Research Article

Suitability of Natural Areas for Representing Ecological Change in the Pacific Northwest

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ABSTRACT

Natural areas are tracts of land with little or no evidence of past human influence and designated for research, education, and conservation. Many sites were selected to represent high-quality examples of both common and rare plant association groups. However, the extent to which natural areas characterize regional environmental conditions or gradients important for measuring and understanding the effects of climate change has not been examined. We compared the current collection of natural areas in Oregon and Washington to the broader natural ecosystems found in the region using four ecological parameters derived from existing datasets: forest structure, dominant tree species, vegetation formation classes, and elevation. We evaluated these data sets at both the regional and ecosystem scales and looked at the influence of land ownership in representing these parameters. Our results suggest that the Pacific Northwest natural areas network is well representative of all four parameters at the regional level. There were some gaps in representation at the ecoregion scale and across some land ownerships. Results from this study further support using natural areas for monitoring long-term climate change effects in the Pacific Northwest.

Index terms: climate change; landscape monitoring; Natural Areas Network; Pacific Northwest

INTRODUCTION

Climate change is influencing ecological systems throughout the world (Nolan et al. 2018). Rising temperatures have resulted in snowpack declines and an earlier onset of spring stream flow (Folland et al. 2001; Mote et al. 2005, 2008; Stewart el al. 2005). Recent warming has also been linked to altered phenological regimes, range movements of both plants and animals, shifts to natural disturbance patterns, and overall reductions to ecosystem resilience and resistance (Cayan et al. 2001; Parmesan and Yohe 2003; Regonda et al. 2005; Stewart et al. 2005; Parmesan 2006; Littell et al. 2009). However, current assumptions and predictions of future effects of climate change are primarily based on modeling and retrospective analyses. Thus, there is a need for empirical data that can be used to test assumptions about the temporal and spatial responses of ecosystems to climate change (Schellnhuber et al. 2006). Satellite imagery from Landsat and MODIS missions has enabled monitoring of coarse-scaled vegetation responses to climate change, but quantifying spatial and temporal impacts of climate change on vegetation at regional and ecoregion scales will be needed (Jennings et al. 2009).

The absence of monitoring data across both forested and non-forested lands has contributed to a suite of challenges in understanding the rate and magnitude of climate change effects on vegetation (Allen et al. 2015). Currently, there are no widely adopted, standardized monitoring protocols for classifying and collecting vegetation data across broad regions in the United States (Brewer et al. 2005; Brohman and Bryant 2005). The Forest Inventory Analysis program (FIA; USDA Forest Service 2013) is the only national-level monitoring program based on natural systems. However, FIA only focuses on forested plots, plots are measured at relatively long (10 y) intervals, plots are spaced systematically at 2428 ha intervals and can miss rare ecosystems, and measures of shrubs, herbaceous vegetation, weeds, and exotic species are limited (Bechtold and Patterson 2005; Williams et al. 2006). Monitoring both woody and herbaceous vegetation will be important as woody plants may be slow to adapt to climate change and herbaceous plants may be most sensitive to near-term effects of climate change (Lenoir et al. 2008). The Bureau of Land Management (BLM) more recently initiated the Assessment, Inventory, and Monitoring Program to monitor grass and rangeland heath, but efforts are limited primarily to non-forested lands managed by BLM (Toevs et al. 2011). Because no single agency manages land that represents the diversity of natural ecosystems, it would be important to also collect monitoring data across diverse land ownerships.

One network of sites that may represent the breadth and depth of non-urban, non-agricultural ecosystems found in the Pacific Northwest (hereafter, PNW) and serve as focal points for monitoring climate change are natural areas (WDNR 2007, 2009; ONHAC 2010). Natural areas represent ecosystems with minimal anthropogenic influences and can serve as reference sites for assessing management activities (Franklin et al. 1972; Evenden et al. 2001; MTCC 2009; Wilson et al. 2009). They can also be used to provide a benchmark for assessing changes in biodiversity (Arcese and Sinclair 1997; Sinclair et al. 2002). The potential role of natural areas for understanding long-term ecological change was highlighted more than 40 y ago (e.g., Jenkins and Bedford 1973). More recently, Massie et al. (2016) evaluated natural areas as a basis for assessing vegetation responses to climate change through bioclimatic modeling, with particular focus on Oregon and Washington. The same study provided a novel approach for using natural areas as part of a comprehensive monitoring effort to quantify future shifts in species composition as a result of climate change. However, it is unclear whether the current network of natural areas sufficiently represents PNW's natural ecosystems. Natural areas are often chosen based on plant association groups within ecoregions and may not adequately represent other environmental parameters important for evaluating environmental changes over time (Wilson et al. 2009).

Our objective for this study was to better understand the suitability of the current natural areas network for representing potential effects of climate change across Oregon and Washington. We selected four ecological parameters to evaluate the proportion and relative representation between the natural areas network and the ecosystems found at both the PNW and ecoregion scales: forest structure, dominant tree species, vegetation formation class, and elevation. We focused on these variables for two reasons. First, systematic, region-wide, spatial datasets are available for each of these parameters. Second, changes in temperature and precipitation patterns will likely result in shifts to growth, survival, and structure of vegetation (Chmura et al. 2011; Furniss et al. 2013).

A natural areas network that is representative of the variation found for each of these parameters would lend further support to the idea that natural areas could serve as a useful part of any long-term monitoring program that measures climate change effects. Likewise, a network that is proportional to the broader natural landscape would suggest that the network could be used in its entirety to represent the region's natural ecological diversity. A network that is missing elements or is disproportionate to PNW would suggest a need to incorporate additional ecosystems, or to carefully choose a subset of sites when developing a region-wide monitoring program.

METHODS

Study Area

PNW is composed of 14 ecoregions and 16 formation classes, based on the highest physiognomic level of the hierarchical National Vegetation Classification System (NVC; FGDC 2008). The dominant formation class in PNW is Cool Temperate Forest (almost 50%; Massie et al. 2016). With elevation gradients ranging from sea level to 4380 m, PNW includes some of the most diverse ecosystems in the United States, from coastal maritime forests, to high alpine meadows, to dry desert steppe. Annual precipitation varies from 12.7 cm (Alvord Desert in southeastern Oregon) to 365 cm (Olympic rainforest) and is driven by topography and macroclimate circulation patterns (Ohmann and Spies 1998; CIG 2012).

We selected 583 natural areas for our analysis (Figure 1). This included 414 natural areas listed in state heritage programs (Washington = 190; Oregon = 224), 118 additional ACECs (Areas of Critical Ecological Concern) managed by BLM in Oregon, and 51 proposed Research Natural Areas by the US Forest Service designated in current forest management plans. We included the latter two groups under the assumption that they would be incorporated in future state heritage plan updates. Natural areas ranged in size between 1 and 30,756 ha (mean = 1012 ha; Table 1). Our comparison group (PNW) included all lands in Oregon and Washington except those occurring in urban and agricultural areas. Anthropogenic influence on PNW ecosystems varied widely, from minimal influence (e.g., wilderness and national parks) to heavy influence (e.g., clearcuts and dense road systems).

Data Analysis

Data from the US Forest Service, Pacific Northwest Research Station, and Oregon State University (Landscape Ecology, Modeling, Mapping, & Analysis team; LEMMA) and the US Geological Survey GAP Analysis program (GAP) were used to identify forest structure, dominant tree species, and vegetation formation classes (Ohmann and Gregory 2002; GAP 2011; LEMMA 2018). The GNN (gradient nearest neighbor) algorithm used by LEMMA quantifies the relationship between vegetation survey plots and environmental variables (climate, topography, soil parent material, and spectral reflectance from Landsat) using a canonical correspondence analysis ordination. The information in the ordination model is leveraged to match each 30 m cell to a single vegetation survey plot. All information contained in the input survey plots are mapped along with plot identifiers (Ohmann and Gregory 2002). We used the GNN data to evaluate the extent to which natural areas represented the dominant tree species and overall forest structure on forested lands (>10% tree canopy cover) within PNW by calculating the total number of occurrences in the natural areas compared to the total number of occurrences on forested landscapes. Specifically, the GNN variable VEGCLASS, based on Quadratic Mean Diameter, basal area, and canopy cover, was used for vegetation structure comparisons. IMAP_DOMSPP, classified by dominant basal area, was used for tree species classification (if basal areas were equal, classification was based on trees per hectare).

Similar to GNN, GAP data are modeled data layers based on field plot data that are combined with other data layers describing topography, soil parent material, climate, and spectral reflectance from Landsat imagery. The primary difference between GNN and GAP data is that GNN is a multivariate data source, while GAP represents a single classification of vegetation. The primary classification units of GAP are ecological systems, which are defined as groups of plant communities occurring under similar ecological constraints and environmental gradients (Jennings 1993; FGDC 1997; Comer et al. 2003). Additionally, ecological systems were cross-walked with the hierarchical NVC, where vegetation classifications were more generally defined and had lower classification error (Comer et al. 2003). We used GAP data to compare occurrences of vegetation cover in natural areas to occurrences across all lands. GAP data included both the fine-scaled ecological systems and the coarse-scaled formation class for both forested and non-forested lands.

We used a 30 m DEM from the National Elevation Dataset to compile and process elevation data (FGDC 1995; Gesch et al.

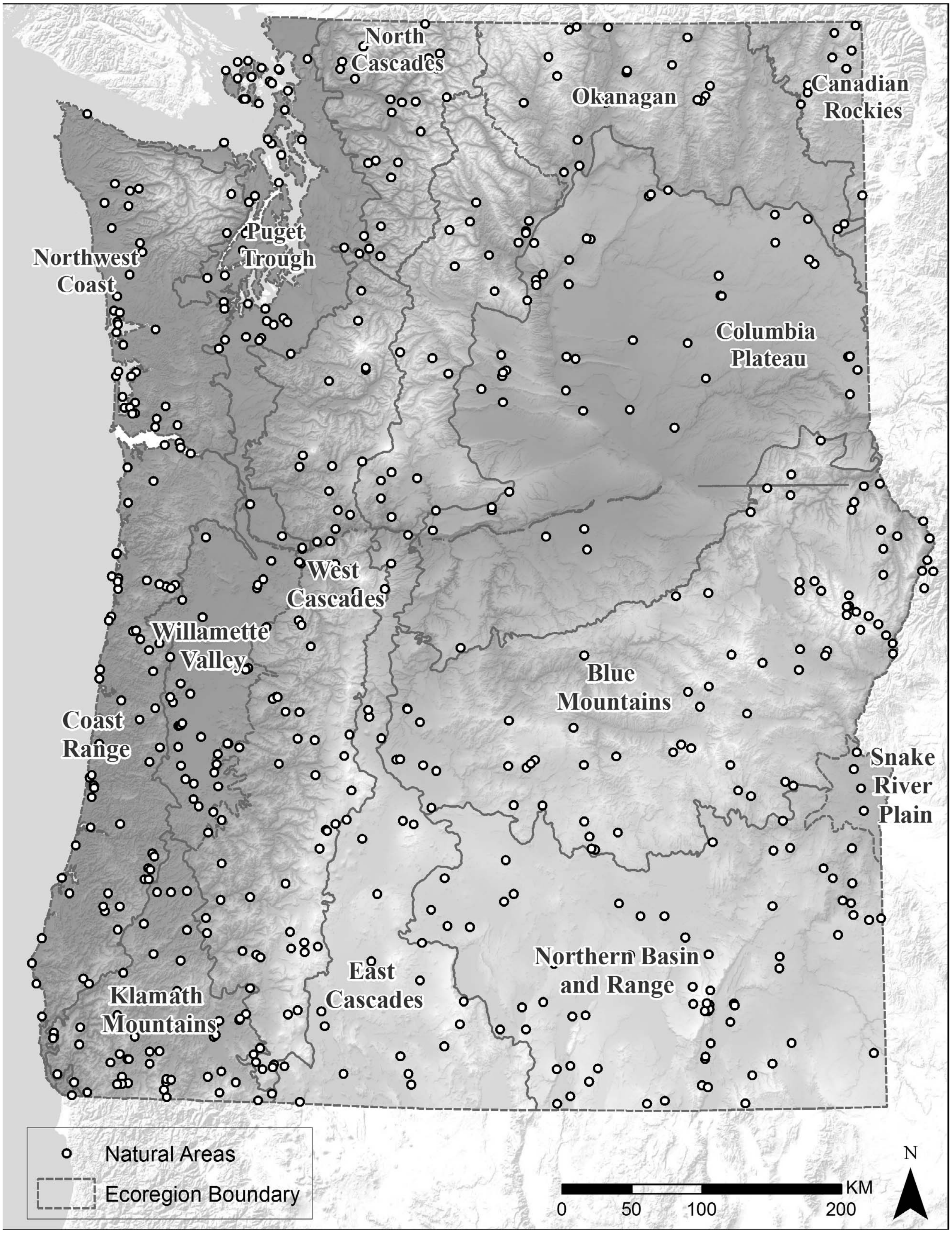

Figure 1.—Geographic distribution of Natural Areas in Oregon and Washington.

Table 1.—Agency management of currently established and proposed natural areas in Oregon and Washington.

Agency	Number of sites	Hectares	Acres	Average size (acres)
Bureau of Land Management	207	338,153	835,239	4035
US Forest Service	141	66,885	165,207	1755
Washington Department of Natural Resources	86	61,100	150,917	1172
The Nature Conservancy	78	60,779	150,125	2302
US Fish and Wildlife Service	19	14,658	36,206	1925
National Park Service	14	13,049	32,230	1906
Other	13	42,463	104,883	—

2002). All anthropogenic classifications (e.g., agricultural, urban) were removed from GAP and LEMMA data layers prior to analyses. The analysis was carried out using ArcMap10 (ESRI 2011; Datum: North American, 1983, Projection: Albers).

We used scatterplots to compare the number of cells between natural areas and the broader PNW region for each category and for all four parameters of interest: vegetation structure, dominant tree species, vegetation cover, and elevation. This allowed us to evaluate any apparent deviations from a 1:1 relationship between the two groups.

RESULTS

Vegetation Structure and Composition

Vegetation structure and composition in natural areas were fairly representative and proportional to PNW (Figures 2, 3). Six of the 11 classifications differed by <1% between natural areas

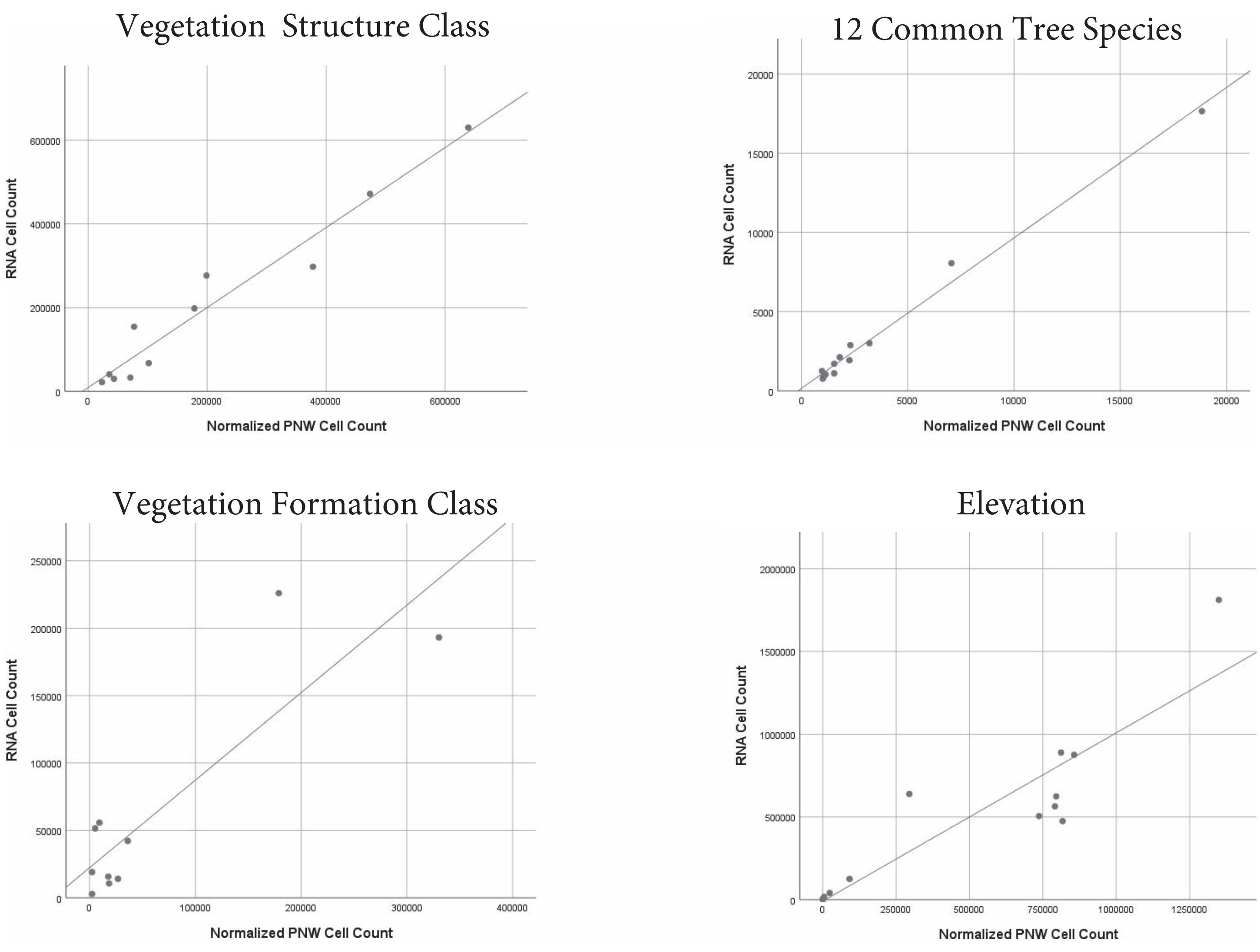

Figure 2.—Scatterplots showing the relationships between 30 m cell counts for natural areas and the broader Pacific Northwest (PNW) landscape for each of the four metrics evaluated. Cell counts for PNW were adjusted to match the sample size for natural areas (e.g., normalized).

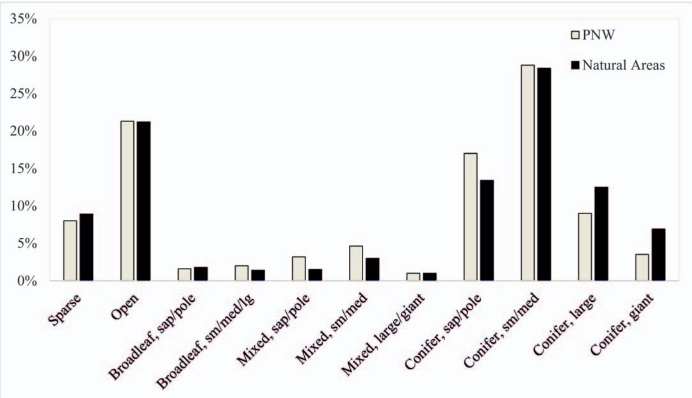

Figure 3.—Assessment of vegetation structure class based on Gradient Nearest Neighbor variable ("VEGCLASS," based on quadratic mean diameter, basal area, and canopy cover) of the natural areas compared to the Pacific Northwest.

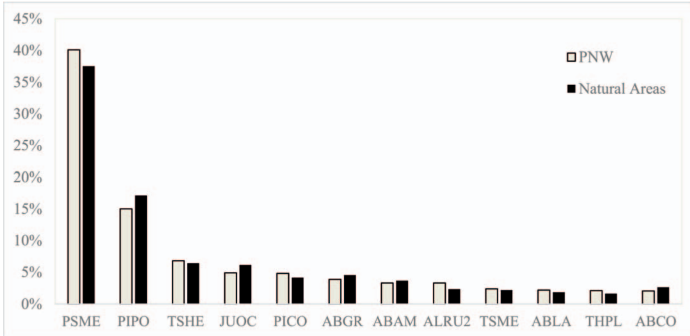

Figure 4.—Assessment of 12 most common tree species on forest land from Gradient Nearest Neighbor: *Pseudotsuga menziesii* ((Mirb.) Franco; PSME), *Pinus ponderosa* (PIPO), *Tsuga heterophylla* ((Raf.) Sarg.; TSHE), *Juniperus occidentalis* (Hook.; JUOC), *Pinus contorta* (Douglas ex Loudon; PICO), *Abies grandis* ((Douglas ex D. Don) Lindl.; ABGR), *Abies amabilis* (Douglas ex Loudon; ABAM), *Alnus rubra* (Bong.; ALRU2), *Tsuga mertensiana* ((Bong.) Carrière; TSME), *Abies lasiocarpa* ((Hook.) Nutt.; ABLA), *Thuja plicata* (Donn ex D. Don; THPL), *Abies concolor* ((Gord. & Glend.) Lindl. Ex Hildebr.; ABCO).

and PNW. Natural areas had more representation than PNW for large and giant conifer classifications (canopy cover $\geq$40%, quadratic mean diameter [QMD] of 50–75 cm, and >75cm; 6.1% and 3.4%, respectively). There was somewhat less representation in natural areas than PNW for mixed (broadleaf–conifer) sapling/pole (QMD <25cm), small/medium (QMD = 25–50 cm), and conifer sapling/pole classifications (1.7%, 1.6%, and 3.6%, respectively).

The 12 most common dominant tree species comprised approximately 91% of forested areas in PNW and 90% of natural areas and there were few apparent differences between natural areas and PNW at the region-wide scale (Figures 2, 4). Less common species (i.e., those comprising <10% of forested cover) had proportionately more representation in natural areas than PNW, except for bigleaf maple (*Acer macrophyllum* Pursh), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine larch (*Larix lyallii* Parl.), but these species were relatively rare on the landscape (e.g., combined, they represented 1.68% of natural areas and 2.36% of PNW). At the ecoregion scale, there was larger variation. For example, 21% of forested land in the Okanogan ecoregion was classified as ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson), but ponderosa pine was dominant in only 2% of the forested land cover within natural areas.

Most vegetation formation classes were well represented by natural areas, but proportionally less so than for structure class and common tree species (Figures 2, 5). The strongest difference was for *Cool Temperate Forest*, with 47% of the formation class covering PNW and only 27% represented by natural areas. Of the 10 most common vegetation formation classes, there was more representation of *Cool Semi-Desert Scrub & Grassland*, *Salt Marsh*, and *Cool Semi-Desert Scrub & Grassland* (Figure 5). Natural areas represented over 90% of fine-scaled ecological systems classified in PNW that were >0.0001% of total land cover for the region. Exceptions for rarer classes included *Mediterranean Grassland & Forb Meadow* and *Freshwater Aquatic Vegetation* where there was less representation for natural areas than for PNW.

There was natural area representation for all formation classes that covered >0.3% of each ecoregion. Some ecoregions were missing rare classes for that ecoregion. For example, natural areas in the East Cascade ecoregion did not have representation of *Polar & Alpine Cliff*, *Scree & Rock Vegetation* and *Barren* formation classes, which collectively comprised 0.22% of the ecoregion's land cover. Likewise, natural areas in the Snake River Plain ecoregion did not have representation of *Temperate Flooded & Swamp Forest*, which occurred in 0.24% of the ecoregion. In the North Cascades, the *Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest* and *Woodland* ecological systems comprised 1.2% of the land cover, but were not represented by natural areas. There was also no natural area representation of the North Pacific Mountain Hemlock Forest ecological system of the Northwest Coast ecoregion.

Elevation and Land Ownership

Natural areas were present across most elevations found in PNW. One notable exception was high-elevation sites. The highest natural area occurred at 2930 m, whereas the highest elevation in PNW was 4390 m (Figure 6). Missing representation at high-elevation sites occurred primarily within the West Cascades, East Cascades, and Puget Trough ecoregions. The highest actual elevation in the West Cascades was 4380 m, East Cascades was 3750 m, and 1240 m in the Puget Trough. However, highest elevation for the natural areas was 2450 m, 2760 m, and 580 m for those same ecoregions, respectively. There was also missing representation at low elevations in the Canadian Rocky ecoregion between 390 and 750 m. This elevation range represented 18% of the total land cover for that ecoregion. Across PNW, the natural areas network was concentrated at 1220–1530 m in elevation, with approximately 41% of the areas between 1000 and 1500 m. Yet, only 24% of PNW exists within that elevation range.

Overall, natural areas represented 93% of the ecological systems found in PNW and were composed of lands managed by

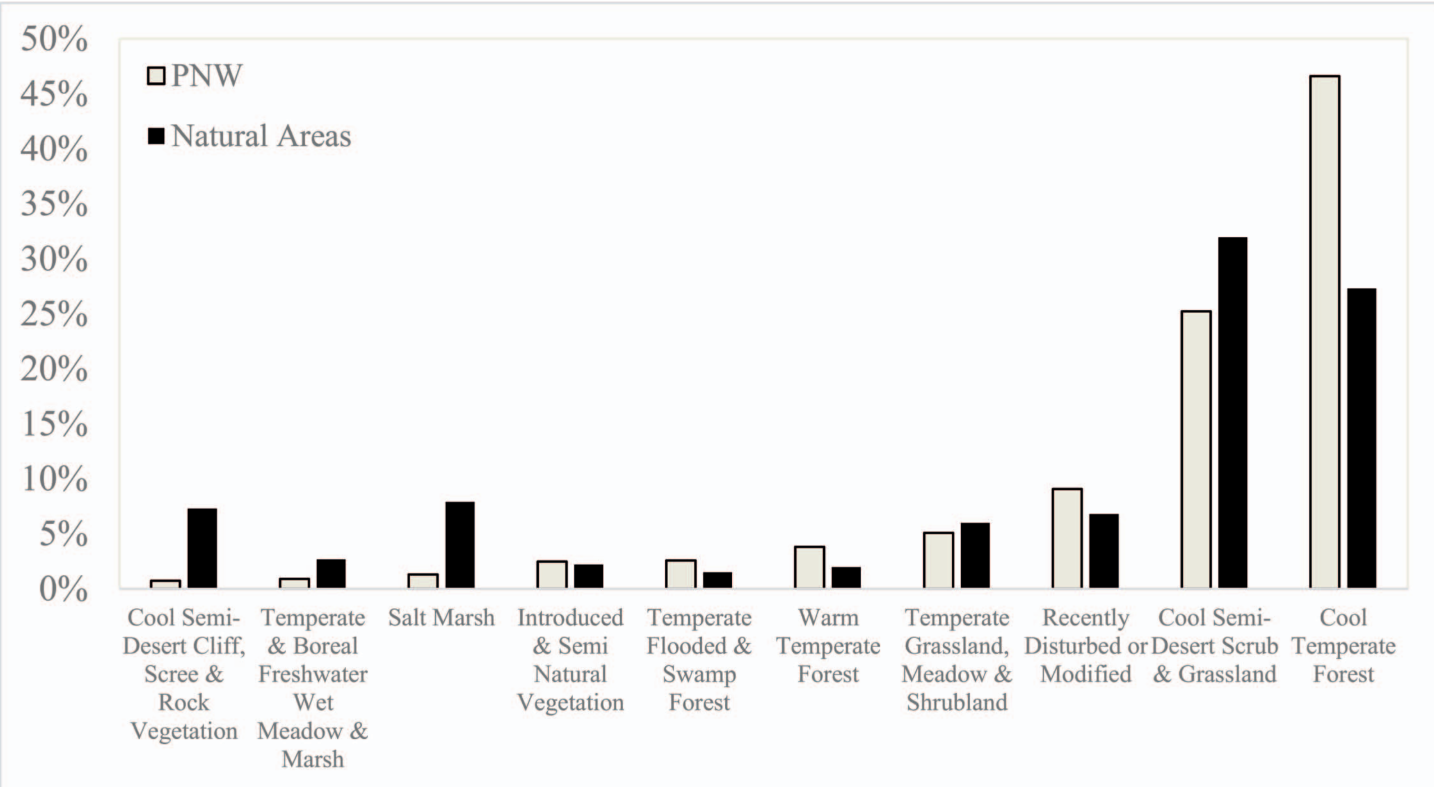

Figure 5.—Assessment of GAP's vegetation formation classes that comprised approximately 98% of overall land cover.

multiple agencies and organizations. At the ecoregion level, the BLM had complete representation of the formation classes found in the Coast Range, Northern Basin and Range, and Snake River Plain. BLM was also the sole agency with representation in the Northern Basin and Range and Snake River Plain ecoregions. For all other ecoregions, representation within natural areas relied on lands managed by multiple agencies, primarily the US Forest Service, US Fish and Wildlife Service, Washington Department of Natural Resources, Oregon Department of State Lands, and the Nature Conservancy (Table 1).

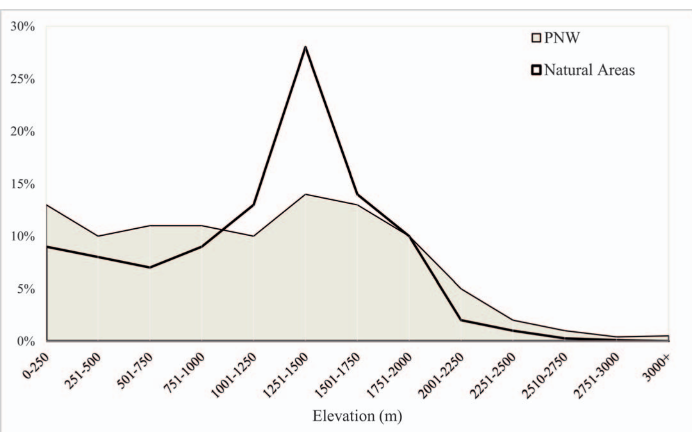

Figure 6.—Elevation assessment of natural areas compared to non-urban, non-agricultural areas of the Pacific Northwest.

DISCUSSION

Our study is the first to evaluate natural areas for their capacity to represent natural ecosystems across a region-wide landscape for study of long-term ecological change. For the most part, the sites we evaluated represented most of the ecosystems identified across PNW. In addition, their representation was fairly proportional to the broader landscape. This suggests that the strategies used by agencies and state heritage programs to designate areas were relatively consistent with selecting a network of sites that appear suitable for region-wide study of climate change across PNW in terms of representing the breadth and depth of ecosystems found across the region.

Natural areas were most representative at the broadest physiognomic level of the hierarchical National Vegetation Classification System. Missing representation at finer-scaled ecological systems could largely be attributed to classification errors of the GAP vegetation source data as a result of combining several independently created data layers. In some regions, fine-grained spatial errors were likely to be more prevalent, while bias against rare categories may be a larger issue in other regions. Both of these issues limit the power of our analyses to accurately describe proportionality for rare ecological systems. However, the GAP vegetation data source is likely to produce robust information for the more common ecological systems. Disparities in representation for common ecological systems highlight the need to designate new sites (such as in riparian areas, higher elevations, and successional ecosystems), and to continue monitoring existing natural areas where disturbances, management history, and climate change are influencing changes in species composition and structure. Lack of proportionality within natural areas for the well-mapped vegetation classifications would also suggest caution in making region-wide inferences of climate change effects without accounting for representation.

State heritage plans have tended to focus on selecting sites that represent late seral condition. The underrepresentation within the natural areas for conifer, sapling/pole classification and overrepresentation of the conifer, giant classification was consistent with this focus. However, vegetation structure, which is primarily driven by disturbances and management history, was accurately represented within natural areas.

For dominant tree species, there was overall good representation at the regional level, but this was apparently due to species being proportionally overrepresented by natural areas in some regions and underrepresented in other regions. For example, ponderosa pine was underrepresented as a dominant tree species in the Okanogan ecoregion but the overall representation for this species was relatively proportional to PNW. In some cases, it may be that ponderosa pine was present at these sites, but simply not categorized as the dominant tree species. Representation may be of more concern for rare species, however, because climate shifts may result in more rapid extirpation (Kipfmueller 2003; Rehfeldt 2004).

The lack of natural areas >2930 m suggests there is opportunity to designate more natural areas at high elevations in PNW to increase the capacity of the network to measure ecosystem range shifts across elevational gradients. Most PNW high-elevation sites are managed by the US Forest Service and National Park Service and include lands designated as national parks and wilderness areas. As such, these areas are largely protected from human disturbance and managed for natural ecological processes. Portions of these parks and wildernesses could simply be included with natural areas in any regional monitoring program. However, one key benefit in formally designating portions of these sites as natural areas would help highlight their value in representing pristine examples of ecosystems not found elsewhere. There are currently >40 natural areas designated within National Parks and wilderness areas in PNW. Part of the reason high-elevation sites were not considered for designation in the past is that heritage plans primarily focused on sites with vegetation, and many of the highest-elevation sites in PNW are not vegetated. There may be more opportunities to consider high-elevation sites as plans now include consideration of sites as natural areas based on their unique geological features (e.g., ONHAC 2010).

One important factor influencing proportionality and representation of natural areas was land ownership distribution across the region. The lack of proportionality for dry and wet mixed conifer types, for example, was likely due to the relatively high amount of private ownership of these lands, particularly in the western portion of PNW. Many of these private lands are managed for timber production and not usually considered for natural area designation given the high level of human influence on ecological processes occurring at these sites. However, these areas could be included in any regional monitoring program as sites that are highly influenced by humans. Our analysis highlights the collective importance of numerous agencies contributing to the natural areas network as no single agency managed natural areas that sufficiently represented the ecological and elevation breadth of PNW.

Our analysis was for the purpose of exploring whether natural areas identified (or being proposed) in Oregon and Washington State Heritage plans were representative of four variables important to the long-term study of climate and ecological change across PNW. The natural areas we used do not represent all of the areas that are currently protected from major anthropogenic influence (see USGS-GAP 2016). In addition, there are other reasons for designating additional natural areas beyond the scope of this study, such as having sufficient amounts of protected areas to account for catastrophic and anthropogenic disturbances, protecting individual species viability, establishing corridors to connect natural areas, and having representation of ecological variables and focal species not considered here (DellaSalla et al. 2001; Scott et al. 2001; Wilson et al. 2009; Aycrigg et al. 2013). However, given the objectives of this study, the current network of natural areas in PNW appears to be a relatively robust platform for understanding the effects of climate change on ecosystems that have had limited human influence. Options to expand the network based on this assessment include (1) designating more high-elevation natural areas (e.g., portions of parks and wildernesses), (2) increasing the size of existing sites, and (3) broadening the scope of natural area designations beyond plant association groups. Future efforts could also focus on (1) continuing dialogue among the agencies that manage natural areas in the network to discuss how best to fill missing representation, (2) developing standardized climate change monitoring protocols that can be used across the natural areas network, (3) collecting data and developing techniques to improve prediction accuracy of vegetation distribution with a climate change emphasis, and (4) reassessing the vulnerability of all natural areas in the network as new information and science become available.

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