet cycles and warm, dry cycles (Mantua et al 1997, Miles et al 2000). The Cascade mountain range separates PNW and results in a significant rain shadow effect, with west-side maritime climate influences and east-side continental climate influences (Little et al, 2009). West of the Cascades is characterized by mild temperatures with precipitation ranging from 75 cm (30 inches) to 250 cm (100 inches) in the Cascade mountains and up to 500 cm (200 inches) in the Olympic Peninsula. East of the Cascades is generally characterized by greater sun exposure, higher temperature variability and less annual precipitation than the west side. Precipitation levels range from approximately 50 cm (20 inches) to as little as 18 cm (7 inches) (CIG 2012).

2.2 Representation Assessment

A representation assessment was carried out by comparing the relative proportions of key ecological characteristics (biotic and abiotic) between the natural areas network and the entire PNW region. Three sources of 30-meter resolution modeled data were used, two for vegetation from the Landscape Ecology, Modeling, Mapping, & Analysis (LEMMA) and the USGS GAP Analysis (GAP) program, and one Digital Elevation Model (DEM). All anthropogenic classifications (e.g., agricultural, urban) were removed prior to assessment.

Spatially explicit vegetation composition and structure data from LEMMA was used to illustrate how well the natural areas represented species composition and structure on forested lands (>10% canopy cover). However, specific species and structure attribute data were assigned only to forested lands, leaving non-forested lands to be classified under the ecological systems from GAP. An additional proportional abundance assessment was performed with GAP's ecological systems to be able to assess natural areas representativeness across all lands by a common classification.

2.3 Climate Envelope Modeling

2.3.1 Vegetation, Soil, Topography data

Development of a baseline regional bioclimatic model to assess climate change effects was limited by the low spatial resolution of future climate projections, which prevented analysis of localized trends and behaviors (Mitchell 2003). As a result, this study focused on projecting suitable climate for vegetation formation class, the third highest classification of the NVCS hierarchal vegetation classification system (Table 2.1). Modeling began with overlaying a uniform 800 square meter point grid over PNW using the "Create Fishnet" tool in ArcMap10 (ESRI 2011; Datum: North American, 1983, Projection: Albers). Second, latitude, longitude (decimal degrees) and elevation were extracted to the centroid point within each grid cell. Third, vegetation formation class was assigned from GAP's vegetation mapping layer of the NVCS hierarchical classification system. Paralleling previous studies, all urban, developed, disturbed, aquatic, and formation classes with fewer than 60 cells of representation were omitted from analyses (Rehfeldt et al 2006; Iverson et al 2008, Rehfeldt et al 2012). The result was 509,816 points representing 16 vegetation formation classes over both forested and non-forested areas. The "Introduced Semi-Natural Vegetation" class was included, even though it is comprised of relatively non-native vegetation species, because it can be related to natural ecological site features (Grossman et al. 1998). Vegetation formation classes were then separated into "upland" and "wetland" vegetation types to improve modelling accuracy (Table 2.2).

Saltmarsh formation class was included in both models. Saltmarsh primarily occurs in inter-mountain basin herbaceous and shrublands and has unique floristic and physiological characteristics shaped by hydrology, soil composition and salinity (Cooper 1986, Yang et al 2011). The USDA characterizes it as a wetland classification but notes it also occurs in non-wetland areas and proximity to upland areas. Static soil and topographic attributes assembled by the Integrated Landscape Assessment Project (ILAP) from soil survey data from the Natural Resource Conservation Service SSURGO (Soil Survey Geographic database) and STATSGO (State Soil Geographic Data Base) were extracted to the grid cell centroid points to further improve model accuracy. ILAP used weighted averaging and merged various scales of the soil data to represent the finest scale possible for the data (Gaines et al. 2013). Median values were inputted for each attribute where there were gaps in soil coverage (Breiman 2001, McCune and Grace 2002). Finally, aspect was cosine-transformed to help standardize north-facing slopes (e.g., 1º and 359º both have a cosine-transformed value near 1.0; Roberts 1986).

2.3.2 *Climate Data*

ClimateWNA (version 4.72) was used to generate climate data for the reference period, 1961-1990, and for three future periods 2011-2040 (2020s), 2041-2070 (2050s), and 2071-2100 (2080s). Using latitude, longitude and the elevation grid as inputs, 214 climate variables (144 monthly, 48 seasonal and 21 annual) were produced for recent climate values and future climate estimates. Recent data were based from interpolated weather station data developed by Parameter-elevation Regression on Independent Slopes Model (PRISM; Daly 1994) and further downscaled for Western North America (Wang et al. 2012a). Thirteen future climate predictions were downscaled from standardized 1° latitude by 1° longitude grids for Global Circulation Models and emission scenarios. A wide spectrum of future climate projections and emission scenarios (A2, A1B, and B1) were chosen based on their applicability and accuracy for PNW (Table 2.3) (Mote et al. 2005, Mote and Salathé 2009, Murdock and Spittlehouse 2011).

2.3.3 *Modeling relationships between climate and ecosystems*

Random Forest (Breiman 2001) classification and R (R Core Team 2013) were used to model the relationships among climate, soil, topography and vegetation formation class). Classification error was reduced by conducting separate upland and wetland vegetation assessments. All monthly, seasonal and annual variables were included simultaneously in the model to improve model accuracy (Wang et al. 2012b). Model building started with relating predictor variables with a random bootstrap sample of 2/3 of the observations. Observations were split (nodes) based on a random selection of predictor variables and continued until no improvements could be made to the classification tree (Breiman 2001). This process was repeated to create a “forest” of classification trees.

Each model was built with 200 "trees" after using the *do.trace* feature in R to test for classification accuracy and compare computational run time. The number of randomly selected predictor variables, *mtry*, was set at 12 based on *tuneRF*, which searches for an optimal value of selected predictor variables (Law and Weiner 2002). This value deviated from the default of the square root of the total number of predictors. Starting with 214 initial predictor variables, a stepwise process was carried out to reduce the amount of predictors. Variables which degraded prediction accuracy when randomly permuted (variable importance) or variables which contributed to a large decrease in impurity from parent to subsequent nodes (gini importance) were kept throughout the elimination process. Final models contained 30 (upland) and 28 (wetland) predictor variables (Table 2.4 & 2.5).

Large differences in vegetation formation class sample size resulted in poor accuracy for the rare cover classes. Down sampling formation classes with < 2000 observations (Wang et al. 2012b) and weighting techniques were tested to reduce error of the smaller classes and improve model performance. *Cuttoff* (weighted majority vote) in Random Forest in R had the greatest reduction in error for smaller cover classes compared to down sampling larger formation classes. The final model was validated by running the originally omitted observations through all of the trees where each "voted" for a particular vegetation formation class and the vegetation formation class with the majority of votes from the trees in the forest became the aggregated prediction (Breiman 2001). Predictions were compared to observed data to assess model accuracy and to calculate classification out-of-bag errors (OOB errors). An error-matrix was created for the upland and wetland models that compared model predictions with reference values and Kappa values (Cohen 1960).

2.3.4 Effects of Climate Change

The estimated effects of future climate change were assessed by comparing current distribution of vegetation formation class as delineated by the two reference models with the 13 prediction models for the 2020's, 2050's, and 2080's. First, regional and ecoregion loss and gain, and elevation shifts in vegetation formation classes were estimated based on average pixel counts for each formation class over all the models. Second, the frequency of future model agreement over the three time periods was assumed to reflect the level of certainty in the future formation class (Wang et al. 2012b). If the grid point classification for the reference model was the same in the future, a score of 0 was given; if different a score of 1. Totals were added and majority (> 6) model consensus was used to identify regions where future formation class differed from the reference period. Analyzing model agreement of not just change from the reference period formation class but also to what the change was predicted too be was calculated by taking the data points which had a majority change consensus and looking at mode classification agreement. Model consensus was used again when the 13 model projections were separated into three categories based on predicted temperature increases: mild (average increase of 0.9º Celsius), moderate (average increase of 2.3º Celsius), and extreme (average increase of 3.3º Celsius) to give a broader range of possible changes in climate suitability (Table 2.6).

2.4. Natural Area Site Selection

Vulnerability of natural areas to climate change was evaluated by intersecting natural area boundaries in ArcMap with the region wide 800-meter pixel grid for 2020s, 2050s, and 2080s. Approximately 75% of the natural areas overlapped with probabilities of future formation class climatic suitability. Natural areas that did not intersect (usually due to small size) were omitted from further analyses. Natural areas with probability values predicting change were classified based on model consensus, percent of model agreement, and percent of natural area.

Data from the Forest Health Protection (Forest Health Assessment – FHA) aerial survey of forest insect, disease and other disturbances and the Monitoring Trends of Burn Severity (MTBS) occurrence of fires > 1000 acres were intersected with the natural areas using ArcMap. Natural areas with disturbance occurrences and also containing pixels with predicted change in climate suitability for their current formation class were recorded.

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Figure 2.1: Geographic Distribution of Oregon and Washington's Natural Areas

Legend

- Natural Areas
- Warm Temperate Forest
- Temperate Grassland, Meadow & Shrubland
- Temperate Flooded & Swamp Forest
- Temperate & Boreal Scrub & Herb Coastal Vegetation
- Temperate & Boreal Freshwater Wet Meadow & Marsh
- Temperate & Boreal Cliff, Scree & Rock Vegetation
- Temperate & Boreal Bog & Fen
- Salt Marsh
- Polar & Alpine Cliff, Scree & Rock Vegetation
- Mediterranean Scrub
- Marine & Estuarine Saltwater Aquatic Vegetation
- Introduced & Semi Natural Vegetation
- Cool Temperate Forest
- Cool Semi-Desert Scrub & Grassland
- Cool Semi-Desert Cliff, Scree & Rock Vegetation
- Barren
- Alpine Scrub, Forb Meadow & Grassland
- Unmodeled

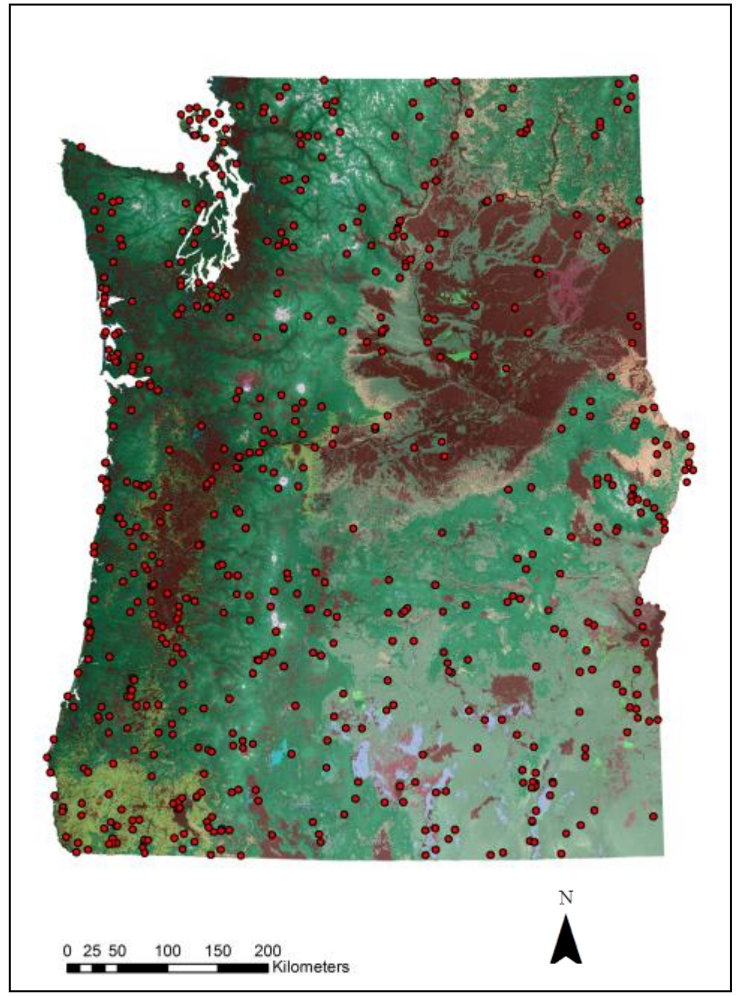


Table 2.1: Hierarchical classification structure of U.S. National Vegetation Classification with the incorporation of ecological systems.

Link to FGDC standard	***Hierarchy level***	***U.S. National Vegetation Classification***	***Ecological Systems***
Included		Division Order	
Included	Physiognomic levels	Formation Class Formation Subclass Formation Group Formation Subgroup Formation	
Hierarchically linked			Ecological Systems
Proposed	Floristic levels	Alliance Association	

Source: (Grossmann et al. 2008)

Table 2.2: Point count from the systematic 800-meter point grid across the PNW for each vegetation formation class in the upland and wetland models.

Code	Upland Formation Classes	Count
1	Alpine Scrub, Forb Meadow & Grassland	799
2	Barren	804
3	Cool Semi-Desert Cliff, Scree & Rock Vegetation	4,387
4	Cool Semi-Desert Scrub & Grassland	145,956
5	Cool Temperate Forest	263,822
6	Introduced & Semi Natural Vegetation	14,100
7	Polar & Alpine Cliff, Scree & Rock Vegetation	787
8	Salt Marsh	7,389
9	Temperate & Boreal Cliff, Scree & Rock Vegetation	1,845
10	Warm Temperate Forest	20,940
Code	**Wetland Formation Classes**	**Count**
1	Marine & Estuarine Saltwater Aquatic Vegetation	98
2	Mediterranean Scrub	429
3	Salt Marsh	7,389
4	Temperate & Boreal Freshwater Wet Meadow & Marsh	4,950
5	Temperate & Boreal Scrub & Herb Coastal Vegetation	264
6	Temperate Flooded & Swamp Forest	14,563
7	Temperate Grassland, Meadow & Shrubland	28,612

Table 2.3: The 13 models used in the future climate predictions and their associated greenhouse gas emission scenarios.

Model	Emission Scenarios	Run	temp_chng	precip_chng
MRI-CGCM2.3.2	B1	5	0.83	5.70%
GISS-AOM	A1B	1	0.95	-8.99%
CSIRO-Mk3.0	B1	1	1.01	0.51%
GFDL-CM2.0	A2	1	2.08	-7.54%
MPI-ECHAM5	A1B	3	2.15	4.65%
UKMO-HadCM3	B1	1	2.37	-2.95%
CCCMA-CGCM3.1	A2	4	2.61	8.41%
IPSL-CM4	A1B	2	2.84	15.00%
NCAR-CCSM3	A1B	5	3.13	-0.47%
UKMO-HadGEM1	A1B	1	3.84	-2.84%

Footnote: Temp_chng and precip_chng are the precipitation and temperature difference between current and predictions for 2050's based on the grid point values. Temperature change is in Celsius.

Table 2.4: Environmnetal variables included in the upland and wetland model (from a total of 214 variables), based on the variable's importance for prediction accuracy or the variables that contributed to a large decrease in impurity from parent to subsequent nodes.

Topographic / Soil	Upland	Wetland
Elevation	X	X
aspect (cosine transformed)	X	
slope	X	X
Depth	X	X
AWC (available water capacity)	X	X
BD (bedrock)	X	X
Sand	X	X
Silt	X	X
Clay	X	X
Rock	X	X
pH	X	
hydr_index		X
taxorder_index		X
AWC_100		X
BD_100		X
Climate - Monthly		
Tmax03 - Max Mean Temperatures (March)		X
Tmax04 – Max Mean Temperature (April)	X	X
Tmax12 – Max Mean Temperature (December)	X	
Tmin02 - Min Temperature (February)	X	
Tmin09 - Min Temperature (September)	X	X
Tmin10 - Min Temperature (October)	X	
PPT01 - Precipitation (January)	X	
PPT06 - Precipitation (June)		
DD5_04 - degree-days above 5°C (April)		X
DD5_06 - degree-days above 5°C	X	
DD5_09 - degree-days above 5°C (September)		X
DD_18_04 - degree-days below 18°C	X	
Eref11 - Hargreaves reference evaporation (November)		X

Footnote: Temperature is in Celsius and precipitation in millimeters.

Table 2.4 (continued)

Climate - Seasonal		
Tmin_at - Min Temperature (Autumn)	X	
PPT_wt - Precipitation (Winter)	X	
PPT_sm - Precipitation (Summer)	X	X
PAS_wt - precipitation as snow -between August in		X
Eref_sm - Hargreaves reference evaporation	X	
Eref_at - Hargreaves reference evaporation	X	
Climate - Annual		
TD - temperature difference between MWMT and MCMT	X	X
MSP - mean summer (May to Sept.) precipitation (mm)	X	
SHM - summer heat:moisture index (MWMT)/(MSP/1000))		X
DD_18 - degree-days below 18°C, heating degree-days		X
bFFP - the Julian date on which FFP begins	X	X
EMT - extreme minimum temperature over 30 years	X	
EXT - extreme maximum temperature over 30 years.		X
CMD - Hargreaves climatic moisture deficit	X	

Table 2.5: The 13 climate models used for analyzing the range of change in climate suitablity and grouped by prediction in temperature increase by the 2050s, and based on point grid averages.

Model	**Emission Scenarios**	**Run**	**temp_chng**	**precip_chng**
Mild				
MRI-CGCM2.3.2	B1	5	0.83	0.06
GISS-AOM	A1B	1	0.95	-0.09
CSIRO-Mk3.0	B1	1	1.01	0.01
BCCR-BCM2.0	A2	1	1.51	0.04
Moderate				
GFDL-CM2.0	A2	1	2.08	-0.08
MPI-ECHAM5	A1B	3	2.15	0.05
MIROC3.2_medres	A2	2	2.12	-0.01
UKMO-HadCM3	B1	1	2.37	-0.03
Extreme				
CCCMA-CGCM3.1	A2	4	2.61	0.08
IPSL-CM4	A1B	2	2.84	0.15
NCAR-CCSM3	A1B	5	3.13	0.00
UKMO-HadGEM1	A1B	1	3.84	-0.03
MIROC3.2_Hires	B1	1	3.03	0.07

Footnote: Temp_chng and precip_chng are the precipitation and temperature difference between current and predictions for 2050's based on the grid point values. Temperature change is in Celsius. The *mild* grouping average temperature increase was 0.9º C, *moderate* grouping predicited increase of an average of 2.3º C and *extreme* were the most extreme predictions with average temperature increases of 3.3ºC.

CHAPTER 3 – RESULTS

3.1 Representation Assessment

The current natural areas network was representative of most of the elevation gradients found in PNW. High elevation sites were the exception (Figure 3.1). Natural areas were concentrated at 1,220-1,530 m with the highest elevation at 2,930 m. In contrast, the highest elevation within PNW reached 4,380 m. Missing elevation representation at the ecoregion level included the West Cascades (natural areas ≤ 2,450 m; ecoregion ≤ 4,380 m), East Cascades (natural areas ≤ 2,760 m; ecoregion ≤ 3,750 and Puget Trough (natural areas ≤580; PNW ≤ 1,240). The natural areas network in the Canadian Rocky ecoregion had no representation at lower elevations from 390-750 meters which represented18% of the total proportion of land cover for that ecoregion. Forest species structure and composition were well represented in the natural areas compared to the PNW as a whole (Figure 3.2, 3.3). Vegetation structure class (GNN variable: "*VEGCLASS*"), based on Quadratic Mean Diameter, basal area, and canopy cover, was represented proportionally in the natural areas compared to the region (Figure 3.2). The 12 most common forest tree species, including Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa)*, and western hemlock (*Tsuga heterophylla*) comprised almost 90% of the total forested land cover in the region and were well represented in the natural areas (Figure 3.3). Less common species were proportionally represented in the natural areas except for bigleaf maple (*Acer macrophyllum*), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine larch (*Larix lyallii*). Collectively, the regional proportion of these three species on forested lands was 2.36%, whereas only 1.68% in natural areas. At the ecoregion scale, discrepancies in proportionality were observed in the Colombia Plateau and Okanagan Ecoregions. In the Columbia Plateau, the common juniper (*Juniperus communis*) represented 1.2% of the total land cover, and 20% of forested area, but the natural areas proportion was only 4%. Thirteen percent of total land cover and 21% of the forested land in the Okanagan ecoregion was classified as ponderosa pine, but the natural areas comprised only 2% of ponderosa pine for this ecoregion.

GAP's vegetation formation classes were well proportioned and representative for classes <5% of overall land cover with the largest difference of 1.23% in warm temperate forest (Figure 3.4). Formations > 5% of land cover were represented in the natural areas, but cool temperate forest type was disproportionately low (Figure 3.5). Fine-scaled classifications of ecological systems were represented in the natural areas for all the types found in the PNW. However, a clustering of four ecological systems nested under cool temperate forest formation classification were disproportionate (Figure 3.6). Three systems (Middle Rocky Mountain Montane Douglas-fir Forest and Woodland, Inter-Mountain Basins Juniper Savanna, and California Montane Jeffrey Pine-(Ponderosa Pine) Woodland) that comprised < 0.0001% of total cover for the region that were not represented. Their geographic location and limited size resulted in the assumption of these classes being in the outer range limits of neighboring ecological regions of California, Idaho, and Nevada.

There was representation of all formation classes in natural areas present within each ecoregion except for a handful of classes unrepresented. However, land cover for the formation classes was < 0.05% in each ecoregion. East Cascades did not have representation of higher elevation polar & alpine cliff, scree & rock vegetation and barren formation classes that comprised 0.2% of the regional land cover. Additionally, the Snake River Plain Ecoregion did not have any representation of temperate flooded & swamp forest, which comprised 0.24% of the total land cover.

Proportionality of fine scaled ecological systems for ecoregions generally followed patterns observed at the regional scale. The East Cascades and Snake River Plain ecoregions had the largest gaps in representation for ecological classifications representing < 0.04% and <0.02 of the land cover, respectively.

3.2 Climate Envelope Modeling

Creation of two climate envelope models for upland and wetland reduced the out-of-bag error rate from 36% to 10.34% and 13.9% and resulted in Kappa values of 0.818 and 0.785 respectively (Table 3.1 and 3.2). Topography, soil, monthly temperature, and seasonal precipitation were important variables for prediction accuracy for both upland and wetland vegetation. However, the upland model included three seasons of variables (summer, autumn and winter) and the wetland model included only two (summer and winter).

Prediction accuracy was strongest for cool semi-desert scrub & grassland and cool temperate forest in the upland vegetation model (>90% for both). The least accurate class was introduced semi-natural vegetation (48.8%). Prediction accuracy for the wetland vegetation model was highest for salt marsh and temperate grassland, meadow & shrubland (> 92% correct). Prediction accuracy was lowest for Mediterranean scrub and temperate & boreal freshwater wet meadow & marsh (> 51% correct).

Cutoff values decreased overall accuracy for the upland vegetation model by 0.39% but reduced individual OOB error rate for less dominant cover classes. Cool semi-desert cliff-scree & rock vegetation, introduced semi-natural vegetation, and warm temperate forest had a reduction of 7.5%, 5.0%, and 9.0% in their OOB errors while the more dominant classes, cool semi-desert scrub & grassland and cool temperate forest, had increases in OOB error of 0.2% and 1.8%. Cutoff values for the wetland vegetation model improved the overall modeling error rate by 0.61% by reducing the individual accuracy of temperate grassland, meadow & shrubland and salt marsh by approximately 1%, but increased the individual percent correct of Mediterranean scrub, temperate & boreal freshwater wet meadow & marsh, and temperate & boreal scrub & herb coastal vegetation by > 4% (Table 3.1 and 3.2).

Overall area of predicted change of formation class increased from 11.1% to 31.3% from the 2020s to 2080s across the region (Figure 3.7). Consensus for the thirteen models was strongest for the 2020s with complete model consensus for 72% of the area. However, by the 2080s, 100% model consensus dropped to 39% (Figure 3.8). Relaxing model consensus to 12 of the 13 models resulted in 79% agreement for 2020s and 52% for the 2080s.

There were significant range shifts for several vegetation formation classes (Table 3.3). Most drastic range reduction was predicted for the upland vegetation formation class cool temperate forest with an approximatly108,000 hectares predicted to be unsuitable by 2080s. Also, alpine scrub, forb meadow & grassland, and polar & alpine cliff, scree & rock vegetation were predicted to have steady reductions of suitability for their current habitat ranges. Contrastingly, warm temperate forest had a predicted increase of an average of 80,000 hectares and cool semi-desert scrub & grassland an increase of 19,000 hectares of suitability over the modeled time period.

Increases in suitable climate for the wetland formation classes were observed for temperate flooded & swamp forest and salt marsh classification with an average of 57,070 and 41,960 hectare increase of suitability over the region from the 2020s through 2080s (Table 3.3). Largest reductions were in temperate & boreal freshwater wet meadow & marsh and temperate grassland, meadow & shrubland with an average decrease of 35,450 and 57,260 hectares for the same time period.

Shifts in formation class were similar between the PNW region and ecoregions. Proportion of suitable climate for the cool temperate forest decreased by > 1000 hectares by the 2080s for all ecoregions except the Canadian Rocky Mountain Ecoregion. The Canadian Rocky Ecoregion saw a decrease of only < 350 hectares in climate suitability for cool temperate forest. East and West Cascades, Klamath Mountain, and Puget Trough ecoregions showed greatest increase (> 4000 hectares in each) in the suitability of climate for warm temperate forest. The largest increase for warm temperate forest was in the Coast Range ecoregion with an increase of >10,000 hectares in suitability coupled with a 10,000 hectare decrease for the cool temperate forest type. Wetland formations generally had predicted reductions in climate suitability for temperate grassland, meadow & shrubland and increases in temperate flooded & swamp forest and salt marsh.

Upward elevation movement of upland formation classes was predicted at the regional level. However, warm temperate forest and introduced semi-natural vegetation also showed a shift towards lower elevations for the 2020s and 2050s (Table 3.4). Ecoregion level assessment showed similar trends. The Klamath Mountain and Northwest Coast Ecoregion had the most significant predicted upward movement of the cool temperate forest class by > 900 meters by the 2080s. The Oregon Coast Range, Columbia Plateau, Northern Basin and Range, and Puget Trough ecoregions showed predictions of > 100 meters in upward elevation movement for the cool temperate forest. Projections of downslope movement for wetland classes were observed for marine & estuarine saltwater aquatic vegetation, Mediterranean scrub temperate & boreal scrub & herb coastal vegetation, temperate flooded & swamp forest. Salt marsh, temperate & boreal freshwater wet meadow & marsh and temperate grassland, meadow & shrubland were projected to shift their ranges upward.

3.3 Natural Area Site Selection

3.3.1 Natural areas and climate envelope modeling

Natural area vulnerability was predicted to increase from the 2020s to the 2080s (Appendix A-C). Using 100% model consensus of all 13 models as a guide, the number of natural areas with pixels predicted to change in suitability from one vegetation formation class to another increased from 29 in 2020s, 57 in 2050s, and 68 in 2080s (Table 3.5-3.7). Every ecoregion had at least one vulnerable natural area based on 100% consensus except for the Okanogan and Snake River Plain ecoregions. The Northern Basin and Range Ecoregion had 6 natural areas with predicted change in the 2020s which increased to 9 by the 2080s. Vulnerable natural areas in the Coast Range and Klamath Mountain ecoregions more than tripled by 2080s and doubled in the Blue Mountains and Puget Trough ecoregions. All the ecoregions in the 100% model consensus analysis, except for the Columbia Plateau, had at least one natural area with consecutive change predicted from the 2020s through the 2080s (18 in total). Separating the models by future predicted temperature increase (mild, moderate, and extreme), relaxing model consensus (> 50%), and analyzing consecutive years of change resulted in 137 natural areas being highlighted for mild scenarios and 193 for the extreme (Figure 3.9).

3.3.2 Natural areas and Qualitative Risk Assessment

Over four hundred natural areas had documented disturbances over the past 30 years as measured by the Forest Health Assessments. This included 15 different beetle infestations by Douglas-fir Beetle, Fir Engraver, Western Pine Beetle, and Moutain Pine Beetle in Whitebark Pine, Lodgepole, Ponderosa, Sugar Pine, and Western White Pine. Other disturbances included blister rust, Swiss needle cast and unspecified hardwood decline. There were148 documented fire occurrences in 84 natural areas since 1984. One hundred and thirty-five natural areas were predicted (model consensus > 50%) to have change in vegetation formation class climate suitability and intersected with disturbance data (Table 3.8). Fifty two natural areas had fire within the last 30 years with twenty five of those also exhibiting additional forest disturbances.

Figure 3.1: Elevation assessment of natural areas compared to the PNW. Natural areas are concentrated at 1,220-1,530 m with the highest elevation at 2,930 m. In contrast, the highest elevation within PNW reaches 4,380 m.

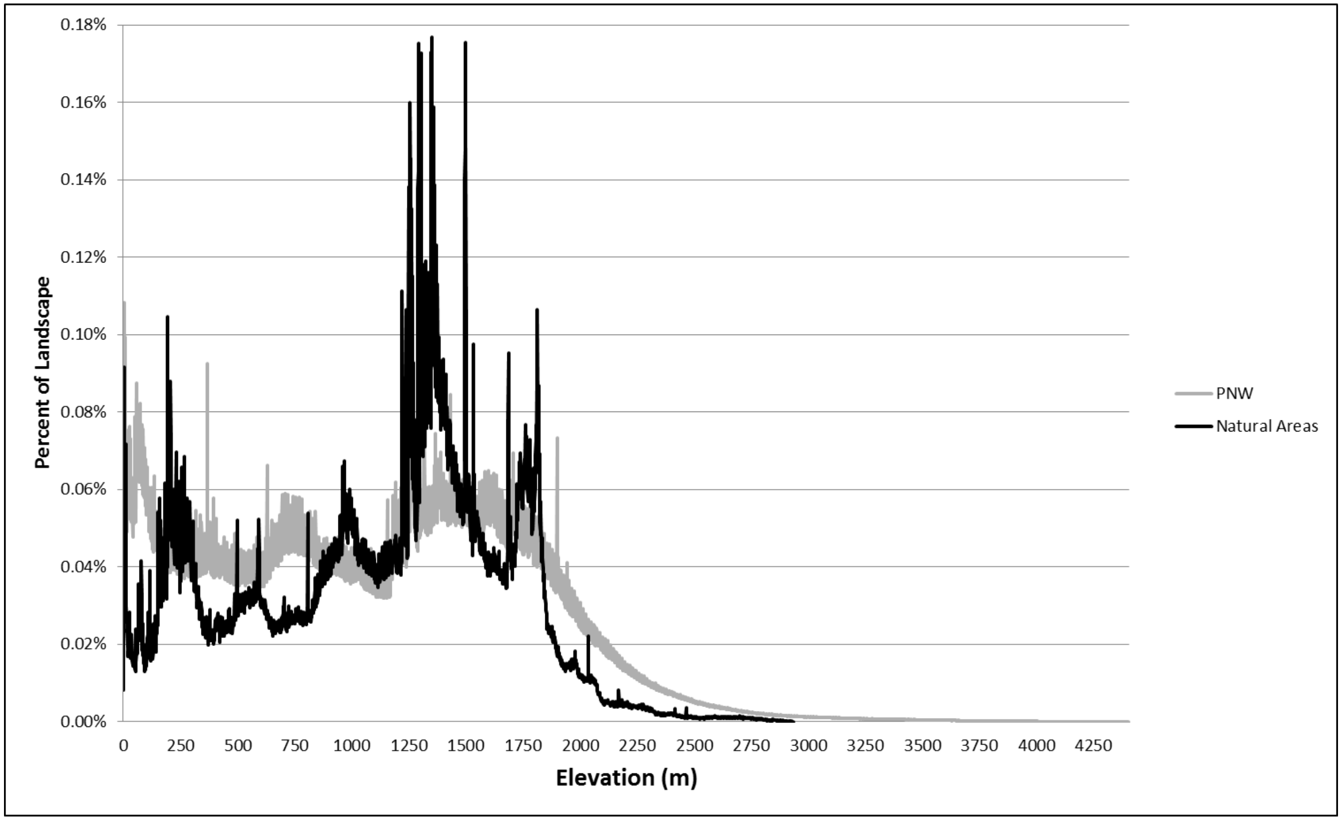


Figure 3.2: Proportionality assessment of vegetation structure class (GNN variable: "*vegclass*" - based on quadratic mean diameter, basal area, and canopy cover) of the natural areas compared to the PNW. 1 - Sparse, 2 – Open, 3 - Broadleaf, sap/pole, mod/closed,4 - Broadleaf, sm/med/lg, mod/closed, 5 - Mixed, sap/pole, mod/closed, 6 - Mixed, sm/med, mod/closed, 7 - Mixed, large/giant, mod/closed, 8 - Conifer, sap/pole, mod/closed, 9 - Conifer, sm/med, mod/closed, 10 - Conifer, large, mod/closed, 11 - Conifer, giant, mod/closed.

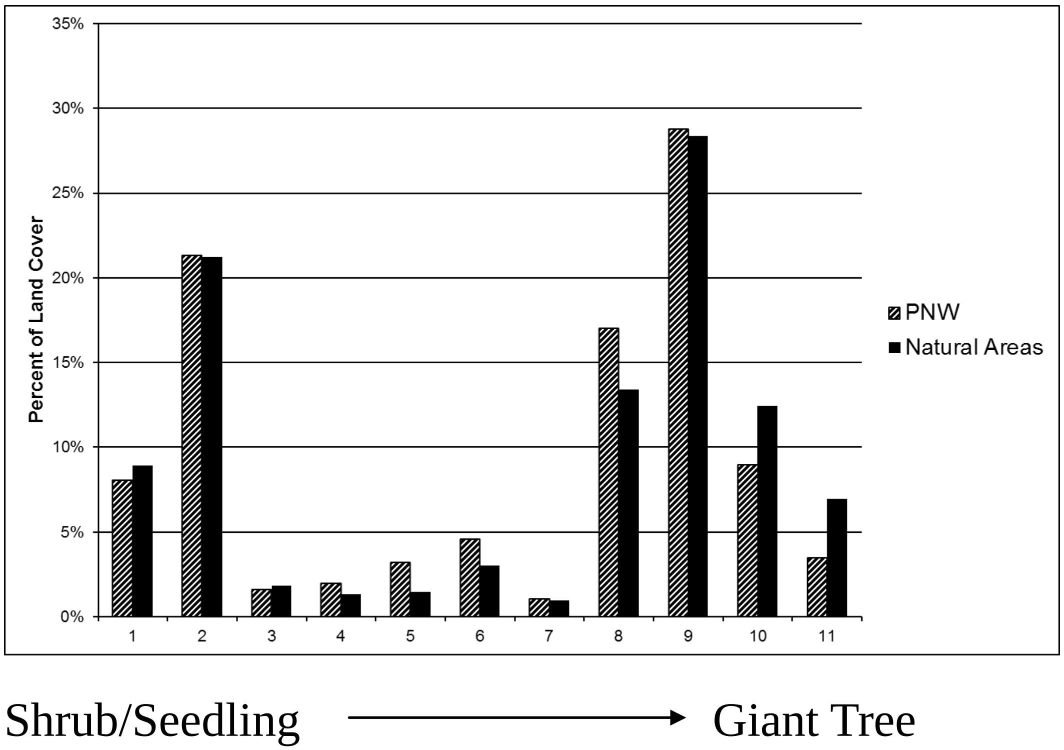


Figure 3.3: Proportionality assessment of natural areas compared to the PNW for the 12 most common species from GNN.

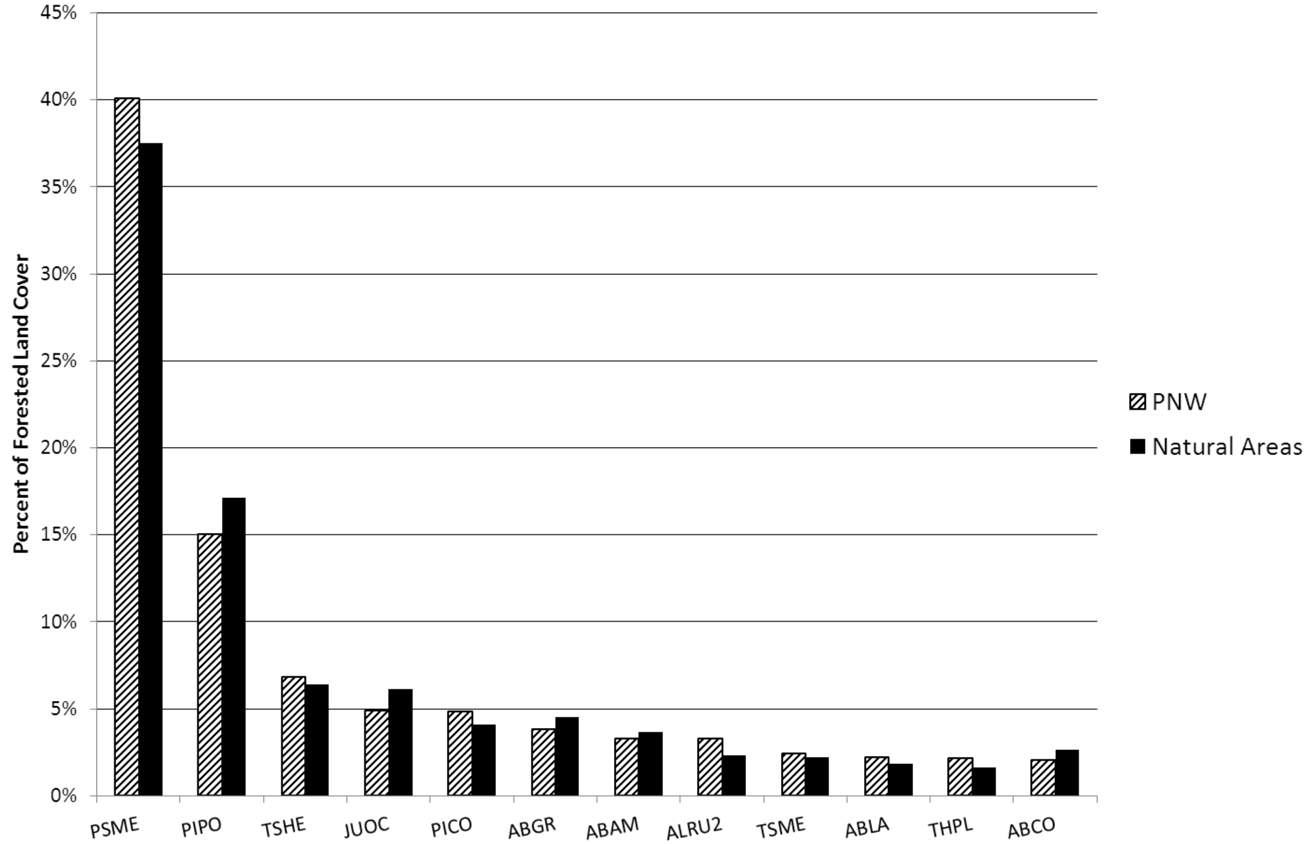


Figure 3.4: Proportion assessment of the natural areas compared to the PNW using GAP's vegetation formation classes that comprised < 5% overall land cover.

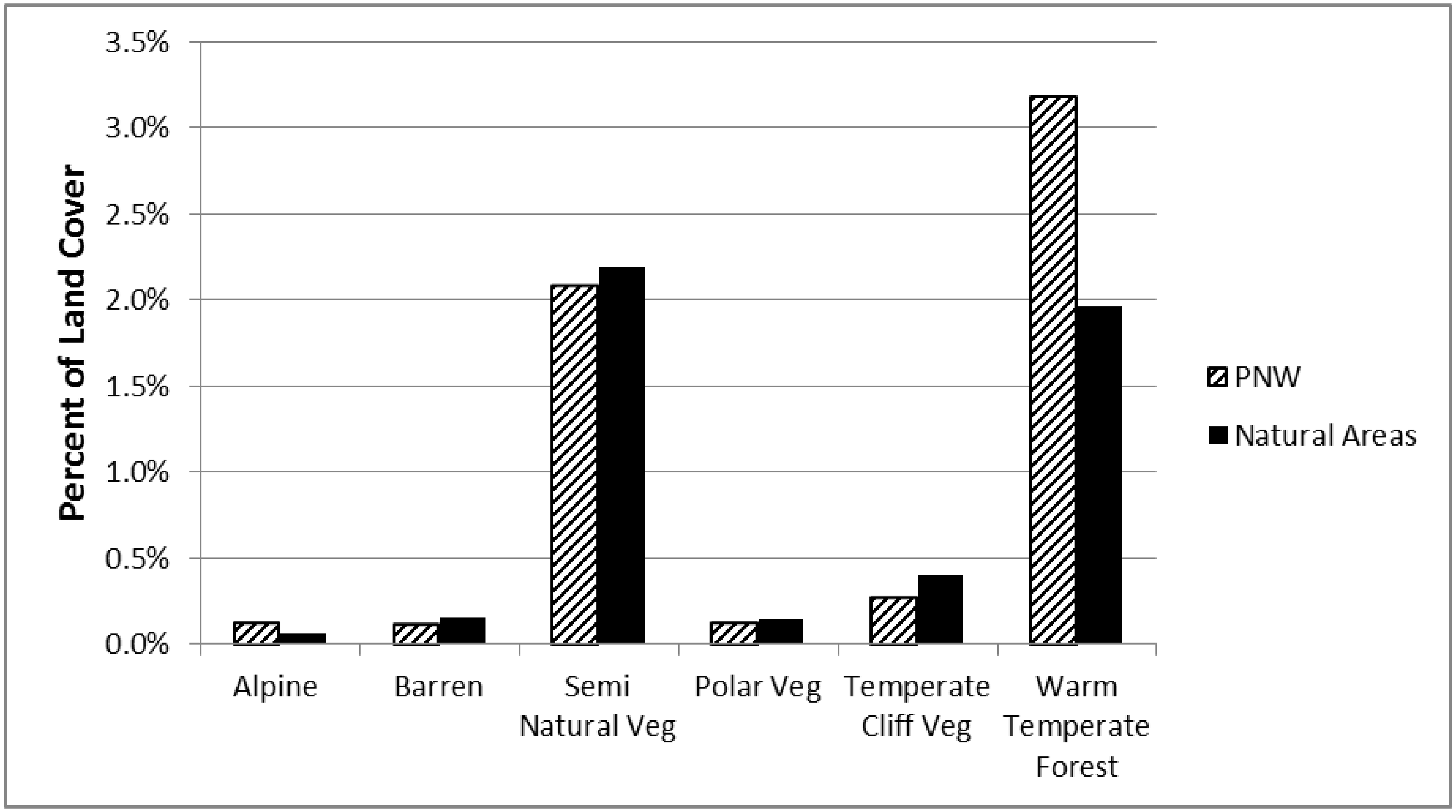


Figure 3.5: Proportion assessment of the natural areas compared to the PNW using GAP's vegetation formation classes that comprised > 5% overall land cover.

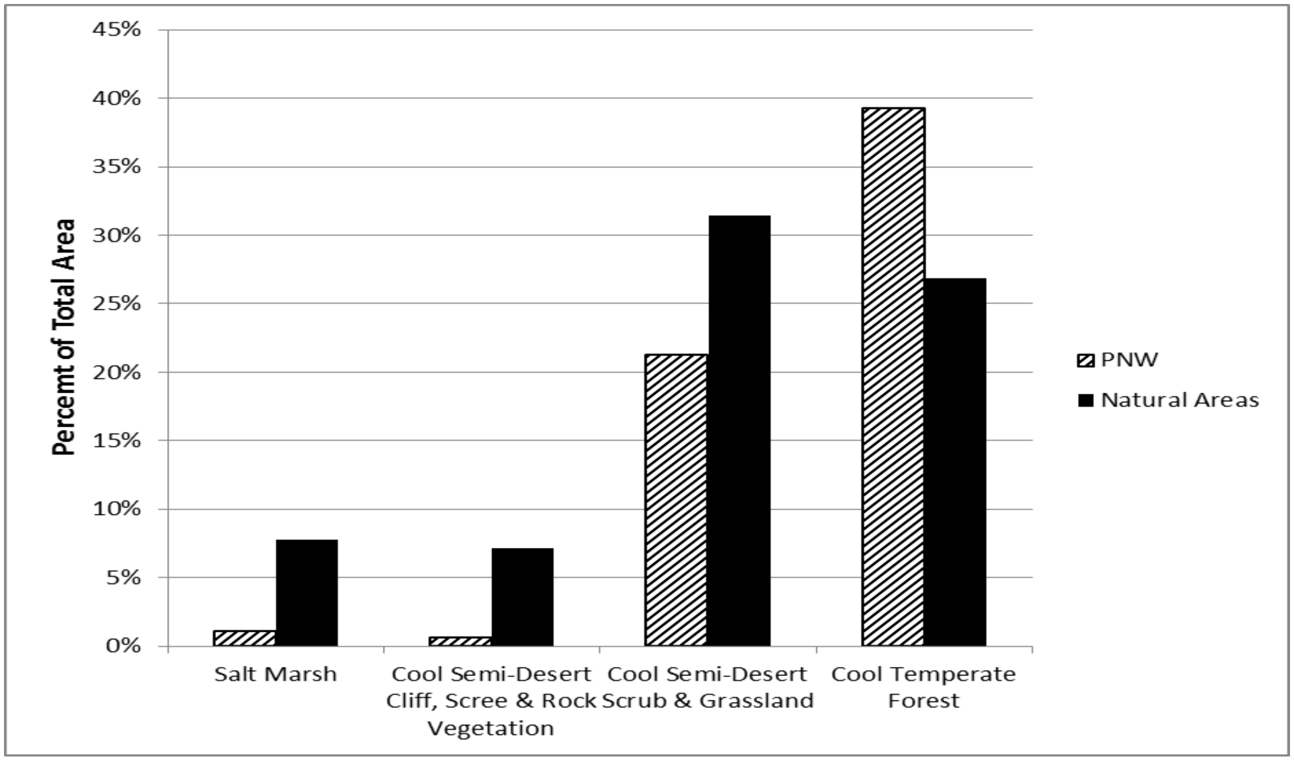


Figure 3.6: Larges proportionality discrepancies of the finer scaled classifications of ecological systems for the cool temperate forest formation class in the natural areas compared to the PNW.

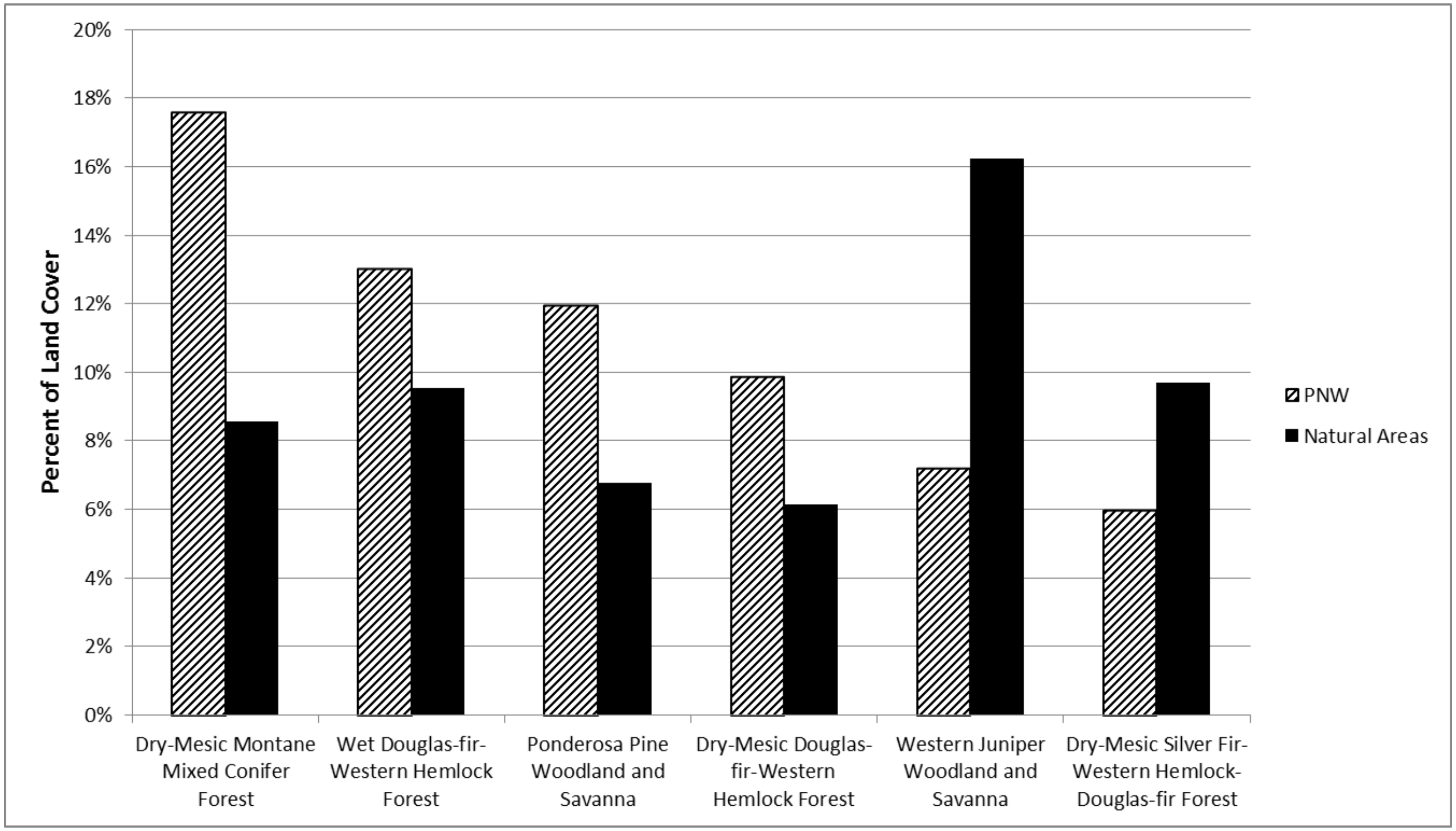


Table 3.1: Accuracy statistics for the upland model. Grey shading indicates number of correct point classifications. Row and column % correct are calculated by subtracting false negative and false positive rates. Total % correct is calculated by subtracting total model OOB-error rate.

	Alpine Scrub, Forb Meadow & Grassland	Barren	Cool Semi-Desert Cliff, Scree & Rock Vegetation	Cool Semi-Desert Scrub & Grassland	Cool Temperate Forest	Introduced & Semi Natural Vegetation	Polar & Alpine Cliff, Scree & Rock Vegetation	Salt Marsh	Temperate & Boreal Cliff, Scree & Rock Vegetation	Warm Temperate Forest	Row Totals	% Correct
Alpine Scrub, Forb Meadow & Grassland	599	2	0	13	172	0	3	0	3	7	**799**	75.0%
Barren	3	678	0	1	87	0	12	8	13	2	**804**	84.3%
Cool Semi-Desert Cliff, Scree & Rock Vegetation	0	0	2687	1238	147	274	0	32	5	4	**4387**	61.2%
Cool Semi-Desert Scrub & Grassland	3	0	894	131596	8424	3459	1	1217	10	352	**145956**	90.2%
Cool Temperate Forest	82	35	88	10704	246720	356	29	81	134	5593	**263822**	93.5%
Introduced & Semi Natural Vegetation	0	0	328	6206	474	6874	0	188	1	29	**14100**	48.8%
Polar & Alpine Cliff, Scree & Rock Vegetation	8	30	0	13	71	1	646	5	12	1	**787**	82.1%
Salt Marsh	1	3	28	1634	107	204	2	5397	1	12	**7389**	73.0%
Temperate & Boreal Cliff, Scree & Rock Vegetation	8	7	11	46	478	7	8	1	1276	3	**1845**	69.2%
Warm Temperate Forest	1	3	0	259	3869	9	0	1	0	16798	**20940**	80.2%
Column Totals	**705**	**758**	**4036**	**151710**	**260549**	**11184**	**701**	**6930**	**1455**	**22801**	Total %	
% Correct	85.0%	89.4%	66.6%	86.7%	94.7%	61.5%	92.2%	77.9%	87.7%	73.7%	Correct	89.66%
Random Forest *cuttoff* values	0.08	0.09	0.07	0.12	0.15	0.09	0.09	0.08	0.08	0.08	Kappa	0.818

Table 3.2: Accuracy statistics for the wetland model. Grey shading indicates number of correct point classifications. Row and column % correct are calculated by subtracting false negative and false positive rates. Total % correct is calculated by subtracting total model OOB-error rate.

	Marine & Estuarine Saltwater Aquatic Vegetation	Mediterranean Scrub	Salt Marsh	Temperate & Boreal Freshwater Wet Meadow & Marsh	Temperate & Boreal Scrub & Herb Coastal Vegetation	Temperate Flooded & Swamp Forest	Temperate Grassland, Meadow & Shrubland	Row Totals	% Correct
Marine & Estuarine Saltwater Aquatic Vegetation	75	0	6	3	0	14	0	**98**	76.5%
Mediterranean Scrub	0	240	0	1	0	126	62	**429**	55.9%
Salt Marsh	5	0	6922	165	2	134	161	**7389**	93.7%
Temperate & Boreal Freshwater Wet Meadow & Marsh	0	0	130	2974	8	1190	648	**4950**	60.1%
Temperate & Boreal Scrub & Herb Coastal Vegetation	0	0	1	11	175	65	12	**264**	66.3%
Temperate Flooded & Swamp Forest	1	92	101	745	39	11808	1777	**14563**	81.1%
Temperate Grassland, Meadow & Shrubland	0	66	114	489	19	1639	26285	**28612**	91.9%
Column Totals	**81**	**398**	**7274**	**4388**	**243**	**14976**	**28945**	Total %	
% Correct	92.6%	60.3%	95.2%	67.8%	72.0%	78.8%	90.8%	Correct	86.10%
Random Forest *cuttoff* values	0.14	0.09	0.14	0.1	0.1	0.12	0.15	Kappa	0.785

Figure 3.7: Overall area of predicted change of vegetation formation class from the 2020s to 2080s across the PNW, based on majority prediction from the 13 future projections resulting in a different formation class compared to the reference period.

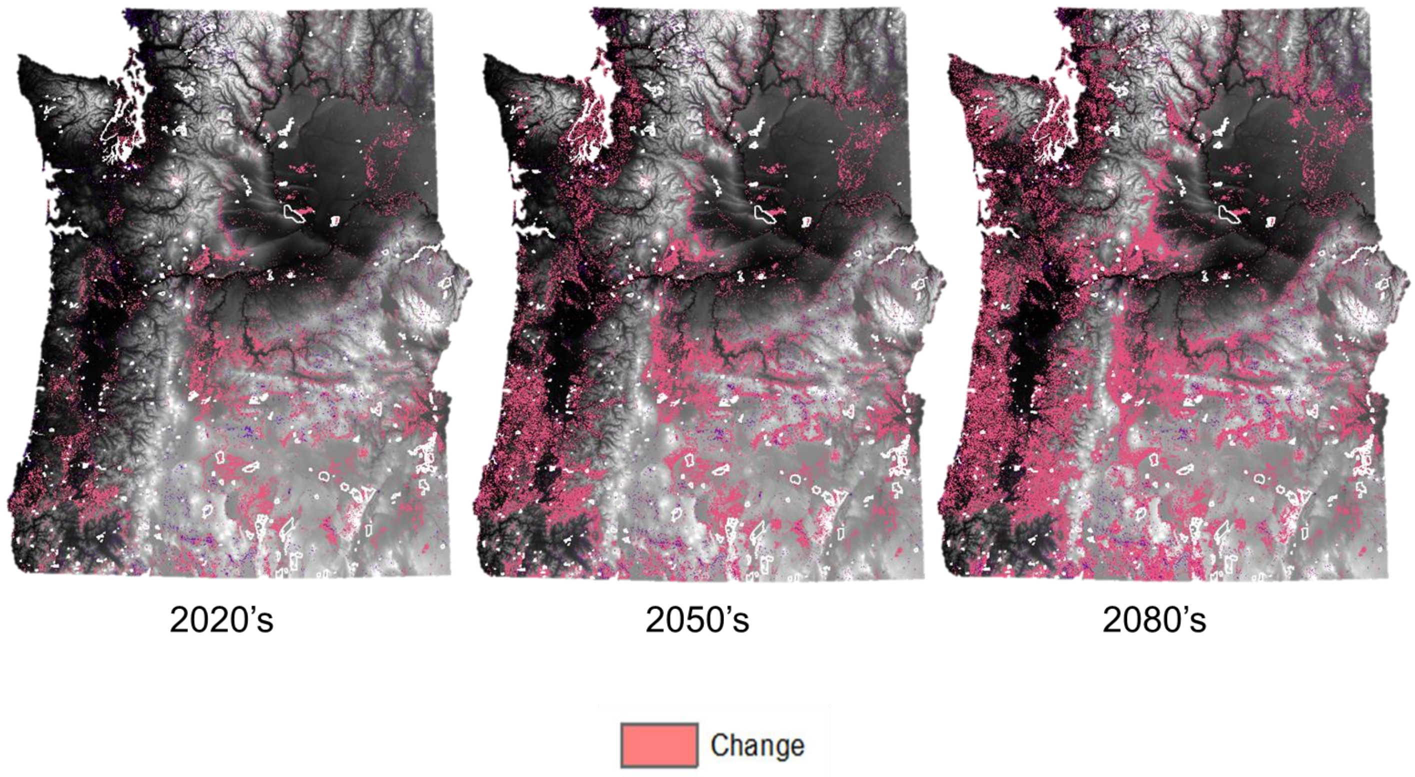


Figure 3.8: Consensus for the 13 climate models from 2020s to 2080s for the PNW, based on majority prediction from the 13 future projections resulting in a different formation class compared to the reference period and the percent agreement of the projections to what the formation class would be suitable.

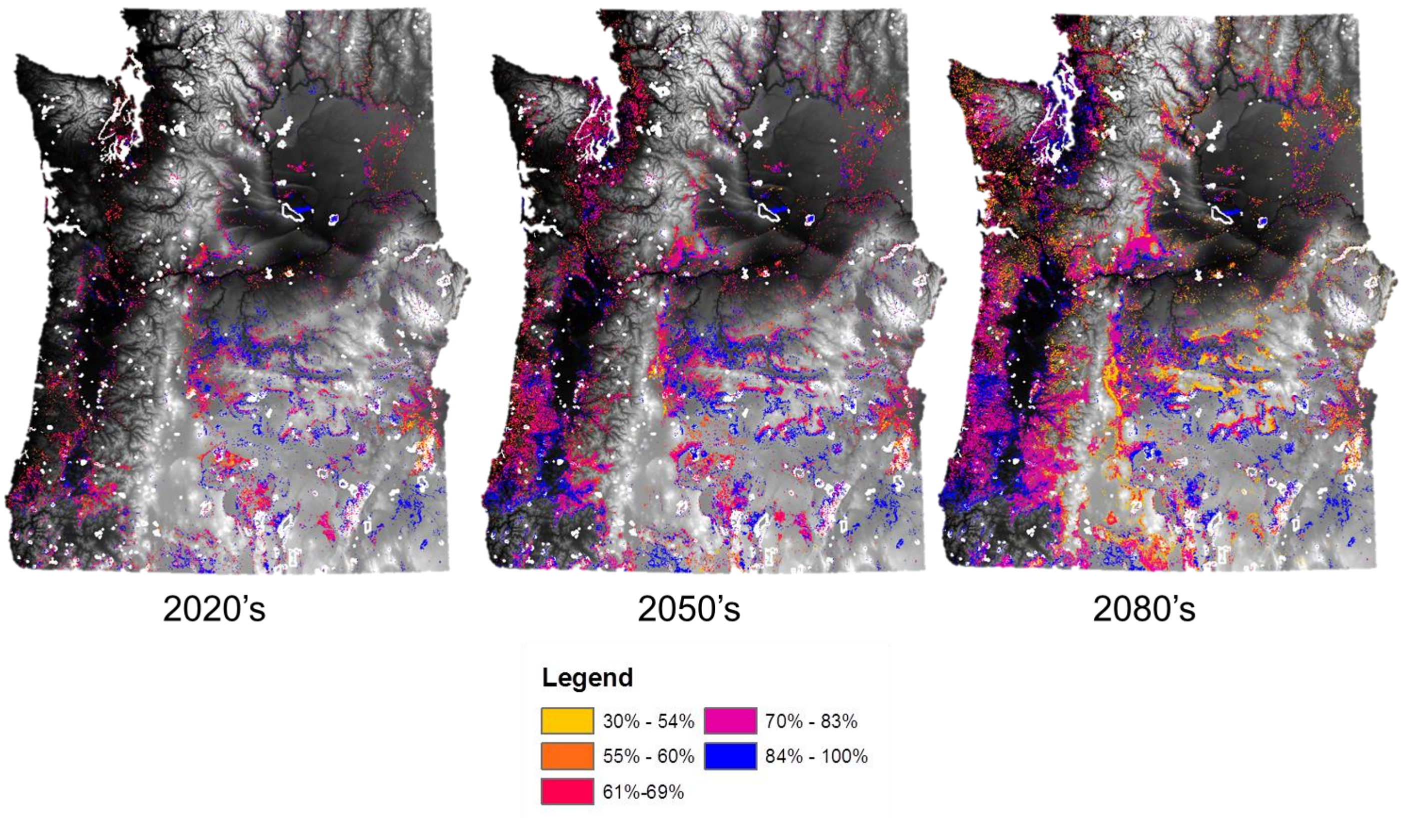


Table 3.3: Regional percent cover change for the upland and wetland formation classes of the PNW, based on averaged pixel counts from the 13 climate model predictions comparing current to the 2020s through the 2080s.

	Current	**2020s**	**2050s**	**2080s**
Upland Vegetation Formation Class	Total % Cover	% Change	% Change	% Change
Alpine Scrub, Forb Meadow & Grassland	0.15%	-0.08%	-0.19%	-0.26%
Barren	0.16%	-0.07%	-0.07%	0.02%
Cool Semi-Desert Cliff, Scree & Rock Veg	0.88%	-0.51%	-0.62%	-0.74%
Cool Semi-Desert Scrub & Grassland	32.92%	0.16%	0.21%	0.20%
Cool Temperate Forest	56.52%	-0.17%	-0.40%	-0.65%
Introduced & Semi Natural Vegetation	2.42%	-0.04%	0.71%	1.68%
Polar & Alpine Cliff, Scree & Rock Veg	0.15%	-0.13%	-0.18%	-0.22%
Salt Marsh	1.50%	0.29%	0.35%	-0.04%
Temperate & Boreal Cliff, Scree & Rock Veg	0.32%	-0.11%	-0.24%	-0.34%
Warm Temperate Forest	4.95%	0.95%	2.84%	5.45%
Wetland Vegetation Formation Class				
Marine & Estuarine Saltwater Aquatic Veg	0.14%	-0.01%	-0.01%	-0.01%
Mediterranean Scrub	0.71%	0.01%	-0.11%	-0.18%
Salt Marsh	12.92%	1.31%	1.25%	0.95%
Temperate & Boreal Freshwater Wet Meadow & Marsh	7.79%	-1.33%	-0.66%	-0.97%
Temperate & Boreal Scrub & Herb Coastal Veg	0.43%	0.34%	-0.02%	-0.01%
Temperate Flooded & Swamp Forest	26.59%	1.67%	0.98%	2.10%
Temperate Grassland, Meadow & Shrubland	51.42%	-1.66%	-1.24%	-1.87%

Table 3.4: Regional elevation change for the upland and wetland formation classes in the PNW, based on averaged pixel counts from the 13 climate model predictions comparing current to the 2020s through the 2080s.

	Current	2020s	2050s	2080s
Upland Vegetation Formation Class	Average Regional Elevation (m)	+/- Elevation from Current	+/- Elevation from Current	+/- Elevation from Current
Alpine Scrub, Forb Meadow & Grassland	2104	6	16	22
Barren	1618	57	62	180
Cool Semi-Desert Cliff, Scree & Rock Vegetation	794	15	-36	-85
Cool Semi-Desert Scrub & Grassland	939	-9	42	56
Cool Temperate Forest	897	50	124	217
Introduced & Semi Natural Vegetation	1101	-125	-129	-94
Polar & Alpine Cliff, Scree & Rock Vegetation	2272	36	36	37
Salt Marsh	628	-29	-32	-24
Temperate & Boreal Cliff, Scree & Rock Vegetation	1526	20	38	59
Warm Temperate Forest	509	-50	-33	47
Wetland Vegetation Formation Class				
Marine & Estuarine Saltwater Aquatic Vegetation	16	-13	-14	-14
Mediterranean Scrub	588	-235	-232	-245
Salt Marsh	535	-31	229	228
Temperate & Boreal Freshwater Wet Meadow & Marsh	695	79	71	22
Temperate & Boreal Scrub & Herb Coastal Vegetation	548	-537	-537	-540
Temperate Flooded & Swamp Forest	676	-15	-12	-35
Temperate Grassland, Meadow & Shrubland	869	46	57	60

Table 3.5: Area of the PNW natural areas predicted to have a shift in climatically suitable habitat for its current vegetation (hectares and percent of total natural area) based on 100% climate model agreement (13 of 13) for the 2020s.

EcoRegion	Name	2020s Hectares (%)
Blue Mountains	Logan Butte	64 (20)
Blue Mountains	The Island	64 (100)
Blue Mountains	Unity Reservoir Bald Eagle Nest Habitat	128 (50)
Canadian Rocky Mountains	Little Pend Oreille River NAP	64 (50)
Coast Range	Cape Blanco	64 (100)
Coast Range	Cascade Head	64 (50)
Coast Range	North Spit	64 (25)
Columbia Plateau	Upper Deep Creek	64 (100)
East Cascades	Monte Cristo	64 (10)
East Cascades	Monte Cristo NAP	64 (14.3)
East Cascades	Thompson Clover	64 (33.3)
Klamath Mountains	Grayback Mountain	64 (20)
Klamath Mountains	Umpqua River Wildlife Area-Woodruff Mountain	64 (100)
North Cascades	Silver Lake	64 (12.5)
Northern Basin and Range	Biscuitroot	512 (12.5)
Northern Basin and Range	Fir Groves	64 (33.3)
Northern Basin and Range	Foster Flat	384 (24)
Northern Basin and Range	Lake Ridge	256 (13.3)
Northern Basin and Range	Poker Jim Ridge	64 (20)
Northern Basin and Range	Stinking Lake	192 (33.3)
Northwest Coast	Grays Bay Estuary	64 (100)
Northwest Coast	Niawiakum River NAP	64 (16.7)
Puget Trough	Ellsworth Woods	256 (57.1)
Puget Trough	Graveyard Spit	64 (50)
Puget Trough	Port Susan Bay	128 (40)
Puget Trough	Thirteenth Division Prairie	128 (40)
West Cascades	McKenzie Pass RNA	64 (33.3)
West Cascades	Sherwood Butte	64 (10)
Willamette Valley	Banks swamp (Killin Wetlands)	64 (50)

Table 3.6: Area of the PNW natural areas predicted to have a shift in climatically suitable habitat for its current vegetation (hectares and percent of total natural area) based on 100% climate model agreement (13 of 13) for the 2050s.

		2050s
EcoRegion	**Name**	Hectares (%)
Blue Mountains	Forest Creek - Rough Canyon	64 (50)
Blue Mountains	Grande Ronde	128 (2.1)
Blue Mountains	Hunt Mountain	64 (14.3)
Blue Mountains	Logan Butte	64 (20)
Blue Mountains	Mill Creek Watershed	64 (2.1)
Blue Mountains	Mount Joseph	64 (20)
Blue Mountains	Nebo	64 (7.1)
Blue Mountains	North Fork Malhuer River	64 (7.7)
Blue Mountains	Silver Creek	128 (6.7)
Blue Mountains	South Fork Crooked River	64 (4.3)
Blue Mountains	Winter Roost	64 (50)
Canadian Rocky Mountains	Little Pend Oreille River NAP	64 (50)
Coast Range	Cape Blanco	64 (100)
Coast Range	Cascade Head	64 (50)
Coast Range	Coquille River Falls	64 (50)
Coast Range	New River	256 (80)
Coast Range	North Spit	64 (25)
Coast Range	Umpqua River Wildlife Area-Cougar Creek	128 (100)
Coast Range	Umpqua River Wildlife Area-Lost Creek	64 (100)
Coast Range	Umpqua River Wildlife Area-Martin Creek	128 (100)
Columbia Plateau	Fitzner/Eberhardt	384 (15)
Columbia Plateau	Lower Crab Creek	64 (2.5)
Columbia Plateau	Sentinel Slope	64 (50)
Columbia Plateau	Yakima River Canyon	64 (3.1)
East Cascades	Mill Creek	64 (20)
East Cascades	Miller Creek	64 (25)
East Cascades	Monte Cristo	64 (10)
East Cascades	Monte Cristo NAP	64 (14.3)
East Cascades	Thompson Clover	64 (33.3)

Table 3.6: Cont.

EcoRegion	**Name**	**2050s** Hectares (%)
East Cascades	Trout Lake NAP	192 (30)
Klamath Mountains	Babyfoot Lake	128 (66.7)
Klamath Mountains	Bobby Creek	64 (8.3)
Klamath Mountains	Bushnell-Irwin Rocks	256 (57.1)
Klamath Mountains	Lemmingsworth Gulch	128 (33.3)
Klamath Mountains	North Myrtle Creek	128 (50)
Klamath Mountains	Umpqua River Wildlife Area-Woodruff Mountain	64 (100)
North Cascades	Silver Lake	64 (12.5)
Northern Basin and Range	Foster Flat	384 (24)
Northern Basin and Range	Jordan Craters	960 (7.5)
Northern Basin and Range	Juniper Mountain	128 (7.7)
Northern Basin and Range	Lake Ridge	256 (13.3)
Northern Basin and Range	Poker Jim Ridge	64 (20)
Northern Basin and Range	Stinking Lake	192 (33.3)
Northern Basin and Range	Toppin Creek Butte	64 (4)
Northwest Coast	Bone River NAP	128 (15.4)
Northwest Coast	Elk River NRCA	192 (15.8)
Northwest Coast	Grays Bay Estuary	64 (100)
Northwest Coast	Niawiakum River NAP	64 (16.7)
Puget Trough	Bower Woods	128 (40)
Puget Trough	Ellsworth Woods	256 (57.1)
Puget Trough	GRAVEYARD SPIT	64 (50)
Puget Trough	Port Susan Bay	128 (40)

Table 3.6: Cont.

		2050s
EcoRegion	**Name**	Hectares (%)
Puget Trough	Thirteenth Division Prairie	192 (60)
Puget Trough	Weir Prairie	128 (66.7)
West Cascades	McKenzie Pass RNA	64 (33.3)
Willamette Valley	Banks swamp (Killin Wetlands)	64 (50)
Willamette Valley	Willow Creek	64 (50)

Table 3.7: Area of the PNW natural areas predicted to have a shift in climatically suitable habitat for its current vegetation (hectares and percent of total natural area) based on 100% climate model agreement (13 of 13) for the 2080s.

		2080s
EcoRegion	**Name**	Hectares (%)
Blue Mountains	Forest Creek - Rough Canyon	64 (50)
Blue Mountains	Logan Butte	64 (20)
Blue Mountains	Nebo	64 (7.1)
Blue Mountains	North Fork Malhuer River	64 (7.7)
Blue Mountains	Sheep Mountain	64 (3)
Blue Mountains	South Fork Crooked River	128 (8.6)
Blue Mountains	Unity Reservoir Bald Eagle Nest Habitat	128 (50)
Blue Mountains	Winter Roost	64 (50)
Canadian Rocky Mountains	Little Pend Oreille River NAP	64 (50)
Coast Range	Cascade Head	64 (50)
Coast Range	Coquille River Falls	64 (50)
Coast Range	Neskia Beach	64 (100)
Coast Range	New River	256 (80)
Coast Range	North Spit	64 (25)
Coast Range	Port Orford Cedar	256 (66.7)
Coast Range	Tenmile Rna	128 (25)
Coast Range	Umpqua River Wildlife Area-Brads Creek	64 (100)
Coast Range	Umpqua River Wildlife Area-Cougar Creek	128 (100)
Coast Range	Umpqua River Wildlife Area-Lost Creek	64 (100)
Columbia Plateau	Badger Mountain	64 (100)
Columbia Plateau	Lower Crab Creek	64 (2.5)
Columbia Plateau	Sentinel Slope	64 (50)
Columbia Plateau	Yakima River Canyon	64 (3.1)
East Cascades	Mill Creek	64 (20)
East Cascades	Thompson Clover	64 (33.3)
East Cascades	Trout Lake NAP	192 (30)

Table 3.7: Cont.

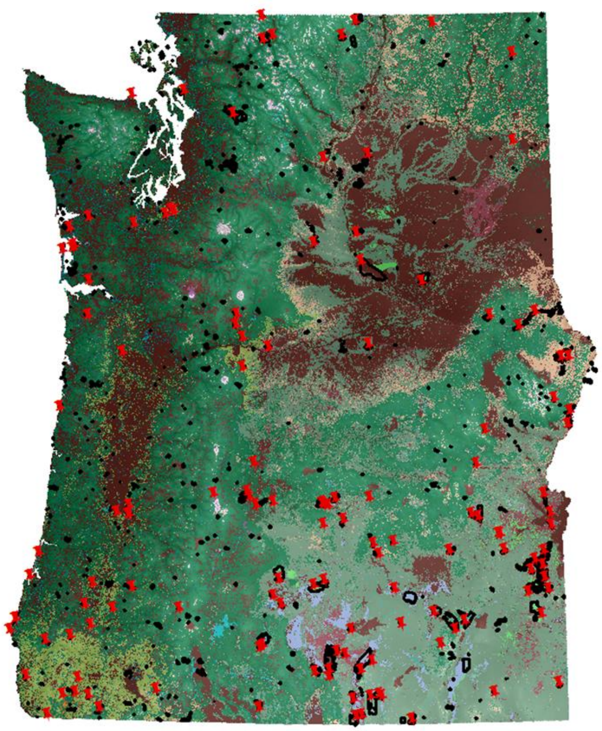
		2080s
EcoRegion	**Name**	Hectares (%)
Klamath Mountains	Babyfoot Lake	128 (66.7)
Klamath Mountains	Beatty Creek	320 (83.3)
Klamath Mountains	Bobby Creek	64 (8.3)
Klamath Mountains	Bushnell-Irwin Rocks	256 (57.1)
Klamath Mountains	Cedar Log Flat	128 (66.7)
Klamath Mountains	Hunter Creek Bog	128 (40)
Klamath Mountains	Lemmingsworth Gulch	128 (33.3)
Klamath Mountains	North Fork Hunter Creek	192 (27.3)
Klamath Mountains	North Myrtle Creek	128 (50)
Klamath Mountains	Umpqua River Wildlife Area-Woodruff Mountain	64 (100)
North Cascades	Big Beaver	128 (9.5)
North Cascades	Perry Creek	64 (6.3)
North Cascades	Silver Lake	64 (12.5)
Northern Basin and Range	Dry Creek Bench	64 (9.1)
Northern Basin and Range	Fish Creek Rim	320 (8.8)
Northern Basin and Range	Foster Flat	384 (24)
Northern Basin and Range	Hammond Hill Sand Hills	64 (4.2)
Northern Basin and Range	Jordan Craters	960 (7.5)
Northern Basin and Range	Owyhee Views	128 (0.6)
Northern Basin and Range	Poker Jim Ridge	64 (20)
Northern Basin and Range	Stinking Lake	192 (33.3)

Table 3.7: Cont.

		2080s
EcoRegion	**Name**	Hectares (%)
Northern Basin and Range	Toppin Creek Butte	64 (4)
Northwest Coast	Bone River NAP	128 (15.4)
Northwest Coast	Chehalis River Surge Plain NAP	832 (81.3)
Northwest Coast	Elk River NRCA	192 (15.8)
Northwest Coast	Grays Bay Estuary	64 (100)
Northwest Coast	Leadbetter Point	384 (75)
Northwest Coast	Niawiakum River Nap	64 (16.7)
Puget Trough	Ellsworth Woods	256 (57.1)
Puget Trough	Foulweather Bluff	64 (100)
Puget Trough	Graveyard Spit	64 (50)
Puget Trough	Iceberg Point - Point Colville	64 (33.3)
Puget Trough	Lake Hancock	64 (100)
Puget Trough	Schumocher Creek NAP	64 (11.1)
Puget Trough	Thirteenth Division Prairie	192 (60)
Puget Trough	Weir Prairie	128 (66.7)
West Cascades	Butter Creek	64 (5.9)
West Cascades	Goat Marsh	128 (22.2)
West Cascades	McKenzie Pass RNA	64 (33.3)
Willamette Valley	Banks swamp (Killin Wetlands)	64 (50)
Willamette Valley	Coburg Ridge - Jaqua	192 (42.9)
Willamette Valley	Willow Creek	64 (50)

Figure 3.9: Geographic distribution of PNW natural areas (red markers) with projected change based on majority climate model consensus from subset of future prediction based on temperature increase. 137 and 193 natural areas were identified as having vulnerable areas for the mild and extreme future temperature projections.

MILD CLIMATE PROJECTIONS **EXTREME MODEL PROJECTIONS**



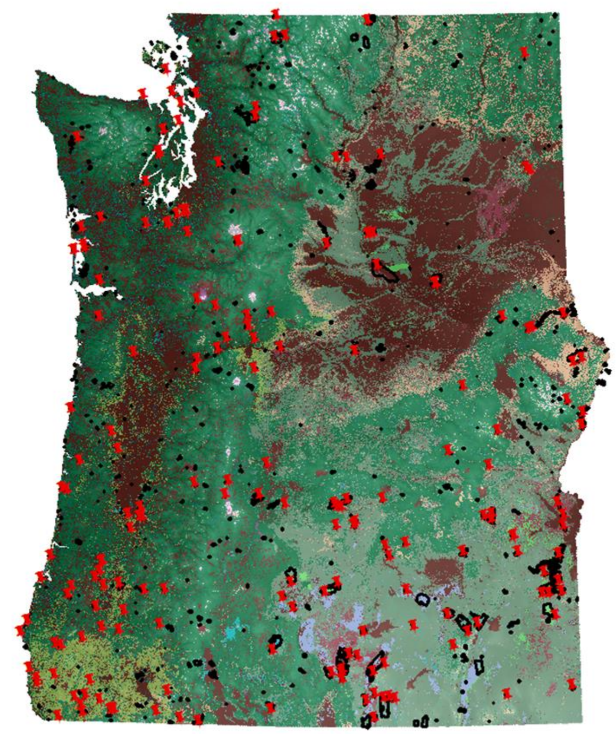


Table 3.8: All PNW natural areas with recorded disturbance from the FHA and MTBS and with predicted change in climate suitability (majority consensus required). Bold indicate fire and bold and italicized indicate fire and other disturbance. Model Agreement is the average of each pixel's model consensus and hectares (%) is area and percent of total natural area

		2020s		**2050s**		**2080s**	
EcoRegion	Name	Hectares (%)	Model Agreement (%)	Hectares (%)	Model Agreement (%)	Hectares (%)	Model Agreement (%)
Blue Mountains	***Castle Rock***	***2496 (27.9)***	***85***	***2496 (27.9)***	***98.4***	***2496 (27.9)***	***96.4***
Blue Mountains	Clear Lake Ridge	64 (4.8)	61.5	128 (9.5)	80.8	128 (9.5)	76.9
Blue Mountains	**Dry Mountain**	**1216 (51.4)**	**79.8**	**1664 (70.3)**	**89.1**	**1664 (70.3)**	**90.5**
Blue Mountains	Forest Creek - Rough Canyon	64 (50)	92.3	64 (50)	100	64 (50)	100
Blue Mountains	***Grande Ronde***	***768 (12.5)***	***63.5***	***1024 (16.7)***	***67.8***	***1024 (16.7)***	***63.5***
Blue Mountains	***Homestead***	***192 (5.7)***	***51.3***	***128 (3.8)***	***84.6***	***640 (18.9)***	***57.7***
Blue Mountains	Hunt Mountain	128 (28.6)	88.5	64 (14.3)	100	64 (14.3)	76.9
Blue Mountains	**Joseph Creek**	**192 (13.6)**	**61.5**	**192 (13.6)**	**61.5**	**320 (22.7)**	**70.8**
Blue Mountains	***Juniper Hills***	***896 (15.9)***	***97.3***	***896 (15.9)***	***97.3***	***1088 (19.3)***	***94.6***
Blue Mountains	Keating Riparian	64 (7.7)	69.2	128 (15.4)	76.9	128 (15.4)	46.2

Table 3.8 cont

Blue Mountains	Middle Fork of the John Day River	128 (28.6)	73.1	128 (28.6)	65.4	128 (28.6)	88.5
Blue Mountains	Mill Creek Watershed	64 (2.1)	92.3	64 (2.1)	100	384 (12.5)	66.7
Blue Mountains	Mount Joseph	64 (20)	53.8	64 (20)	100	64 (20)	84.6
Blue Mountains	***Nebo***	***64 (7.1)***	***92.3***	***64 (7.1)***	***100***	***64 (7.1)***	***100***
Blue Mountains	North Fork Crooked River	1344 (44.7)	93.4	1600 (53.2)	91.1	1728 (57.4)	88
Blue Mountains	North Fork Malhuer River	64 (7.7)	100	64 (7.7)	100	64 (7.7)	100
Blue Mountains	***Pleasant Valley***	***128 (25)***	***50***	***128 (25)***	***65.4***	***128 (25)***	***73.1***
Blue Mountains	***Sheep Mountain***	***384 (18.2)***	***73.1***	***448 (21.2)***	***62.6***	***512 (24.2)***	***74***
Blue Mountains	***Silver Creek***	***128 (6.7)***	***100***	***128 (6.7)***	***100***	***384 (20)***	***75.6***
Blue Mountains	**South Fork Crooked River**	**64 (4.3)**	**100**	**64 (4.3)**	**100**	**64 (4.3)**	**100**
Blue Mountains	***Stinger Creek***	***576 (42.9)***	***81.2***	***832 (61.9)***	***81.7***	***832 (61.9)***	***88.8***
Blue Mountains	Unity Reservoir Bald Eagle Nest Habitat	128 (50)	100	128 (50)	96.2	128 (50)	100
Blue Mountains	Winter Roost	64 (50)	84.6	64 (50)	100	64 (50)	100

Table 3.8 cont

Canadian Rocky Mountains	Little Pend Oreille River NAP	64 (50)	100	64 (50)	100	64 (50)	100
Coast Range	Cape Blanco	64 (100)	100	64 (100)	100	64 (100)	69.2
Coast Range	Cascade Head	64 (50)	100	64 (50)	100	64 (50)	100
Coast Range	Coquille River Falls	64 (50)	76.9	64 (50)	100	64 (50)	100
Coast Range	Cummins/Gwynn Creeks RNA	64 (2.8)	53.8	1344 (58.3)	69.6	2112 (91.7)	82.3
Coast Range	New River	64 (20)	92.3	64 (20)	100	64 (20)	100
Coast Range	North Spit	64 (25)	100	64 (25)	100	64 (25)	100
Coast Range	Port Orford Cedar	256 (66.7)	80.8	256 (66.7)	96.2	256 (66.7)	100
Coast Range	Tenmile RNA	128 (25)	92.3	128 (25)	96.2	128 (25)	100
Coast Range	Umpqua River Wildlife Area-Brads Creek	64 (100)	53.8	64 (100)	92.3	64 (100)	100
Coast Range	Umpqua River Wildlife Area-Cougar Creek	128 (100)	69.2	128 (100)	100	128 (100)	100
Columbia Plateau	Badger Mountain	64 (100)	69.2	64 (100)	92.3	64 (100)	100
Columbia Plateau	**Boardman Research Natural Area**	**640 (33.3)**	**56.9**	**896 (46.7)**	**64.3**	**640 (33.3)**	**59.2**
Columbia Plateau	Columbia Hills NAP	384 (31.6)	85.9	512 (42.1)	85.6	640 (52.6)	74.6
Columbia Plateau	**Fitzner/Eberhardt**	**384 (15)**	**78.2**	**384 (15)**	**100**	**448 (17.5)**	**86.8**

Table 3.8 cont

Columbia Plateau	**Horn Butte**	**128 (5.1)**	**73.1**	**128 (5.1)**	**76.9**	**256 (10.3)**	**57.7**
Columbia Plateau	**Juniper Forest**	**4288 (56.3)**	**93**	**4480 (58.8)**	**92.4**	**4352 (57.1)**	**94.5**
Columbia Plateau	Spring Creek Canyon NAP	128 (100)	57.7	128 (100)	50	128 (100)	69.2
Columbia Plateau	Turnbull Pine	64 (100)	61.5	64 (100)	84.6	64 (100)	76.9
Columbia Plateau	**Yakima River Canyon**	**64 (3.1)**	**100**	**64 (3.1)**	**100**	**64 (3.1)**	**100**
East Cascades	Klickitat Canyon NRCA	384 (75)	59	512 (100)	76.9	512 (100)	81.7
East Cascades	Mill Creek	64 (20)	92.3	64 (20)	100	64 (20)	100
East Cascades	Miller Creek	64 (25)	92.3	64 (25)	100	64 (25)	92.3
East Cascades	Monte Cristo	64 (10)	100	64 (10)	100	192 (30)	69.2
East Cascades	Monte Cristo NAP	64 (14.3)	100	64 (14.3)	100	128 (28.6)	76.9
East Cascades	Sycan Marsh	1984 (16.9)	83.4	2112 (18)	74.8	2112 (18)	85.3
East Cascades	***Thompson Clover***	***64 (33.3)***	***100***	***64 (33.3)***	***100***	***64 (33.3)***	***100***
East Cascades	Upper Klamath River	128 (4.7)	92.3	320 (11.6)	61.5	704 (25.6)	67.1
East Cascades	White Salmon Oak NRCA	128 (66.7)	76.9	128 (66.7)	88.5	128 (66.7)	88.5
Klamath Mountains	Ashland	384 (54.5)	69.2	512 (72.7)	88.5	512 (72.7)	94.2
Klamath Mountains	Babyfoot Lake	128 (66.7)	76.9	128 (66.7)	100	128 (66.7)	100
Klamath Mountains	Bobby Creek	64 (8.3)	100	64 (8.3)	100	64 (8.3)	100

Table 3.8 cont

Klamath Mountains	Brewer Spruce	256 (36.4)	82.7	256 (36.4)	98.1	256 (36.4)	94.2
Klamath Mountains	***Eight Dollar Mountain***	***448 (87.5)***	***72.5***	***512 (100)***	***89.4***	***512 (100)***	***88.5***
Klamath Mountains	Grayback Glades	64 (14.3)	69.2	448 (100)	81.3	448 (100)	83.5
Klamath Mountains	Grayback Mountain	64 (20)	100	64 (20)	92.3	192 (60)	71.8
Klamath Mountains	Hunter Creek Bog	128 (40)	80.8	128 (40)	96.2	128 (40)	100
Klamath Mountains	***Lemmingsworth Gulch***	***128 (33.3)***	***92.3***	***128 (33.3)***	***100***	***128 (33.3)***	***100***
Klamath Mountains	North Bank	64 (2.7)	53.8	64 (2.7)	69.2	128 (5.4)	65.4
Klamath Mountains	North Fork Hunter Creek	128 (18.2)	84.6	192 (27.3)	92.3	192 (27.3)	100
Klamath Mountains	North Myrtle Creek	128 (50)	88.5	128 (50)	100	128 (50)	100
Klamath Mountains	Oregon Gulch	64 (16.7)	69.2	128 (33.3)	84.6	128 (33.3)	88.5
Klamath Mountains	Pipe Fork	64 (33.3)	76.9	128 (66.7)	92.3	128 (66.7)	88.5
Klamath Mountains	***Rough and Ready***	***192 (42.9)***	***61.5***	***192 (42.9)***	***76.9***	***192 (42.9)***	***76.9***
Klamath Mountains	***Sourgame***	***64 (50)***	***69.2***	***128 (100)***	***84.6***	***128 (100)***	***92.3***
Klamath Mountains	***Woodcock Bog***	***64 (50)***	***61.5***	***64 (50)***	***92.3***	***64 (50)***	***84.6***

Table 3.8 cont

North Cascades	***Big Beaver***	***128 (9.5)***	***92.3***	***128 (9.5)***	***92.3***	***64 (4.8)***	***53.8***
North Cascades	Morning Star NRCA	320 (2.5)	75.4	448 (3.6)	73.6	704 (5.6)	70.6
North Cascades	Perry Creek	64 (6.3)	53.8	64 (6.3)	84.6	64 (6.3)	100
North Cascades	***Silver Lake***	***64 (12.5)***	***100***	***64 (12.5)***	***100***	***64 (12.5)***	***100***
Northern Basin and Range	**Fir Groves**	**64 (33.3)**	**100**	**64 (33.3)**	**84.6**	**192 (100)**	**71.8**
Northern Basin and Range	**Foley Lake**	**320 (35.7)**	**83.1**	**320 (35.7)**	**73.8**	**320 (35.7)**	**76.9**
Northern Basin and Range	**Honeycombs**	**3392 (52.5)**	**59.4**	**4224 (65.3)**	**60**	**4096 (63.4)**	**58.5**
Northern Basin and Range	**Jordan Craters**	**960 (7.5)**	**100**	**960 (7.5)**	**100**	**960 (7.5)**	**100**
Northern Basin and Range	**Juniper Mountain**	**128 (7.7)**	**100**	**128 (7.7)**	**100**	**192 (11.5)**	**76.9**
Northern Basin and Range	**Kiger Mustang**	**5504 (20)**	**85.9**	**5504 (20)**	**91**	**5504 (20)**	**93.1**
Northern Basin and Range	***Lake Abert***	***1728 (13.6)***	***87.5***	***1984 (15.6)***	***89.1***	***2240 (17.6)***	***82.2***

Table 3.8 cont

Northern Basin and Range	**Leslie Gulch**	**1536 (32.9)**	**74.7**	**1536 (32.9)**	**72.8**	**1472 (31.5)**	**59.2**
Northern Basin and Range	Lost Forest	512 (12.7)	69.2	1088 (27)	63.8	256 (6.3)	82.7
Northern Basin and Range	Lost Forest-Sand Dunes-Fossil Lake	3008 (23.4)	72.7	4736 (36.8)	69.4	3520 (27.4)	65.7
Northern Basin and Range	**Owyhee Below Dam**	**3712 (55.8)**	**55.2**	**3776 (56.7)**	**60.4**	**3456 (51.9)**	**64.1**
Northern Basin and Range	**Owyhee Views**	**8704 (41)**	**57.7**	**10752 (50.6)**	**61.2**	**12480 (58.7)**	**58.5**
Northern Basin and Range	**Red Knoll**	**256 (5.6)**	**92.3**	**256 (5.6)**	**82.7**	**256 (5.6)**	**75**
Northern Basin and Range	**South Warner Basin**	**64 (12.5)**	**61.5**	**192 (37.5)**	**79.5**	**192 (37.5)**	**87.2**
Northern Basin and Range	Table Rock	832 (36.1)	67.5	896 (38.9)	78.6	320 (13.9)	84.6
Northern Basin and Range	**Warner Wetlands**	**320 (1)**	**87.7**	**448 (1.4)**	**78**	**960 (3)**	**68.2**
Northwest Coast	Grays Bay Estuary	64 (100)	100	64 (100)	100	64 (100)	100
Northwest Coast	Leadbetter Point	64 (12.5)	61.5	64 (12.5)	92.3	64 (12.5)	100

Table 3.8 cont

Okanogan	***Loomis NRCA***	***256 (2.7)***	***82.7***	***256 (2.7)***	***78.8***	***128 (1.4)***	***76.9***
Puget Trough	Bower Woods	128 (40)	76.9	128 (40)	100	128 (40)	92.3
Puget Trough	Dabob Bay NAP	64 (11.1)	61.5	576 (100)	76.9	576 (100)	85.5
Puget Trough	Ellsworth Woods	256 (57.1)	100	256 (57.1)	100	256 (57.1)	100
Puget Trough	Foulweather Bluff	64 (100)	46.2	64 (100)	84.6	64 (100)	100
Puget Trough	Graveyard Spit	64 (50)	100	64 (50)	100	64 (50)	100
Puget Trough	Kitsap Forest NAP	64 (25)	53.8	192 (75)	76.9	192 (75)	82.1
Puget Trough	Mima Mounds NAP	256 (80)	78.8	256 (80)	96.2	256 (80)	92.3
Puget Trough	Port Susan Bay	128 (40)	100	128 (40)	50	128 (40)	61.5
Puget Trough	Schumocher Creek	64 (100)	69.2	64 (100)	84.6	64 (100)	100
Puget Trough	South Puget Prairies	64 (100)	69.2	64 (100)	92.3	64 (100)	92.3
Puget Trough	Thirteenth Division Prairie	64 (20)	69.2	64 (20)	100	64 (20)	100
Puget Trough	Weir Prairie	128 (66.7)	84.6	128 (66.7)	100	128 (66.7)	100
Snake River Plain	**Oregon Trail, Keeney Pass**	**768 (63.2)**	**67.9**	**832 (68.4)**	**69.8**	**640 (52.6)**	**73.8**
Snake River Plain	**Oregon Trail, Tub Mountain**	**640 (29.4)**	**68.5**	**896 (41.2)**	**67.6**	**832 (38.2)**	**64.5**
Snake River Plain	**South Alkali Sand Hills**	**640 (43.5)**	**66.9**	**768 (52.2)**	**66**	**896 (60.9)**	**73.6**
West Cascades	Butter Creek	64 (5.9)	61.5	64 (5.9)	92.3	64 (5.9)	100
West Cascades	***Limpy Rock***	***64 (8.3)***	***61.5***	***768 (100)***	***64.1***	***768 (100)***	***78.8***
West Cascades	Lost Lake	64 (25)	92.3	192 (75)	79.5	192 (75)	92.3
West Cascades	McKenzie Pass RNA	64 (33.3)	100	64 (33.3)	100	64 (33.3)	100
West Cascades	North Umpqua River	640 (76.9)	66.2	768 (92.3)	82.1	768 (92.3)	92.3
West Cascades	Sandy River Gorge	128 (33.3)	65.4	128 (33.3)	80.8	128 (33.3)	80.8
West Cascades	Sherwood Butte	64 (10)	100	64 (10)	76.9	64 (10)	61.5

Table 3.8 cont

West Cascades	***Squaw Flat***	***192 (100)***	***64.1***	***192 (100)***	***92.3***	***192 (100)***	***84.6***
West Cascades	Table Mountain/Greenleaf Peak NRCA	64 (5.6)	53.8	256 (22.2)	78.8	704 (61.1)	73.4
West Cascades	Three Creek RNA	64 (20)	92.3	64 (20)	84.6	64 (20)	84.6
Willamette Valley	Banks swamp (Killin Wetlands)	64 (50)	100	64 (50)	100	64 (50)	100
Willamette Valley	Camas Swale	64 (50)	76.9	128 (100)	84.6	128 (100)	88.5
Willamette Valley	Coburg Ridge - Jaqua	192 (42.9)	76.9	192 (42.9)	92.3	192 (42.9)	100
Willamette Valley	Willamette Confluence	128 (25)	73.1	128 (25)	92.3	128 (25)	96.2
Willamette Valley	Willow Creek	64 (50)	76.9	64 (50)	100	64 (50)	100

CHAPTER 4 – DISCUSSION

4.1 Representation assessment

This study represents the first analytical effort to examine PNW natural areas as a network of sites, and the first to evaluate the efficacy of the network to measure long-term study of environmental change across PNW. The current natural areas network appeared well-proportioned and representative of the broader ecological gradients found across Oregon and Washington. One notable exception was a lack of sites at elevations > 2,930 meters. Most high-elevation sites are designated as wilderness areas or national parks (Hendee 1968). Inclusion of high elevation sites in monitoring and analyses may be especially important given the projections of decreasing snowpack and earlier onsets of snowmelt and range shifts (Mote 2009, Chmura 2011). Most high elevation wild lands are designated as wilderness areas or national parks (Hendee 1968). These areas often have their own monitoring programs. However, effort could be made to designate portions of these areas as natural areas so that they are more likely to be included in any region-wide monitoring efforts that are based on natural areas. More than 40 natural areas have already been designated in National Parks and wilderness areas.

This analysis showed the importance of having numerous agencies contribute to the natural areas network. This multiple involvement resulted in a diverse network from widespread to rare vegetation compositions and structures. No single agency had sufficient ecological diversity to fully represent the variables analyzed in this study.

Representation is especially important for rare species because any shift in climate may result in extirpation. For example, climate related studies have predicted widespread range reduction of Engelmann spruce and have shown reduced climate-growth relationships for subalpine larch because of temperature increases (Kipfmueller 2003, Rehfeldt 2004).

Land ownership distribution did have an influence on the relative proportion of representation for some variables. For example, overrepresentation of the Western juniper ecological system stemmed from large land designations by the BLM in eastern Oregon. In contrast, under-representation of dry and wet mixed conifer types arose because these types occurring in areas of patchwork ownership in the western portion of the PNW region. However, proportionality may not be necessary, as long as there is sufficient representation to capture the finer scaled biodiversity and ecological processes occurring throughout the region.

4.2 Climate Modeling and Effects of Climate Change

Accuracy of the reference predictive vegetation models for upland and wetland formation classes used in this study was influenced by the methods used for developing the random forest models, classification of the modeled response variables, and the derived explanatory variables (Ohmann and Gregory 2002). High accuracy for cool semi-desert scrub & grassland, cool temperate forest, and temperate grassland, meadow & shrubland was a reflection of large land areas for each classification and the response to broad climatic patterns found in the region. The formation class with the lowest accuracy (48.8%) was introduced semi-natural vegetation. Responses for semi-natural vegetation were harder to predict because its distribution is primarily dependent on anthropogenic influences change over time. Bioclimatic modeling is based on the ecological niche theory of relating climate and species occurrence and does not incorporate anthropogenic influence (Hutchinson 1957, Grossman et al. 1998, Araújo and Peterson 2012).

Future prediction consensus of climate suitability projected reduction for cool temperate forest types and increase in warm temperate forest and scrub and grassland types. The shift to drier ecosystem types supports similar findings elsewhere (Rehfeldt et al. 2012, Hamann and Wang 2006, Wang et al. 2012). The Coast Range and the Puget Trough ecoregion exhibited the most dramatic shifts in suitability from cool temperate to warm temperate forest. Average temperature in the Puget Trough has already increased 1.3°C (2.3°F) over the 20th century, which is higher than the global trends (Snover et al. 2005). The decreased suitability for cool temperate forest and under-representation in the natural areas suggest that there may be need for designating more cool temperate forest natural areas. Another possibility is to enlarge existing natural areas to better include fine- scaled classifications of cool temperate forest formation classes within the network. Reduction in suitability for higher elevation alpine and polar formation class types is also consistent with previous findings (Rehfeldt et al. 2012, Wang et al. 2012). These classes are rare in PNW and may be especially vulnerable to extirpation.

Wetland formation classes exhibited fewer changes in suitability for vegetation formation class compared to upland vegetation. Generally, wetland species are adapted to site specific hydrological regimes, chemical and nutrient cycling, soil composition and salinity (Christy 2009). Thus, range shifts for specialized wetland species will be limited by site specific conditions. Generalist wetland species such as *Atripex Spp.*, included in the salt marsh formation class, may be more capable of inhabiting new areas (Howard 2003). Additionally, physiological characteristics (e.g., C_4 photosynthesis) of *Atripex Spp.* may make it more suitable for a warming climate (Edwards and Walker 1983).

4.3. Natural Area Site Selection

Selecting a subset of natural areas for monitoring climate change could be carried out in many different ways to meet current and future management objectives. One approach would be to use consensus mapping, where consensus and agreement of change is 100% between all the models. Highlighting areas with the strongest model consensus and agreement may be the most straightforward approach for developing the initial monitoring design. A second approach would be to concentrate monitoring where change consensus is high but model agreement is mixed. Reduced model agreement may require greater flexibility in management plans to account for unpredictability (Wang et al. 2012). Integration of both approaches and inclusion of sites where there is high model consensus for no change could also prove informative.

Natural area site selection could also be based on temperature projections (mild, moderate, extreme). Reducing the number of models (with change still based on model consensus) increases the number of natural areas being selected across the region and within individual ecoregions. Including more areas would represent greater regional ecological diversity and depth to a monitoring program. Another important consideration in site selection may be the incorporation of disturbance data. Coupling climate change and abiotic and biotic disturbances may provide a catalyst for rapid shifts in successional patterns, species composition and structure and fundamentally change ecological processes.

4.4 Exploratory / Preliminary Multivariate Analysis

A preliminary multivariate analysis was conducted to analyze the correlation of future formation class predictions and the relationship to environmental variables. Understanding the association and strength of the relationship between formation class and environmental variables may be useful to help identify the specific factors most influential in the geographic distribution of vegetation. The Random Forest reference models produced two outputs: (1) A univariate classification prediction (used in the main analysis) and (2) multidimensional response of vegetation class probabilities based on the inputted climate variables. Non-Metric Multidimensional Scaling (NMS) and data from the second output was used to assess changes in natural area vegetation formation classes and correlation to environmental variables in PC-ORD 6.14 (McCune and Grace 2002; McCune and Mefford 2011). The large data set resulted in computational limitation and, therefore, multiple subsets were analyzed separately. Preliminary subset exploration included analyzing current vegetation probabilities based on different ecoregions, jurisdiction, vegetation type, and selections of different future prediction. A majority of the subset data matrices were tested for outliers beyond two standard deviations (calculated using Euclidean and Sørensen's distance measure; Bray and Curtis 1957). The analysis highlighted several peripheral outliers in each of the data subsets. Due to the amount and the severity of the outlier statistics, all of the outliers were removed from each matrix to test their significance and the sensitivity on the resultant ordinations.

Further investigation is needed to make inferences from the NMS analysis but preliminary finding produced ordinations resulting in 2-dimensional solutions and produced similar final stress levels and instability. Additionally, cumulative R^2 values for the ordination axes generally were > 0.95. The removal of outliers resulted in minimal shifts in the axis correlation and slightly altered ordination structure. Interestingly, the outliers were generally grouped by spatial points, meaning that all the future model projections agreed in producing an outlier for a given point. These outliers could be a result of modeling error or could provide insight on specific natural areas that have the highest probability of shifting climatic suitability for its current vegetation type.

Exploration of this multivariate output not only has the potential to describe change in formation class presence and absence, but the rate and direction of change could be calculated based on the methodologies from Menges et al. 1993 and Philippi et al. 1998. Understanding regions and areas with the greatest magnitude of change could provide additional information for prioritization of natural areas for a monitoring network.

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CHAPTER 4 – CONCLUSION

The natural areas network appears sufficiently robust to serve as a strong platform for examining long-term environmental change across PNW. Establishment of a climate change monitoring program based on natural areas will benefit the conservation of the Pacific Northwest's natural ecosystems by serving as reference sites and providing data to better understand the effects that climate change may bring to ecosystems. It may also help improve the resiliency of the natural areas network given the uncertainty associated with future climate change effects by providing unique and diverse examples of ecosystem response to ecological stress. Gaps identified in representation and proportionality could lead to the establishment of new natural areas or encourage interagency cooperation with other land conservation programs that perhaps protect the missing gradients and ecosystem characteristics.

Now that baseline data has been generated for prioritizing sites for long-term monitoring, future efforts could focus on (1) initiating dialogue with the agencies that have natural areas in the network to discuss how best to use the data generated in this study to start selecting sites for monitoring; (2) developing standardized protocols that can be used across the natural areas network; (3) collecting data and developing techniques to improve model and prediction accuracy; (4) and periodically reassessing the vulnerability of all the natural areas in the network as new information and science becomes available.

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Appendix A: Natural area vulnerability for 2020s based on majority model consensus. Hectares (%): is the area and percent of the natural area with predicted change. Model Agreement (%): is the averaged model consensus for all pixels in the natural area which are predicted to change.

EcoRegion	Name	Hectares (%)	Model Agreement (%)
Blue Mountains	Castle Rock	2496 (27.9)	85
Blue Mountains	Clear Lake Ridge	64 (4.8)	61.5
Blue Mountains	Craig Mountain Lake	64 (50)	53.8
Blue Mountains	Dixie Butte	64 (50)	84.6
Blue Mountains	Dry Mountain	1216 (51.4)	79.8
Blue Mountains	Forest Creek - Rough Canyon	64 (50)	92.3
Blue Mountains	Gerald S. Strickler	64 (100)	92.3
Blue Mountains	Grande Ronde	896 (14.6)	81.75
Blue Mountains	Haystack Rock	64 (33.3)	53.8
Blue Mountains	Homestead	320 (9.5)	73.75
Blue Mountains	Hunt Mountain	128 (28.6)	88.5
Blue Mountains	Joseph Creek	192 (13.6)	61.5
Blue Mountains	Juniper Hills	1280 (22.7)	91.6
Blue Mountains	Keating Riparian	128 (15.4)	69.2
Blue Mountains	Logan Butte	64 (20)	100
Blue Mountains	Middle Fork of the John Day River	128 (28.6)	73.1
Blue Mountains	Mill Creek Watershed	64 (2.1)	92.3
Blue Mountains	Mount Joseph	64 (20)	53.8
Blue Mountains	Nebo	64 (7.1)	92.3
Blue Mountains	North Fork Crooked River	1344 (44.7)	93.4
Blue Mountains	North Fork Malhuer River	64 (7.7)	100
Blue Mountains	Oregon Trail	64 (8.3)	84.6
Blue Mountains	Peck's Milkvetch	2496 (45.9)	52.15
Blue Mountains	Pleasant Valley	128 (25)	50
Blue Mountains	Powell Butte	128 (66.7)	76.9
Blue Mountains	Sheep Mountain	384 (18.2)	73.1
Blue Mountains	Silver Creek	256 (13.4)	100
Blue Mountains	South Fork Crooked River	128 (8.6)	84.6
Blue Mountains	Stinger Creek	576 (42.9)	81.2
Blue Mountains	The Island	128 (200)	100

Appendix A: cont.

Blue Mountains	Tumalo Canal	320 (83.3)	55.4
Blue Mountains	Unity Reservoir Bald Eagle Nest Habitat	128 (50)	100
Blue Mountains	Wagon Roads	320 (62.5)	67.7
Blue Mountains	Winter Roost	64 (50)	84.6
Blue Mountains	Zumwalt Prairie	832 (6.3)	81.6
Canadian Rocky Mts	Little Pend Oreille River NAP	64 (50)	100
Coast Range	Blind Slough Swamp	128 (50)	69.2
Coast Range	Cape Blanco	64 (100)	100
Coast Range	Cascade Head	64 (50)	100
Coast Range	Coquille River Falls	64 (50)	76.9
Coast Range	Cummins/Gwynn Creeks RNA	64 (2.8)	53.8
Coast Range	Neskia Beach	64 (100)	69.2
Coast Range	New River	256 (80)	96.15
Coast Range	North Spit	64 (25)	100
Coast Range	Port Orford Cedar	256 (66.7)	80.8
Coast Range	Saddle Mountain	128 (25)	73.1
Coast Range	Tenmile Rna	128 (25)	92.3
Coast Range	Umpqua River Wildlife Area-Brads Creek	64 (100)	53.8
Coast Range	Umpqua River Wildlife Area-Cougar Creek	128 (100)	69.2
Coast Range	Umpqua River Wildlife Area-Lost Creek	64 (100)	69.2
Coast Range	Umpqua River Wildlife Area-Martin Creek	128 (100)	73.1
Columbia Plateau	Badger Mountain	64 (100)	69.2
Columbia Plateau	Boardman Research Natural Area	640 (33.3)	56.9
Columbia Plateau	Columbia Hills NAP	384 (31.6)	85.9
Columbia Plateau	Fitzner/Eberhardt	384 (15)	78.2
Columbia Plateau	Horn Butte	128 (5.1)	73.1
Columbia Plateau	Juniper Forest	4416 (58)	79.2
Columbia Plateau	Lower Crab Creek	320 (12.5)	75
Columbia Plateau	Moses Coulee	64 (3.1)	84.6
Columbia Plateau	Sentinel Slope	64 (50)	84.6
Columbia Plateau	Spring Creek Canyon NAP	128 (100)	57.7
Columbia Plateau	Turnbull Pine	64 (100)	61.5
Columbia Plateau	Upper Deep Creek	64 (100)	100
Columbia Plateau	Yakima River Canyon	128 (6.2)	100

Appendix A: cont.

East Cascades	Klickitat Canyon NRCA	384 (75)	59
East Cascades	Mill Creek	64 (20)	92.3
East Cascades	Miller Creek	64 (25)	92.3
East Cascades	Monte Cristo	64 (10)	100
East Cascades	Monte Cristo NAP	64 (14.3)	100
East Cascades	Sycan Marsh	2368 (20.2)	81.45
East Cascades	Thompson Clover	64 (33.3)	100
East Cascades	Trout Lake NAP	192 (30)	94.9
East Cascades	Upper Klamath River	192 (7)	80.75
East Cascades	White Salmon Oak NRCA	128 (66.7)	76.9
Klamath Mountains	Ashland	384 (54.5)	69.2
Klamath Mountains	Babyfoot Lake	128 (66.7)	76.9
Klamath Mountains	Bear Gulch	256 (100)	59.6
Klamath Mountains	Beatty Creek	320 (83.3)	70.8
Klamath Mountains	Bobby Creek	64 (8.3)	100
Klamath Mountains	Brewer Spruce	256 (36.4)	82.7
Klamath Mountains	Bushnell-Irwin Rocks	256 (57.1)	98.1
Klamath Mountains	Cedar Log Flat	192 (100)	80.75
Klamath Mountains	Eight Dollar Mountain	896 (175)	72.5
Klamath Mountains	Grayback Glades	64 (14.3)	69.2
Klamath Mountains	Grayback Mountain	64 (20)	100
Klamath Mountains	Hunter Creek Bog	128 (40)	80.8
Klamath Mountains	Lemmingsworth Gulch	128 (33.3)	92.3
Klamath Mountains	Lower Table Rocks	64 (11.1)	69.2
Klamath Mountains	North Bank	64 (2.7)	53.8
Klamath Mountains	North Fork Hunter Creek	128 (18.2)	84.6
Klamath Mountains	North Myrtle Creek	128 (50)	88.5
Klamath Mountains	Oregon Gulch	64 (16.7)	69.2
Klamath Mountains	Pipe Fork	64 (33.3)	76.9
Klamath Mountains	Rough and Ready	192 (42.9)	61.5
Klamath Mountains	Sourgame	64 (50)	69.2
Klamath Mountains	Umpqua River Wildlife Area-Woodruff Mountain	64 (100)	100
Klamath Mountains	Woodcock Bog	64 (50)	61.5
North Cascades	Big Beaver	128 (9.5)	92.3
North Cascades	Morning Star NRCA	320 (2.5)	75.4
North Cascades	Perry Creek	64 (6.3)	53.8
North Cascades	Silver Lake	64 (12.5)	100

Appendix A: cont.

North Cascades	Stetattle Creek	320 (6)	98.5
Northern Basin and Range	Abert Rim	896 (12.5)	76.9
Northern Basin and Range	Biscuitroot	512 (12.5)	100
Northern Basin and Range	Black Canyon	448 (38.9)	89.65
Northern Basin and Range	Connley Hills	960 (68.2)	88.2
Northern Basin and Range	Devils Garden Lava Beds	8704 (72)	83.7
Northern Basin and Range	Diamond Craters	832 (13.7)	96.4
Northern Basin and Range	Dry Creek Bench	64 (9.1)	92.3
Northern Basin and Range	Dry Creek Gorge	1088 (18.3)	52
Northern Basin and Range	Fir Groves	64 (33.3)	100
Northern Basin and Range	Fish Creek Rim	448 (12.3)	79.2
Northern Basin and Range	Foley Lake	320 (35.7)	83.1
Northern Basin and Range	Foster Flat	960 (60)	94
Northern Basin and Range	Guano Creek-Sink Lakes	320 (6.8)	85.6
Northern Basin and Range	Hammond Hill Sand Hills	64 (4.8)	84.6
Northern Basin and Range	Hawksie-Walksie	448 (6.1)	86.8
Northern Basin and Range	High Lakes	448 (2.6)	73.05
Northern Basin and Range	Honeycombs	3392 (52.5)	59.4
Northern Basin and Range	Jordan Craters	960 (7.5)	100
Northern Basin and Range	Juniper Mountain	128 (7.7)	100
Northern Basin and Range	Kiger Mustang	5696 (20.7)	89.1
Northern Basin and Range	Lake Abert	1728 (13.6)	87.5
Northern Basin and Range	Lake Ridge	256 (13.3)	100
Northern Basin and Range	Leslie Gulch	1536 (32.9)	74.7
Northern Basin and Range	Lost Forest	512 (12.7)	69.2
Northern Basin and Range	Lost Forest-Sand Dunes-Fossil Lake	3008 (23.4)	72.7
Northern Basin and Range	Owyhee Below Dam	3712 (55.8)	55.2
Northern Basin and Range	Owyhee Views	8832 (41.6)	67.3
Northern Basin and Range	Poker Jim Ridge	64 (20)	100
Northern Basin and Range	Rahilly-Gravelly	128 (1.7)	69.2
Northern Basin and Range	Red Knoll	256 (5.6)	92.3
Northern Basin and Range	South Warner Basin	64 (12.5)	61.5
Northern Basin and Range	Spanish Lake	320 (12.5)	80
Northern Basin and Range	Stinking Lake	192 (33.3)	100
Northern Basin and Range	Table Rock	832 (36.1)	67.5
Northern Basin and Range	Toppin Creek Butte	64 (4)	100
Northern Basin and Range	Warner Wetlands	320 (1)	87.7

Appendix A: cont.

Northwest Coast	Bone River NAP	128 (15.4)	92.3
Northwest Coast	Chehalis River Surge Plain NAP	832 (81.3)	89.9
Northwest Coast	Elk River NRCA	192 (15.8)	92.3
Northwest Coast	Grays Bay Estuary	64 (100)	100
Northwest Coast	Leadbetter Point	384 (75)	76.15
Northwest Coast	Niawiakum River NAP	64 (16.7)	100
Okanogan	Chewuch River	128 (3.8)	88.5
Okanogan	Little Vulcan Mountain	64 (100)	69.2
Okanogan	Loomis NRCA	256 (2.7)	82.7
Puget Trough	Bower Woods	128 (40)	76.9
Puget Trough	Dabob Bay NAP	64 (11.1)	61.5
Puget Trough	Ellsworth Woods	256 (57.1)	100
Puget Trough	Foulweather Bluff	64 (100)	46.2
Puget Trough	Graveyard Spit	64 (50)	100
Puget Trough	Kitsap Forest NAP	64 (25)	53.8
Puget Trough	Lake Hancock	64 (0.5)	53.8
Puget Trough	Mima Mounds NAP	256 (80)	78.8
Puget Trough	Port Susan Bay	128 (40)	100
Puget Trough	Schumocher Creek NAP	64 (100)	69.2
Puget Trough	South Puget Prairies	64 (100)	69.2
Puget Trough	Thirteenth Division Prairie	192 (60)	84.6
Puget Trough	Weir Prairie	128 (66.7)	84.6
Snake River Plain	Oregon Trail, Keeney Pass	768 (63.2)	67.9
Snake River Plain	Oregon Trail, Tub Mountain	640 (29.4)	68.5
Snake River Plain	South Alkali Sand Hills	640 (43.5)	66.9
West Cascades	Bald Hill NAP	64 (50)	53.8
West Cascades	Butter Creek	128 (11.8)	61.5
West Cascades	Cache Mtn Research Natural Area	64 (5.9)	53.8
West Cascades	Goat Marsh	128 (22.2)	57.7
West Cascades	Limpy Rock	64 (8.3)	61.5
West Cascades	Lost Lake	64 (25)	92.3
West Cascades	McKenzie Pass RNA	64 (33.3)	100
West Cascades	North Umpqua River	640 (76.9)	66.2
West Cascades	Sandy River Gorge	256 (66.6)	65.4
West Cascades	Sherwood Butte	64 (10)	100
West Cascades	Squaw Flat	192 (100)	64.1
West Cascades	Table Mountain/Greenleaf Peak NRCA	64 (5.6)	53.8

Appendix A: cont.

West Cascades	Three Creek RNA	64 (20)	92.3
Willamette Valley	Banks swamp (Killin Wetlands)	64 (50)	100
Willamette Valley	Camas Swale	64 (50)	76.9
Willamette Valley	Coburg Ridge - Jaqua	192 (42.9)	76.9
Willamette Valley	Rattlesnake Butte	64 (100)	69.2
Willamette Valley	Willamette Confluence	256 (50)	82.7
Willamette Valley	Willow Creek	64 (50)	76.9

Appendix B: Natural area vulnerability for 2050s based on majority model consensus. Hectares (%): is the area and percent of the natural area with predicted change. Model Agreement (%): is the averaged model consensus for all pixels in the natural area which are predicted to change.

EcoRegion	**Name**	**Hectares (%[1])**	**Model Agreement (%)[2]**
Blue Mountains	Baldy Mountain	64 (4)	53.8
Blue Mountains	Basin Creek	64 (25)	61.5
Blue Mountains	Castle Rock	2496 (27.3)	83.8
Blue Mountains	Clear Creek Ridge	64 (16.7)	84.6
Blue Mountains	Clear Lake Ridge	128 (9.5)	80.8
Blue Mountains	Dry Mountain	1664 (70.3)	89.1
Blue Mountains	Forest Creek - Rough Canyon	64 (50)	100
Blue Mountains	Gerald S. Strickler	64 (100)	84.6
Blue Mountains	Grande Ronde	1152 (18.8)	83.9
Blue Mountains	Homestead	320 (9.5)	84.6
Blue Mountains	Hunt Mountain	64 (14.3)	100
Blue Mountains	Joseph Creek	192 (13.6)	61.5
Blue Mountains	Juniper Hills	1280 (22.7)	89.05
Blue Mountains	Kahler Creek Butte	64 (100)	53.8
Blue Mountains	Keating Riparian	256 (30.8)	76.9
Blue Mountains	Logan Butte	64 (20)	100
Blue Mountains	Middle Fork of the John Day River	128 (28.6)	65.4
Blue Mountains	Mill Creek Watershed	128 (4.2)	88.45
Blue Mountains	Mount Joseph	64 (20)	100
Blue Mountains	Nebo	64 (7.1)	100
Blue Mountains	North Fork Crooked River	1600 (53.2)	91.1
Blue Mountains	North Fork Malhuer River	64 (7.7)	100
Blue Mountains	Peck's Milkvetch	5056 (93)	74.55
Blue Mountains	Pleasant Valley	128 (25)	65.4
Blue Mountains	Powell Butte	192 (100)	94.9
Blue Mountains	Shaketable	128 (100)	69.2
Blue Mountains	Sheep Mountain	512 (24.2)	62.05
Blue Mountains	Silver Creek	256 (13.4)	100
Blue Mountains	South Fork Crooked River	128 (8.6)	92.3

Appendix B: cont.

Blue Mountains	The Island	128 (200)	92.3
Blue Mountains	Tumalo Canal	384 (100)	76.9
Blue Mountains	Unity Reservoir Bald Eagle Nest Habitat	128 (50)	96.2
Blue Mountains	Wagon Roads	320 (62.5)	72.3
Blue Mountains	Winter Roost	64 (50)	100
Blue Mountains	Zumwalt Prairie	1280 (9.6)	80
Canadian Rocky Mountains	Little Pend Oreille River NAP	64 (50)	100
Coast Range	Blind Slough Swamp	64 (25)	61.5
Coast Range	Cape Blanco	64 (100)	100
Coast Range	Cascade Head	64 (50)	100
Coast Range	Cherry Creek	128 (66.7)	73.1
Coast Range	Coquille River Falls	64 (50)	100
Coast Range	Cummins/Gwynn Creeks Rna	1344 (58.3)	69.6
Coast Range	Elk Creek	64 (11.1)	61.5
Coast Range	Flynn Creek Rna	128 (50)	65.4
Coast Range	Grass Mountain	128 (33.3)	61.5
Coast Range	High Peak - Moon Creek	320 (50)	61.5
Coast Range	Neskia Beach	64 (100)	84.6
Coast Range	New River	256 (80)	100
Coast Range	North Fork Coquille River	64 (100)	76.9
Coast Range	North Spit	64 (25)	100
Coast Range	Port Orford Cedar	256 (66.7)	96.2
Coast Range	Saddle Mountain	128 (25)	88.5
Coast Range	Tenmile Rna	128 (25)	96.2
Coast Range	Umpqua River Wildlife Area-Brads Creek	64 (100)	92.3
Coast Range	Umpqua River Wildlife Area-Cougar Creek	128 (100)	100
Coast Range	Umpqua River Wildlife Area-Lost Creek	64 (100)	100
Coast Range	Umpqua River Wildlife Area-Martin Creek	128 (100)	100
Coast Range	Wassen Creek	384 (31.6)	56.4
Columbia Plateau	Badger Mountain	64 (100)	92.3
Columbia Plateau	Boardman Research Natural Area	896 (46.7)	64.3
Columbia Plateau	Columbia Hills NAP	512 (42.1)	85.6
Columbia Plateau	Fitzner/Eberhardt	384 (15)	100

Appendix B: cont.

Columbia Plateau	Horn Butte	128 (5.1)	76.9
Columbia Plateau	Juniper Forest	4608 (60.5)	82.75
Columbia Plateau	Lower Crab Creek	256 (10)	85.9
Columbia Plateau	Moses Coulee	64 (3.1)	76.9
Columbia Plateau	Pine Creek	64 (100)	76.9
Columbia Plateau	Sentinel Slope	64 (50)	100
Columbia Plateau	Spring Creek Canyon NAP	128 (100)	50
Columbia Plateau	Turnbull Pine	64 (100)	84.6
Columbia Plateau	Upper Dry Gulch NAP	64 (50)	69.2
Columbia Plateau	Yakima River Canyon	128 (6.2)	100
East Cascades	Camas Meadows NAP	128 (14.3)	53.8
East Cascades	Chiwaukum Creek	64 (12.5)	53.8
East Cascades	Entiat Slopes NAP	256 (33.3)	65.4
East Cascades	Goodlow Mountain	128 (25)	57.7
East Cascades	Klickitat Canyon NRCA	512 (100)	76.9
East Cascades	Metolius Research Natural Area	256 (50)	48.1
East Cascades	Mill Creek	64 (20)	100
East Cascades	Miller Creek	64 (25)	100
East Cascades	Monte Cristo	64 (10)	100
East Cascades	Monte Cristo NAP	64 (14.3)	100
East Cascades	Sycan Marsh	2112 (18)	74.8
East Cascades	Thompson Clover	64 (33.3)	100
East Cascades	Trout Lake NAP	192 (30)	100
East Cascades	Upper Klamath River	448 (16.3)	76.9
East Cascades	Vee Pasture	64 (20)	69.2
East Cascades	White Salmon Oak NRCA	128 (66.7)	88.5
Klamath Mountains	Ashland	512 (72.7)	88.5
Klamath Mountains	Babyfoot Lake	128 (66.7)	100
Klamath Mountains	Bear Gulch	256 (100)	86.5
Klamath Mountains	Beatty Creek	320 (83.3)	98.5
Klamath Mountains	Bobby Creek	64 (8.3)	100
Klamath Mountains	Brewer Spruce	256 (36.4)	98.1

Appendix B:cont

Klamath Mountains	Bushnell-Irwin Rocks	256 (57.1)	100
Klamath Mountains	Cedar Log Flat	192 (100)	86.55
Klamath Mountains	Eight Dollar Mountain	1024 (200)	89.4
Klamath Mountains	Grayback Glades	448 (100)	81.3
Klamath Mountains	Grayback Mountain	64 (20)	92.3
Klamath Mountains	Hoover Gulch	64 (11.1)	84.6
Klamath Mountains	Hunter Creek Bog	128 (40)	96.2
Klamath Mountains	Lemmingsworth Gulch	128 (33.3)	100
Klamath Mountains	North Bank	64 (2.7)	69.2
Klamath Mountains	North Fork Hunter Creek	192 (27.3)	92.3
Klamath Mountains	North Myrtle Creek	128 (50)	100
Klamath Mountains	Oregon Gulch	128 (33.3)	84.6
Klamath Mountains	Pipe Fork	128 (66.7)	92.3
Klamath Mountains	Rough and Ready	192 (42.9)	76.9
Klamath Mountains	Scotch Creek	192 (25)	64.1
Klamath Mountains	Sourgame	128 (100)	84.6
Klamath Mountains	Umpqua River Wildlife Area-Woodruff Mountain	64 (100)	100
Klamath Mountains	Woodcock Bog	128 (100)	80.75
North Cascades	Big Beaver	128 (9.5)	92.3
North Cascades	Morning Star NRCA	448 (3.6)	73.6
North Cascades	Mount Si NRCA	64 (1.5)	53.8
North Cascades	Perry Creek	64 (6.3)	84.6
North Cascades	Silver Lake	64 (12.5)	100
North Cascades	Skagit Bald Eagle NAP	64 (10)	53.8
North Cascades	Stetattle Creek	320 (6)	86.2

Appendix B:cont

Northern Basin and Range	Abert Rim	1600 (22.3)	75
Northern Basin and Range	Biscuitroot	512 (12.5)	96.2
Northern Basin and Range	Black Canyon	448 (38.9)	94.6
Northern Basin and Range	Connley Hills	960 (68.2)	90.3
Northern Basin and Range	Devils Garden Lava Beds	8768 (72.5)	96.1
Northern Basin and Range	Diamond Craters	1216 (20)	89.9
Northern Basin and Range	Dry Creek Bench	64 (9.1)	92.3
Northern Basin and Range	Dry Creek Gorge	960 (16.1)	48.7
Northern Basin and Range	Fir Groves	64 (33.3)	84.6
Northern Basin and Range	Fish Creek Rim	448 (12.3)	73.7
Northern Basin and Range	Foley Lake	320 (35.7)	73.8
Northern Basin and Range	Foster Flat	960 (60)	80.35
Northern Basin and Range	Guano Creek-Sink Lakes	448 (9.5)	78.2
Northern Basin and Range	Hammond Hill Sand Hills	64 (4.2)	92.3
Northern Basin and Range	Hawksie-Walksie	768 (10.4)	68.6
Northern Basin and Range	High Lakes	640 (3.7)	64.1
Northern Basin and Range	Honeycombs	4224 (65.3)	60
Northern Basin and Range	Jordan Craters	960 (7.5)	100
Northern Basin and Range	Juniper Mountain	128 (7.7)	100
Northern Basin and Range	Kiger Mustang	5760 (20.9)	82.05
Northern Basin and Range	Lake Abert	2048 (16.1)	83
Northern Basin and Range	Lake Ridge	256 (13.3)	100

Appendix B:cont

Northern Basin and Range	Leslie Gulch	1536 (32.9)	72.8
Northern Basin and Range	Lost Forest	1088 (27)	63.8
Northern Basin and Range	Lost Forest-Sand Dunes-Fossil Lake	4736 (36.8)	69.4
Northern Basin and Range	Owyhee Below Dam	3776 (56.7)	60.4
Northern Basin and Range	Owyhee Views	10880 (51.2)	78.7
Northern Basin and Range	Poker Jim Ridge	64 (20)	100
Northern Basin and Range	Rahilly-Gravelly	960 (12.5)	60.5
Northern Basin and Range	Red Knoll	256 (5.6)	82.7
Northern Basin and Range	South Warner Basin	192 (37.5)	79.5
Northern Basin and Range	Toppin Creek Butte	64 (4)	100
Northern Basin and Range	Warner Wetlands	448 (1.4)	78
Northwest Coast	Bone River NAP	128 (15.4)	100
Northwest Coast	Chehalis River Surge Plain NAP	832 (81.3)	98.2
Northwest Coast	Clearwater Corridor NRCA	320 (38.5)	67.7
Northwest Coast	Devils Lake NRCA	64 (100)	69.2
Northwest Coast	Elk River NRCA	192 (15.8)	100
Northwest Coast	Ellsworth Creek	192 (16.7)	59
Northwest Coast	Grays Bay Estuary	64 (100)	100
Northwest Coast	Higley Creek	128 (50)	61.5
Northwest Coast	Jackson Creek	192 (37.5)	69.2
Northwest Coast	Leadbetter Point	384 (75)	95.4
Northwest Coast	Niawiakum River NAP	64 (16.7)	100
Northwest Coast	Quinault	384 (35.3)	60.3
Northwest Coast	Twin Creeks	128 (33.3)	61.5
Okanogan	Chewuch River	128 (3.8)	50
Okanogan	Little Vulcan Mountain	64 (25)	61.5
Okanogan	Loomis NRCA	256 (2.7)	78.8
Okanogan	Wolf Creek	64 (100)	53.8
Puget Trough	Bower Woods	128 (40)	100
Puget Trough	Dabob Bay NAP	576 (100)	76.9

Appendix B:cont

Puget Trough	Ebey's Landing	128 (100)	84.6
Puget Trough	Ellsworth Woods	256 (57.1)	100
Puget Trough	Foulweather Bluff	64 (100)	84.6
Puget Trough	Graveyard Spit	64 (50)	100
Puget Trough	Iceberg Point - Point Colville	64 (33.3)	84.6
Puget Trough	Ink Blot NAP	64 (20)	61.5
Puget Trough	Kitsap Forest NAP	192 (75)	76.9
Puget Trough	Lake Hancock	64 (100)	92.3
Puget Trough	Mima Mounds NAP	256 (80)	96.2
Puget Trough	Port Susan Bay	256 (80)	75
Puget Trough	South Puget Prairies	64 (100)	92.3
Puget Trough	Stavis Creek NRCA	448 (87.5)	75.8
Puget Trough	Thirteenth Division Prairie	192 (60)	100
Puget Trough	Weir Prairie	128 (66.7)	100
Puget Trough	Woodard Bay NRCA	64 (50)	61.5
Snake River Plain	Oregon Trail, Keeney Pass	832 (68.4)	69.8
Snake River Plain	Oregon Trail, Tub Mountain	896 (41.2)	67.6
Snake River Plain	South Alkali Sand Hills	768 (52.2)	66
West Cascades	Bald Hill NAP	128 (100)	76.9
West Cascades	Butter Creek	128 (11.8)	80.75
West Cascades	Cache Mtn Research Natural Area	128 (20)	88.5
West Cascades	Cedar Flats	64 (25)	76.9
West Cascades	Columbia Falls NAP	128 (40)	53.8
West Cascades	Goat Marsh	128 (22.2)	88.5
West Cascades	Gumjuwac-Tolo	64 (4.8)	53.8
West Cascades	Limpy Rock	768 (100)	64.1
West Cascades	Lost Lake	192 (75)	79.5
West Cascades	McKenzie Pass RNA	64 (33.3)	100
West Cascades	Middle Santiam River	64 (1.9)	61.5
West Cascades	Mohawk	128 (100)	57.7
West Cascades	North Umpqua River	768 (92.3)	82.1
West Cascades	Pumice Desert	576 (100)	53.8
West Cascades	Red Pond	64 (100)	76.9
West Cascades	Sherwood Butte	64 (10)	76.9
West Cascades	Squaw Flat	192 (100)	92.3
West Cascades	Table Mountain/Greenleaf Peak NRCA	256 (22.2)	78.8
West Cascades	Tater Hill	64 (100)	76.9

Appendix B:cont

West Cascades	Three Creek RNA	64 (20)	84.6
West Cascades	Weigle Hill	448 (41.2)	62.6
West Cascades	West Tiger Mtn NRCA	128 (7.4)	53.8
Willamette Valley	Banks swamp (Killin Wetlands)	64 (50)	100
Willamette Valley	Camas Swale	128 (100)	84.6
Willamette Valley	Coburg Hills RFI	128 (40)	61.5
Willamette Valley	Coburg Ridge - Jaqua	192 (42.9)	92.3
Willamette Valley	Forest Peak	64 (100)	76.9
Willamette Valley	Little Sink	64 (100)	76.9
Willamette Valley	Rattlesnake Butte	64 (100)	53.8
Willamette Valley	The Butte	64 (100)	53.8
Willamette Valley	Washougal Oaks NAP	64 (100)	76.9
Willamette Valley	Wilhoit Springs	64 (100)	69.2
Willamette Valley	Willamette Confluence	256 (50)	92.3
Willamette Valley	Willow Creek	64 (50)	100

Appendix C: Natural area vulnerability for 2080s based on majority model consensus. Hectares (%): is the area and percent of the natural area with predicted change. Model Agreement (%): is the averaged model consensus for all pixels in the natural area which are predicted to change.

EcoRegion	Name	Hectares (%)	Model Agreement (%)
Blue Mountains	Baldy Mountain	320 (20)	53.85
Blue Mountains	Basin Creek	64 (25)	61.5
Blue Mountains	Castle Rock	29.3 (2624)	90.5
Blue Mountains	Clear Creek Ridge	64 (16.7)	92.3
Blue Mountains	Clear Lake Ridge	128 (9.5)	76.9
Blue Mountains	Dixie Butte	64 (50)	53.8
Blue Mountains	Dry Mountain	3328 (140.6)	90.5
Blue Mountains	Forest Creek - Rough Canyon	64 (50)	100
Blue Mountains	Gerald S. Strickler	64 (100)	53.8
Blue Mountains	Grande Ronde	1216 (19.8)	77.9
Blue Mountains	Homestead	832 (24.6)	72.45
Blue Mountains	Hunt Mountain	64 (14.3)	76.9
Blue Mountains	Joseph Creek	320 (22.7)	70.8
Blue Mountains	Juniper Hills	1472 (26.1)	88.35
Blue Mountains	Kahler Creek Butte	64 (100)	61.5
Blue Mountains	Keating Riparian	256 (30.8)	46.2
Blue Mountains	Logan Butte	64 (20)	100
Blue Mountains	Middle Fork of the John Day River	128 (28.6)	88.5
Blue Mountains	Mill Creek Watershed	448 (14.6)	67.95
Blue Mountains	Mount Joseph	64 (20)	84.6
Blue Mountains	Nebo	64 (7.1)	100
Blue Mountains	North Fork Crooked River	1728 (57.4)	88
Blue Mountains	North Fork Malhuer River	64 (7.7)	100
Blue Mountains	Ochoco Divide	128 (16.6)	65.35
Blue Mountains	Peck's Milkvetch	5376 (98.8)	78.9
Blue Mountains	Pleasant Valley	128 (25)	73.1
Blue Mountains	Powell Butte	192 (100)	89.7
Blue Mountains	Shaketable	128 (100)	57.7
Blue Mountains	Sheep Mountain	576 (27.2)	87
Blue Mountains	Silver Creek	1024 (53.4)	80.1

Appendix C: cont.

Blue Mountains	South Fork Crooked River	128 (8.6)	100
Blue Mountains	South Fork Walla Walla River	128 (15.4)	65.4
Blue Mountains	Spanish Gulch	192 (100)	55.75
Blue Mountains	Stinger Creek	832 (61.9)	88.8
Blue Mountains	The Island	128 (200)	84.6
Blue Mountains	Tumalo Canal	384 (100)	55.1
Blue Mountains	Unity Reservoir Bald Eagle Nest Habitat	128 (50)	100
Blue Mountains	Wagon Roads	320 (62.5)	69.2
Blue Mountains	Winter Roost	64 (50)	100
Blue Mountains	Zumwalt Prairie	1344 (10.1)	70.3
Canadian Rocky Mountains	Little Pend Oreille River NAP	64 (50)	100
Coast Range	Cape Blanco	64 (100)	69.2
Coast Range	Cape Lookout/Netarts Sand Spit	64 (25)	61.5
Coast Range	Cascade Head	64 (50)	100
Coast Range	Cherry Creek	192 (100)	79.5
Coast Range	China Wall	64 (100)	76.9
Coast Range	Coquille River Falls	64 (50)	100
Coast Range	Cummins/Gwynn Creeks Rna	2176 (94.5)	79.6
Coast Range	Elk Creek	448 (77.8)	69.2
Coast Range	Flynn Creek Rna	256 (100)	76.9
Coast Range	Grass Mountain	384 (100)	73.1
Coast Range	High Peak - Moon Creek	576 (90)	76.1
Coast Range	Marys Peak	64 (50)	76.9
Coast Range	Neskia Beach	64 (100)	100
Coast Range	Neskowin Crest Rna	256 (57.1)	65.4
Coast Range	Nestucca River	256 (80)	71.2
Coast Range	New River	256 (80)	100
Coast Range	North Fork Coquille River	64 (100)	92.3
Coast Range	North Spit	64 (25)	100
Coast Range	Port Orford Cedar	256 (66.7)	100
Coast Range	Reneke Creek Rna	192 (100)	69.2
Coast Range	Saddle Mountain	128 (25)	96.2
Coast Range	Sheridan Peak	64 (50)	53.8
Coast Range	TENMILE RNA	128 (25)	100
Coast Range	Umpqua River Wildlife Area-Brads Creek	64 (100)	100

Appendix C: cont.

Coast Range	Umpqua River Wildlife Area-Cougar Creek	128 (100)	100
Coast Range	Umpqua River Wildlife Area-Lost Creek	64 (100)	100
Coast Range	Umpqua River Wildlife Area-Martin Creek	128 (100)	96.2
Coast Range	Wassen Creek	960 (78.9)	75.4
Columbia Plateau	Badger Mountain	64 (100)	100
Columbia Plateau	Boardman Research Natural Area	640 (33.3)	59.2
Columbia Plateau	Columbia Hills NAP	640 (52.6)	74.6
Columbia Plateau	Fitzner/Eberhardt	448 (17.5)	86.8
Columbia Plateau	Horn Butte	256 (10.3)	57.7
Columbia Plateau	Juniper Forest	4480 (58.8)	83.8
Columbia Plateau	Klickitat Oaks	128 (40)	65.4
Columbia Plateau	Lower Crab Creek	192 (7.5)	86.55
Columbia Plateau	Moses Coulee	64 (3.1)	61.5
Columbia Plateau	Pine Creek	64 (100)	76.9
Columbia Plateau	Rock Island Canyon	448 (43.8)	61.5
Columbia Plateau	Sentinel Slope	64 (50)	100
Columbia Plateau	Smoot Hill	64 (100)	53.8
Columbia Plateau	Spring Creek Canyon NAP	128 (100)	69.2
Columbia Plateau	Turnbull Pine	64 (100)	76.9
Columbia Plateau	Upper Dry Gulch NAP	128 (100)	73.1
Columbia Plateau	Yakima River Canyon	128 (6.2)	100
East Cascades	Camas Meadows NAP	832 (92.8)	61.85
East Cascades	Cannon Well	192 (60)	61.5
East Cascades	Chiwaukum Creek	64 (12.5)	69.2
East Cascades	Entiat Slopes NAP	256 (33.3)	61.5
East Cascades	Goodlow Mountain	448 (87.5)	76.9
East Cascades	Keystone Point	128 (50)	61.5
East Cascades	Klickitat Canyon NRCA	512 (100)	81.7
East Cascades	Metolius Research Natural Area	512 (100)	46.2
East Cascades	Mill Creek	64 (20)	100
East Cascades	Miller Creek	64 (25)	92.3
East Cascades	Monte Cristo	192 (30)	69.2
East Cascades	Monte Cristo NAP	128 (28.6)	76.9
East Cascades	Sycan Marsh	3072 (26.2)	66.75

Appendix C: cont.

East Cascades	Thompson Clover	64 (33.3)	100
East Cascades	Tieton River	128 (50)	65.4
East Cascades	Trout Lake NAP	192 (30)	100
East Cascades	Upper Klamath River	832 (30.3)	70.1
East Cascades	Vee Pasture	64 (20)	76.9
East Cascades	White Salmon Oak NRCA	128 (66.7)	88.5
East Cascades	Wildhaven	64 (12.5)	61.5
East Cascades	Yainax Butte	192 (75)	56.4
Klamath Mountains	Ashland	512 (72.7)	94.2
Klamath Mountains	Babyfoot Lake	128 (66.7)	100
Klamath Mountains	Bear Gulch	256 (100)	86.5
Klamath Mountains	Beatty Creek	320 (83.3)	100
Klamath Mountains	Bobby Creek	64 (8.3)	100
Klamath Mountains	Brewer Spruce	256 (36.4)	94.2
Klamath Mountains	Bushnell-Irwin Rocks	256 (57.1)	100
Klamath Mountains	Cedar Log Flat	192 (100)	80.75
Klamath Mountains	Eight Dollar Mountain	1024 (200)	88.5
Klamath Mountains	Grayback Glades	448 (100)	83.5
Klamath Mountains	Grayback Mountain	256 (80)	74.35
Klamath Mountains	Hinkle Lake	192 (100)	66.7
Klamath Mountains	Hoover Gulch	64 (11.1)	84.6
Klamath Mountains	Hunter Creek Bog	128 (40)	100
Klamath Mountains	King Mountain Rock Garden	64 (100)	84.6
Klamath Mountains	Lemmingsworth Gulch	128 (33.3)	100
Klamath Mountains	North Bank	128 (5.4)	65.4
Klamath Mountains	North Fork Hunter Creek	192 (27.3)	100

Appendix C: cont.

Klamath Mountains	North Myrtle Creek	128 (50)	100
Klamath Mountains	Oliver Mathews / Craggy Peaks	384 (100)	76.9
Klamath Mountains	Oregon Gulch	128 (33.3)	88.5
Klamath Mountains	Pipe Fork	128 (66.7)	88.5
Klamath Mountains	Rough and Ready	192 (42.9)	76.9
Klamath Mountains	Scotch Creek	192 (25)	87.2
Klamath Mountains	Sourgame	128 (100)	92.3
Klamath Mountains	Umpqua River Wildlife Area-Woodruff Mountain	64 (100)	100
Klamath Mountains	Woodcock Bog	128 (100)	84.6
North Cascades	Big Beaver	192 (14.3)	76.9
North Cascades	Morning Star NRCA	704 (5.6)	70.6
North Cascades	Mount Si NRCA	576 (13.3)	73.55
North Cascades	Perry Creek	64 (6.3)	100
North Cascades	Silver Lake	64 (12.5)	100
North Cascades	Skagit Bald Eagle NAP	192 (30)	61.5
North Cascades	Skagit/Sauk River	320 (41.7)	67.7
North Cascades	Stetattle Creek	320 (6)	53.8
Northern Basin and Range	Abert Rim	2944 (41.1)	69.9
Northern Basin and Range	Biscuitroot	512 (12.5)	76.9
Northern Basin and Range	Black Canyon	448 (38.9)	95
Northern Basin and Range	Black Hills	64 (4.5)	53.8
Northern Basin and Range	Connley Hills	896 (63.6)	93.4
Northern Basin and Range	Devils Garden Lava Beds	8704 (72)	98.1
Northern Basin and Range	Diamond Craters	1216 (20)	91.9
Northern Basin and Range	Dry Creek Bench	64 (9.1)	100

Appendix C: cont.

Northern Basin and Range	Dry Creek Gorge	960 (16.1)	50.3
Northern Basin and Range	East Kiger Plateu	64 (16.7)	53.8
Northern Basin and Range	Fir Groves	192 (100)	71.8
Northern Basin and Range	Fish Creek Rim	384 (10.6)	80.75
Northern Basin and Range	Foley Lake	320 (35.7)	76.9
Northern Basin and Range	Foster Flat	960 (60)	77.8
Northern Basin and Range	Guano Creek-Sink Lakes	448 (9.5)	74.25
Northern Basin and Range	Hammond Hill Sand Hills	64 (4.2)	100
Northern Basin and Range	Hawksie-Walksie	768 (10.4)	78.8
Northern Basin and Range	High Lakes	320 (1.9)	75
Northern Basin and Range	Honeycombs	4096 (63.4)	58.5
Northern Basin and Range	Jordan Craters	960 (7.5)	100
Northern Basin and Range	Juniper Mountain	192 (11.5)	76.9
Northern Basin and Range	Kiger Mustang	5824 (21.2)	78.1
Northern Basin and Range	Lake Abert	2304 (18.1)	71.85
Northern Basin and Range	Lake Ridge	256 (13.3)	96.2
Northern Basin and Range	Leslie Gulch	1472 (31.5)	59.2
Northern Basin and Range	Lost Forest	256 (6.3)	82.7
Northern Basin and Range	Lost Forest-Sand Dunes-Fossil Lake	3520 (27.4)	65.7
Northern Basin and Range	Owyhee Below Dam	3456 (51.9)	64.1
Northern Basin and Range	Owyhee Views	12608 (59.3)	79.25
Northern Basin and Range	Poker Jim Ridge	64 (20)	100

Appendix C: cont.

Northern Basin and Range	Rahilly-Gravelly	640 (8.3)	56.2
Northern Basin and Range	Red Knoll	256 (5.6)	75
Northern Basin and Range	South Warner Basin	192 (37.5)	87.2
Northern Basin and Range	Spanish Lake	448 (17.5)	72.5
Northern Basin and Range	Stinking Lake	192 (33.3)	100
Northern Basin and Range	Table Rock	320 (13.9)	84.6
Northern Basin and Range	Toppin Creek Butte	64 (4)	100
Northern Basin and Range	Warner Wetlands	960 (3)	68.2
Northwest Coast	Bone River NAP	448 (53.9)	82.3
Northwest Coast	Chehalis River Surge Plain NAP	896 (87.6)	84.6
Northwest Coast	Clearwater Bogs NAP	128 (100)	61.5
Northwest Coast	Clearwater Corridor NRCA	704 (84.6)	81.1
Northwest Coast	Devils Lake NRCA	64 (100)	76.9
Northwest Coast	Elk River NRCA	640 (52.6)	80.75
Northwest Coast	Ellsworth Creek	1024 (88.9)	71.6
Northwest Coast	Ellsworth Creek NRCA	128 (100)	76.9
Northwest Coast	Grays Bay Estuary	64 (100)	100
Northwest Coast	Hades Creek	64 (20)	69.2
Northwest Coast	Hendrickson Canyon NRCA	64 (100)	69.2
Northwest Coast	Higley Creek	256 (100)	75
Northwest Coast	Jackson Creek	320 (62.5)	80
Northwest Coast	Leadbetter Point	384 (75)	100
Northwest Coast	Niawiakum River NAP	192 (50)	75
Northwest Coast	Quinault	640 (58.8)	76.9
Northwest Coast	South Nemah NRCA	896 (87.5)	72
Northwest Coast	South Nolan NRCA	64 (100)	61.5
Northwest Coast	Twin Creeks	384 (100)	74.4
Okanogan	Brewster Roost	64 (50)	69.2
Okanogan	Little Vulcan Mountain	64 (25)	38.5
Okanogan	Loomis NRCA	128 (1.4)	76.9
Okanogan	Wolf Creek	64 (100)	76.9
Puget Trough	Bower Woods	128 (40)	92.3

Appendix C: cont.

Puget Trough	Dabob Bay NAP	576 (100)	85.5
Puget Trough	Ebey's Landing	128 (100)	88.5
Puget Trough	Ellsworth Woods	256 (57.1)	100
Puget Trough	Foulweather Bluff	64 (100)	100
Puget Trough	Graveyard Spit	64 (50)	100
Puget Trough	Iceberg Point - Point Colville	64 (33.3)	100
Puget Trough	Ink Blot NAP	64 (20)	76.9
Puget Trough	Kitsap Forest NAP	192 (75)	82.1
Puget Trough	Lake Hancock	64 (100)	100
Puget Trough	Mima Mounds NAP	256 (80)	92.3
Puget Trough	Port Susan Bay	256 (80)	76.9
Puget Trough	Schumocher Creek NAP	64 (100)	100
Puget Trough	South Puget Prairies	64 (100)	92.3
Puget Trough	Stavis Creek NRCA	448 (87.5)	81.3
Puget Trough	Thirteenth Division Prairie	192 (60)	100
Puget Trough	Weir Prairie	128 (66.7)	100
Puget Trough	Woodard Bay NRCA	64 (50)	76.9
Snake River Plain	Oregon Trail, Keeney Pass	640 (52.6)	73.8
Snake River Plain	Oregon Trail, Tub Mountain	832 (38.2)	64.5
Snake River Plain	South Alkali Sand Hills	896 (60.9)	73.6
West Cascades	Bald Hill NAP	128 (100)	84.6
West Cascades	Big Bend Mountain	64 (3.4)	53.8
West Cascades	Butter Creek	384 (35.4)	78.85
West Cascades	Cache Mtn Research Natural Area	128 (20)	88.5
West Cascades	Carolyn's Crown - Shafer Creek	128 (40)	57.7
West Cascades	Cedar Flats	256 (100)	71.2
West Cascades	Cherry Creek Basin	768 (29.3)	65.4
West Cascades	Columbia Falls NAP	256 (80)	75
West Cascades	Desert Creek	704 (91.7)	59.4
West Cascades	Goat Marsh	192 (33.3)	80.75
West Cascades	Grassy Mountain	64 (100)	53.8
West Cascades	Gumjuwac-Tolo	128 (9.5)	57.7
West Cascades	Horse Rock Ridge	256 (133.4)	61.5
West Cascades	Limpy Rock	768 (100)	78.8
West Cascades	Llao Rock	64 (33.3)	61.5
West Cascades	Lost Lake	192 (75)	92.3
West Cascades	McKenzie Pass RNA	64 (33.3)	100

Appendix C: cont.

West Cascades	Middle Santiam River	256 (7.5)	67.3
West Cascades	Mohawk	128 (100)	73.1
West Cascades	Mt. Hagan RNA	512 (100)	73.1
West Cascades	North Umpqua River	768 (92.3)	92.3
West Cascades	Pumice Desert	576 (100)	76.9
West Cascades	Red Pond	64 (100)	84.6
West Cascades	Sandy River Gorge	256 (66.6)	80.8
West Cascades	Sharon Lake Fen	64 (100)	76.9
West Cascades	Sherwood Butte	64 (10)	61.5
West Cascades	Squaw Flat	192 (100)	84.6
West Cascades	Table Mountain/Greenleaf Peak NRCA	960 (83.3)	81.9
West Cascades	Tater Hill	64 (100)	84.6
West Cascades	Thorton T. Munger	448 (100)	70.3
West Cascades	Three Creek RNA	64 (20)	84.6
West Cascades	Upper Elk Meadows	128 (100)	65.4
West Cascades	Weigle Hill	1088 (100)	74.7
West Cascades	West Tiger Mtn NRCA	1216 (70.4)	70
West Cascades	Wickiup Springs	192 (27.3)	64.1
Willamette Valley	Banks swamp (Killin Wetlands)	64 (50)	100
Willamette Valley	Camas Swale	128 (100)	88.5
Willamette Valley	Coburg Hills RFI	256 (80)	75
Willamette Valley	Coburg Ridge - Jaqua	192 (42.9)	100
Willamette Valley	Forest Peak	64 (100)	76.9
Willamette Valley	Little Sink	64 (100)	84.6
Willamette Valley	Rattlesnake Butte	64 (100)	84.6
Willamette Valley	The Butte	64 (100)	84.6
Willamette Valley	Washougal Oaks NAP	64 (100)	84.6
Willamette Valley	Wilhoit Springs	64 (100)	76.9
Willamette Valley	Willamette Confluence	256 (50)	96.2
Willamette Valley	Willow Creek	64 (50)	100