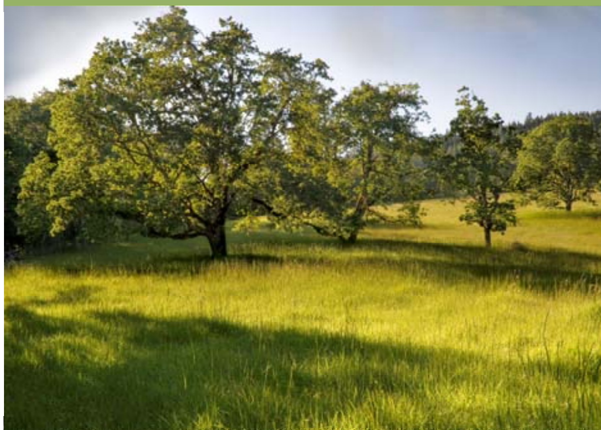
Conserving Nature's Stage:
Identifying Resilient Terrestrial Landscapes in the Pacific Northwest



Pacific Northwest and Northern California
Final Report
to the Doris Duke Charitable Foundation
February 2015

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Acknowledgements

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Thanks to all,

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CHAPTER 2

Project History and Scope

This report represents the culmination of a project completed in two phases funded by the Doris Duke Charitable Foundation. The first phase focused on adapting a process developed by The Nature Conservancy in the Northeastern US to identify and map sites most resilient to climate change (Anderson et al. 2012) to the landscapes and environments of the Pacific Northwest. The 67 million hectare project area included all of the Columbia Plateau, East Cascades/Modoc Plateau, and Middle Rockies/Blue Mountains ecoregions as well as the US portion of the Canadian Rockies (see map 4.1). The second phase expanded our geography to include the ecoregions west of the Cascade crest. This 25 million hectare area includes all of the West Cascades, Klamath Mountains, California North Coast and Sierra Nevada ecoregions and the US portions of the Willamette Valley/Puget Trough, Pacific Northwest Coast, and North Cascades ecoregions.

For the first phase, staff members from within TNC were selected to be part of a project Core Team. This team had the responsibilities of managing this phase, performing the analyses and documenting results. The Core Team also recruited a Steering Committee, comprised of representatives of state and federal land and natural resource management agencies, the academic community, and members of the applied conservation community that were leading or planning climate change projects/programs. The role of this Steering Committee was to:

- Provide technical review and advice to the Core Team to promote confidence in the specific methods and final products.
- Provide information on other existing and planned projects to reduce redundancy, and maximize the value of all projects.
- Assist the Core Team with communication of its methods and products to their colleagues and constituencies, and to seek feedback from the same.

The Steering Committee first met in person on February 16, 2012 in Portland and met as a group, via WebEx, four additional times during the duration of the project. Steering Committee members provided valuable input throughout the planning process and spent considerable time assisting us by providing data and vetting our methods and products, especially those associated with the creation of land facets and the calculation of topoclimate diversity. The Core Team worked closely through one-on-one discussions with most members of the Steering Committee in between WebEx meetings to discuss and seek feedback on many aspects of our project.

The Core Team met once every two weeks during the majority of the project period and published the results (Buttrick et al. 2014) on the *Conservation Gateway website* in April of 2014.

The second phase began as two parallel efforts; one analyzing the California portion of this project area and a second focused on the western Oregon and Washington extent. However, it soon became apparent that merging the teams would be more efficient. Biweekly calls were scheduled to make joint data and modeling decisions and to produce seamless products across the two geographies while minimizing redundancy in analyses. For instance, Jim Platt from the California team compiled the soils base data for the entire CA, OR, WA project area and Michael Schindel calculated topoclimate diversity for the same area.

Analyses and mapping for this combined phase footprint were completed in January 2015 and are reported for the first time in this combined report.

Applying the methods we developed in the first phase, east of the Cascades, to the more densely populated west-side ecoregions led us to identify a few issues with our methods that required modification. These modifications are discussed in detail in Appendix A. We desired a uniform methodology across our entire 92 million hectare project area, so lessons learned on the west-side were then applied across the entire east side, updating the products and datasets described and presented in Buttrick et al. (2014).

This report represents the results of land facet mapping, and the calculation of local permeability, topoclimate diversity and terrestrial landscape resilience across the entire 92 million hectare/11 ecoregion project area using uniform methods. Many of those methods have been translated into geoprocessing scripts to facilitate terrestrial resilience mapping in other regions.

Terrestrial Resilience Concepts

CHAPTER 3

The goal of this project was to identify areas in the Northwest that collectively and individually best sustain native biodiversity, even as the changing climate alters current distribution patterns, in order to guide future conservation investment (TNC 2011, 2013). We refer to these areas as *resilient sites*. Herein we use the term *resilience* (modified from Gunderson 2000) to refer to the capacity of a landscape or ecoregion to maintain biological diversity and ecological function despite climatic change.

The central tenet of this work is that by mapping key geophysical features and evaluating all occurrences of these features for characteristics that buffer against climate effects, we can identify representative examples of geophysical features that are most resilient to climate change. This methodology is based on two solid premises:

Premise #1: Geophysical features underlie the spatial distribution of biodiversity and a region's biological richness is due, in part, to its geophysical diversity.

The distribution of any species is a function of climate, disturbance patterns, interactions with other species, and geophysical features including topography, geology and soils. Indeed, many ecologists have used combinations of geophysical features as a surrogate for vegetation communities and species when conservation planning in data-poor regions.

Anderson and Ferree (2010) showed that these geophysical features influence not only the patterns of biodiversity but also the amount of biodiversity in a region. They demonstrated that, within the Northeastern U.S., the total number of species in a state could be very accurately estimated using a combination of the number of geologic types, elevation range and latitudinal range found within that state; the greater the number of geophysical combinations (i.e., geophysical settings) in a state, the higher the species richness. Among the factors influencing the distribution of species and communities, the geophysical features of topography, geology and soils are the most stable over time and under changing climates. We refer to unique combinations of these features as *land facets,* but they have also been called *geophysical settings, enduring features*, and the *geophysical stage* or *arena* (Anderson and Ferree 2010, Beier and Brost 2010). Such combinations are thought to provide the *stage* on which ecological systems function. With climate change, species may move within and among land facets, and communities will disaggregate and reshuffle, with the land facets acting as templates upon which new communities develop and evolve. These templates are relatively permanent whereas the species and communities they harbor are transitory.

We may be able to use these land facets as *coarse filters* that can address both current and future biodiversity needs. The Nature Conservancy has traditionally used plant communities or ecological systems as a coarse filter to help inform our conservation priorities. The coarse filter concept is that by capturing geographically dispersed, representative occurrences of each plant community or ecological system we can ensure the protection of much of the region's current biodiversity. However, with a changing climate these plant communities, and most of the other types of species associated with them, will move or disassociate. However, as these species move, higher numbers should be supported in areas with the most geophysical diversity. Thus, by using land facets as a coarse filter, we may be able to protect biodiversity both where it is currently found and where it may found in the future.

This report describes which geophysical features we used to define land facets and how these land facets are distributed across the project region. We also report on the representation of land facets within The Nature Conservancy's existing conservation portfolios and the need to modify existing portfolios to fully capture land facet diversity.

The conservation of geographically dispersed, representative occurrences of all land facets can facilitate resilience across a region by maintaining the diversity of geophysical templates upon which species and communities can evolve. Our second hypothesis focuses on patterns of variation in resilience within a land facet, a key step toward identifying resilient sites.

Premise # 2: Topoclimate diversity and local permeability convey resilience to a landscape or site.

From the perspective of conservation planning, *resilient sites* are those that provide resident species the maximum opportunity to respond on-site to climate change. Many species have a preferred temperature and moisture regime, i.e. a preferred local climate to which they are adapted. As precipitation and temperature patterns change in the future, many organisms are likely to disperse along moisture and temperature gradients in order to stay within their preferred temperature and moisture regimes. By having a greater diversity of topoclimates, resilient sites are more likely to have microsites that these dispersing organisms find acceptable.

There is evidence that spatial heterogeneity in topoclimate represents an important buffer in response to climate change (Ackerly et al. 2010, Dobrowski 2011). Thus, the variety of topoclimates present in a landscape should be positively correlated with the capacity of the site to maintain species and functions. This hypothesis supposes that we can identify resilient sites within each geophysical setting *in part* by evaluating its local topoclimate diversity.

We say *in part* because for species to take advantage of alternative topoclimates they need to be able to move across the landscape. A *permeable* landscape or site is necessary to enable movement as individuals disperse to take advantage of the diversity of topoclimates. As used here, permeability is not based on the unique needs of individual species, but is a measure of *the hardness of barriers, the connectedness of natural cover, and the arrangement of land uses* (Anderson et al. 2012).

Combining topoclimate diversity with local permeability provides a resilience metric that can be used to identify the most resilient occurrences of each land facet.

This report describes how local permeability was calculated using a resistance layer and a resistant kernel algorithm. We describe a new approach to calculate topoclimate diversity and how topoclimate diversity and local permeability were combined to reflect terrestrial landscape resilience. We also report on the representation of land facets and sites with higher than average resilience values within The Nature Conservancy's existing conservation portfolios.

The Pacific Northwest team had a secondary objective to evaluate and adapt the methods developed by The Nature Conservancy for use in the Northeastern U.S. by Anderson et al. (2012) to the landscapes in the Pacific Northwest in particular and the western U.S. in general. Both studies followed the overall methods described in the two premises above; however, the specific details of the analyses were adapted in response to data availability, landscape structure and observations from work currently being carried out by partners in the Northwest.

Project Setting

CHAPTER

4

Our project area covers 92 million hectares (227 million acres) of the Pacific Northwest and northern California, including all of the California North Coast, Klamath Mountains, Sierra Nevada, West Cascades, East Cascades/Modoc Plateau, Columbia Plateau, and Middle Rockies/Blue Mountains ecoregions as well as the U.S. portion of the Pacific Northwest Coast, Willamette Valley/Puget Trough, North Cascades and Canadian Rockies ecoregions (Map 4.1).

Ecoregions

Ecoregions are large units of land with similar environmental conditions, landforms, geology and soils, which share a distinct assemblage of natural communities and species. The term "ecoregion" was coined by J.M. Crowley (1967) and later popularized by Robert Bailey (1995) of the U.S. Forest Service (USFS). In recent decades, ecoregions have become a defining construct of larger conservation efforts because they provide a needed ecological context for understanding conservation activities by enabling the evaluation of properties considered critical to conserving biodiversity (e.g. representation, redundancy, ecological function, linkages, and endemism). Following are brief descriptions of each of the ecoregions analyzed. Detailed descriptions can be found within the ecoregional assessments discussed at the end of this chapter.

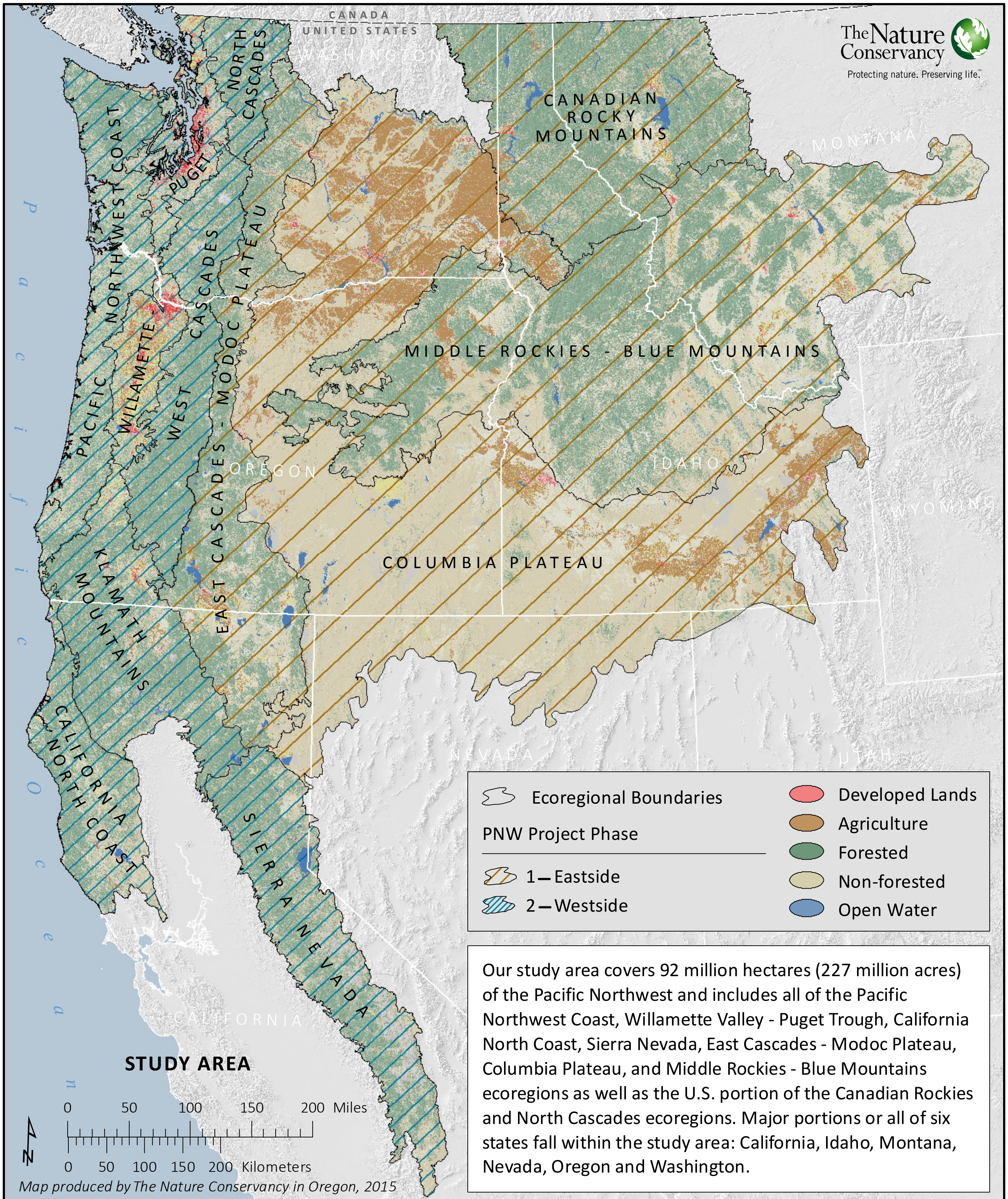
<u>California North Coast</u>

The California North Coast ecoregion is a landscape of some 3.3 million hectares (ha) encompassing all coastal watersheds from the Russian River north to the Chetco River in extreme southwestern Oregon. Much of the ecoregion is characterized by a series of mountain ranges that run parallel to the coast with each range becoming successively higher from west to east (inland). Elevations range from sea level along the coast to over 2,100 m on the crest of the Yolla Bolly Mountains. Between the mountain ranges are long, narrow valleys through which some of the ecoregion's major rivers flow before reaching the coast. Climate in this ecoregion is dominated by the marine influence of the Pacific Ocean with temperatures along the coast averaging 40 to 60 degrees F and summers characterized by fog and cool breezes. Inland, the marine influence is greatly diminished, resulting in hotter summers and colder winters. Coastal ecological systems include coastal terrace prairies, dunes and closed-cone pine forests. Lowland areas near the coast are dominated by redwood and Douglas-fir/tan oak forest. Inland the ecoregion is dominated by Douglas-fir/tan oak forest, Oregon oak woodland, annual grasslands, and mixed evergreen forests.

<u>Canadian Rockies – US portion</u>

This 8.4 million ha U.S. portion of the ecoregion is geologically complex and characterized by steep glaciated mountains with sharp alpine ridges and cirques at higher elevations. Historic and current glaciation has sculpted the mountainous landscape filling many of the

Map 4.1: Study Area - Ecoregions and Land Use



Only 11% of the study area falls in converted classes in the 2011 NLCD data; the rest is in a more natural condition. Agriculture, logging and grazing are common or dominant land uses. Annual precipitation averages 20-30 inches, but varies dramatically from over 100 inches in portions of the coastal mountains to less than 10 inches in portions of the plateaus east of the Cascades. *Data Source: USGS NLCD, 2011.*

intermountain valleys with glaciofluvial deposits and moraines. The dominant vegetation community is coniferous forest with the forest structure largely dictated by elevation. Dominant species include Douglas-fir, western hemlock, western redcedar, western white pine, and western larch. Lodgepole pine stands are common where stand-replacing fires have occurred. Higher elevation forests are dominated by Engelmann spruce and subalpine fir, and at the highest elevations, alpine tundra dominated by sedges and dwarf shrubs are common. Lower elevations merge into the Montana Valley and Foothill Grasslands ecoregion dominated by fescues, wheatgrasses and oatgrass.

Columbia Plateau

The Columbia Plateau ecoregion covers over 29 million ha of plains and tablelands of the Columbia and Snake Plateaus in parts of four states: Washington, Oregon, Idaho and Nevada. The plateaus in central Washington are at relatively low elevations (152-610 m) and fertile, with the Columbia River traveling south from Canada through areas dominated by agriculture. The extensive high desert plateaus in central and southeast Oregon are at elevations between 1,220 and 1,800 m and grade into the basin and range topography of the Great Basin ecoregion to the south. Throughout much of the ecoregion soils have been derived from the underlying basalt. In the Columbia River Basin loess deposits can be up to 46 m feet thick and soils developed from them are complex and relatively fertile. Vegetation is a distinguishing feature in the Columbia Plateau, which is dominated by sagebrush steppe composed primarily of sagebrush species and bunch grasses. Western juniper woodlands are common in central Oregon and in many of the uplands through the ecoregion.

East Cascades/Modoc Plateau

The East Cascades/Modoc Plateau ecoregion encompasses 7 million ha, extending east from the crest of the Cascade Mountains to the warmer, drier high desert of the Columbia Plateau. The East Cascades in Oregon and Washington resulted from tectonic uplift and subsequent erosion by alpine glaciers and landslides. The combination of these processes and volcanic activity created rugged ridges extending southeast to east from the Cascade crest. Broad valleys occupy the lowlands between the mountain ridges. Typically, the elevation range is between 610 and 2,100 m. The highest peak is Mt. Adams in Washington (3,742 m) and the lowest elevation is only 55 km away in the Columbia River Gorge (at a little over 30 m). This ecoregion has one of the most extensive ponderosa pine forests in the western U.S. with Douglas-fir, grand fir and white fir at mid elevations and hemlock and spruce at higher elevations. Snowmelt from the Cascade peaks can provide water to the Columbia and Klamath River systems, as well as the many lakes, wetlands and springs found throughout the ecoregion. The southern portion of the ecoregion in the Modoc Plateau has extensive valleys and flatlands between the forested mountains and foothills with large marshes, juniper and sagebrush steppe.

Klamath Mountains

The Klamath Mountains ecoregion of northwestern California and southwestern Oregon is one of the most distinctive and complex ecological zones in the United States. Covering 4.9 million ha, its dramatic topography, complex fire history, extensive watercourses and often abrupt climate changes create a region rich in natural beauty, diverse vegetation, and scientific value. The ecoregion consists primarily of a series of conifer forest ecosystems interspersed with smaller non-forested habitats such as meadows, oak savanna and chaparrals. The geologic underpinnings of the ecoregion are best thought of as a patchwork of folded, faulted, intruded, and metamorphosed rocks that comprise the main geologic features of southern Oregon and northern California. Extreme climatic variations are superimposed over the entire region; there are strong differences in seasonal climates (extended cool, moist winter conditions and hot, semi-arid summers) and a west-east gradient in precipitation (from about 330 cm per year near the coast to about 74 cm in the eastern rain shadow). Because of the region's varied topography, these climatic variations have produced a wide range of habitat types within a relatively small geographic area. As a result, a diverse assemblage of species can be found within the borders of the Klamath Mountains ecoregion.

Middle Rockies/Blue Mountains

The Middle Rockies/Blue Mountains ecoregion represents a large mass of mountains and intermontane valleys covering major portions of Oregon, Idaho, and Montana. The ecoregion covers over 21 million ha and at this size, is only slightly smaller than the state of Idaho. While the ecoregion is topographically diverse, it can generally be characterized as rugged. Abrupt elevation changes of 1,000 to 1,200 m from valley floors to mountain summits are not uncommon. Sixty-two percent of the ecoregion lies between 1,000 and 2,000 m and 32 percent between 2,000 and 3,000 m. Lower elevation forests are dominated by Douglas-fir, grand fir, ponderosa pine and western red cedar. Subalpine fir, lodgepole pine and whitebark pine dominate the high country. Sagebrush grasslands occur in the intermontane valleys. Montane prairies and high-elevation grasslands are significant components of the vegetation in the western part of the ecoregion.

North Cascades

Thirty-five percent of the North Cascades ecoregion (1.3 million ha) occurs in the US with the remainder in British Columbia, Canada. More than 96% of the US portion is uninhabited and uncultivated, and has the lowest human impact of any of Washington's terrestrial ecoregions. The North Cascades includes highly dissected, glaciated mountain terrain mostly between 300 and 2,100 m, and the US portion contains the greatest concentration of active glaciers in the conterminous US. The variability of soils and geology, combined with extensive effects of glaciation and topography, has led to large localized differences in climate, species, and ecological systems.

Pacific Northwest Coast

The US portion of the Pacific Northwest Coast ecoregion is a highly diverse ecological region with a land area of 4.2 million hectares. Although the average elevation is only 445 m, the ecoregion's rare combination of physical characteristics – coastal mountains, glaciers, marine shoreline and estuaries, rolling coastal plains, and extreme rainfall – has created a region rich in endemic plant communities and sensitive habitats. The dominant vegetation of the ecoregion is coastal coniferous forest with Sitka spruce near the coast at lower elevations to Douglas-fir, western hemlock and silver fir and noble fir at the highest elevations in Oregon. Mount Olympus on the Olympic Peninsula is the highest point in the ecoregion at 2400 meters.

Sierra Nevada
The Sierra Nevada ecoregion is a rugged mountainous area of snow-capped granite peaks, glacier-carved valleys, and dense coniferous forests, exemplified by places like Yosemite and Sequoia National Parks, Lake Tahoe and the 4418 m Mount Whitney. The ecoregion encompasses a northwest trending mountain range extending 650 km, and covers an area of almost 5 million hectares. On the west side, a foothill zone is comprised of broad-leaved woodlands and evergreen shrublands. The montane zone from 750 to 2100 m is characterized by coniferous forests such as ponderosa pine and mixed conifer communities. The subalpine zone ranges from 2100 m to 3300 m and includes red fir, white fir, mountain hemlock, and lodgepole pine. Desert-facing slopes on the east side of the Sierra Nevada below 2000 m are more arid and include pinyon-juniper woodlands and sagebrush communities.

West Cascades
The West Cascades ecoregion encompasses 3.8 million ha. This mountainous, heavily forested ecoregion is bounded on the west by farms, woodlands and cities in the Puget Trough and the Willamette Valley or by the drier forests and valleys of the Klamath Mountains. The eastern boundary is the crest of the Cascades, where the mesic forests begin to give way to the drier forests of the East Cascades. The topography and soils of the West Cascades ecoregion have been shaped dramatically by its volcanic past. Elevation range is typically 300 to 2,100 m with the lowest elevation in the Columbia Gorge (15 m) and the highest on Mount Rainier (4,300 m). Natural lakes are numerous, with most being created by glacial processes and landslides. Conifer forests dominate the vegetation with Douglas-fir/western hemlock at low elevations, Pacific silver fir, western hemlock, Douglas-fir and noble fir at mid elevations and mountain hemlock/silver fir forests and subalpine parklands at the higher elevations.

Willamette Valley/Puget Trough
This ecoregion's full name is Willamette Valley/Puget Trough/Georgia Basin. Only the Willamette Valley and Puget Trough (3.1 million ha) occur in the US so we have shortened the name. This ecoregion is a long ribbon of broad valley lowlands and inland sea flanked by the Cascades on the east and the coastal mountain ranges on the west. This ecoregion's elevation averages only 136 m, but the effects of the adjacent mountains, ocean intrusions, and glaciation result in dramatic localized differences in the climate, soils, and geology. Ecological communities range from coniferous forests to open prairies, rocky balds and oak savannas, though much of the area and associated biodiversity is at risk from development and conversion.

Land Use and Land Management

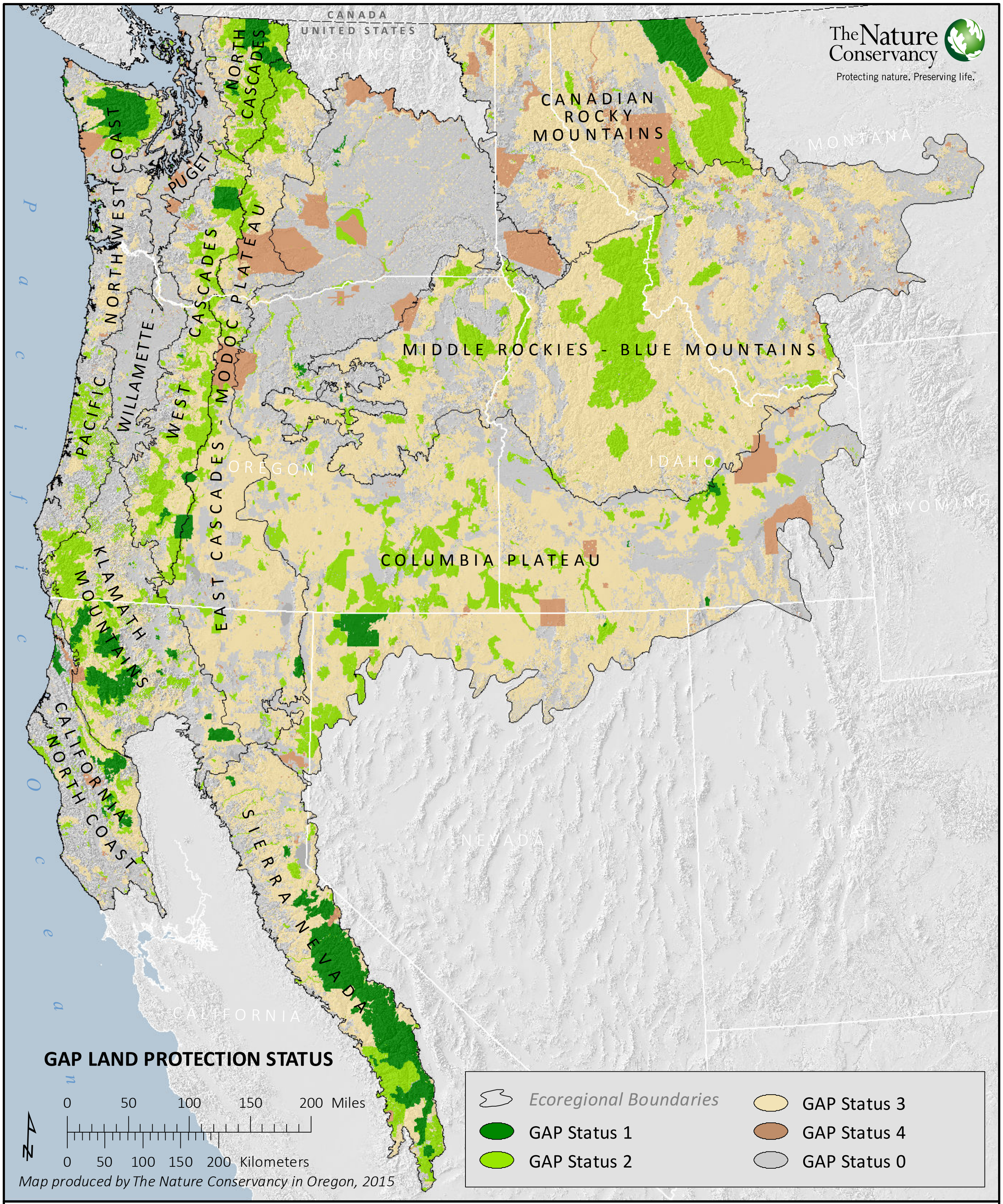
As described in the National Land Cover Database (NLCD, http://landcover.usgs.gov/uslandcover.php), eleven percent of the project area has been converted from natural conditions (NLCD categories: developed open space, and low, medium, or high intensity development; cultivated crops; pasture/hay; Table 4.1). In the remaining un-converted areas, logging and grazing are common land uses. The Columbia Plateau ecoregion (especially in central Washington) and the Willamette Valley/Puget Trough have experienced the greatest conversion with 21% and 48%, respectively, of their land surface in a converted condition. The level landscapes and fertile soils of central Washington are impacted by agricultural activities while the Willamette Valley/Puget Trough ecoregion, with 86% of the landscape in private ownership, supports many of the population centers as well as agricultural development (Table 4.1).

The USGS National Gap Analysis Program (GAP) publishes a Protected Areas Database (PAD-US) that represents public land ownership and conservation lands, including privately protected areas for the continental U.S., Alaska, and Hawaii, (http://gapanalysis.usgs.gov/padus/). The lands classified by PAD-US are assigned conservation status (GAP) codes that denote the level of biodiversity preservation and indicate other natural, recreational and cultural uses. The codes and their definitions as used in this report are:

GAP 1: managed for biodiversity and disturbance events are allowed to proceed or are mimicked by management actions;
GAP 2: managed for biodiversity and disturbance events are suppressed;
GAP 3: public lands managed for multiple uses and subject to extractive use (e.g. mining or logging) or off road vehicle use;
GAP 4: no known mandate for protection, includes military and tribal lands; and
GAP 0: lands not in any protections status; assumed private

Map 4.2 shows GAP status for the project area. Sixty percent of the project area is in public ownership, with most of that (42%) in GAP 3 status (Table 4.1), and managed by the U.S. Forest Service and Bureau of Land Management.

Map 4.2: GAP Land Protection Status



GAP1 = managed for biodiversity and disturbance events proceed or are mimicked
GAP2 = managed for biodiversity and disturbance events suppressed
GAP3 = public lands managed for multiple uses and subject to extractive use (e.g. mining or logging) or OHV use
GAP4 = no known mandate for protection and includes military bases and tribal lands
GAP0 = assigned to lands not in GAP1 - 4 status (assumed private, unprotected)

Data Source: USGS Protected Areas Database, 2013.

Table 4.1. GAP status and percent of landscape converted by ecoregion. Converted types include: developed (open, low, medium, high intensity), cultivated crops, and pasture/hay land use categories from the NLCD. GAP codes 1 and 2 include lands managed for biodiversity. See the report text for full definitions of GAP status codes.

Ecoregion	Area (hectares)	Percent by Cover		Percent by GAP Status Code				
		Natural	Converted	GAP1	GAP2	GAP3	GAP4	GAP0
California North Coast	2,856,054	97	3	6	11	17	2	64
Canadian Rockies (US portion)	8,419,090	96	4	5	9	51	10	25
Columbia Plateau	29,247,939	79	21	1	9	40	6	44
East Cascades/Modoc Plateau	7,076,585	95	5	1	12	54	6	26
Klamath Mountains	4,863,604	95	5	10	19	31	1	39
Middle Rockies/Blue Mountains	21,002,058	95	5	<1	13	54	1	31
North Cascades (US portion)	1,302,519	99	1	15	46	24	1	14
Pacific Northwest Coast	4,193,704	97	3	9	15	20	3	53
Sierra Nevada	4,930,344	99	1	26	11	42	1	20
West Cascades	3,788,168	99	1	4	31	35	2	28
Willamette Valley/Puget Sound	3,107,530	52	48	<1	2	7	4	86
Total Area	90,787,595	89	11	4	12	42	4	38

Ecoregional Assessments

Ecoregional assessments have been completed by The Nature Conservancy for each of the eleven ecoregions in the project area. The purpose of each assessment was to identify priority areas for conserving the biodiversity of that ecoregion. These assessments created a blueprint - a portfolio - of public and private conservation areas that, if conserved or managed for biodiversity, would collectively protect the full biological diversity of an ecoregion (Map 4.3). Methods are described in detail by Groves (2003), but below we briefly describe the methods most commonly used in past assessments to create the portfolio of sites used for analyses later in this report. The ecoregional assessment reports covering this project area, completed between 1999 and 2007, can be found on the Conservation Gateway website (http://www.conservationgateway.org/ConservationPlanning/SettingPriorities/EcoregionalReports/)

The first step in the planning process is to select conservation targets. Traditional conservation targets are those elements of biodiversity – plants, animals, and ecological systems – that are included in the assessment. Targets are chosen to represent the full range of biodiversity in the ecoregion. Ecological systems represent a coarse filter; the conservation of a representative example of each ecological system could conserve up to 90% of the ecoregion's species (Dobson 1996 and Groves 2003). Species that are less common, and may not be conserved using the coarse-filter approach, are included as unique targets. All targets are then attributed to assessment units, wall-to-wall polygonal features from which the conservation portfolio will be constructed.

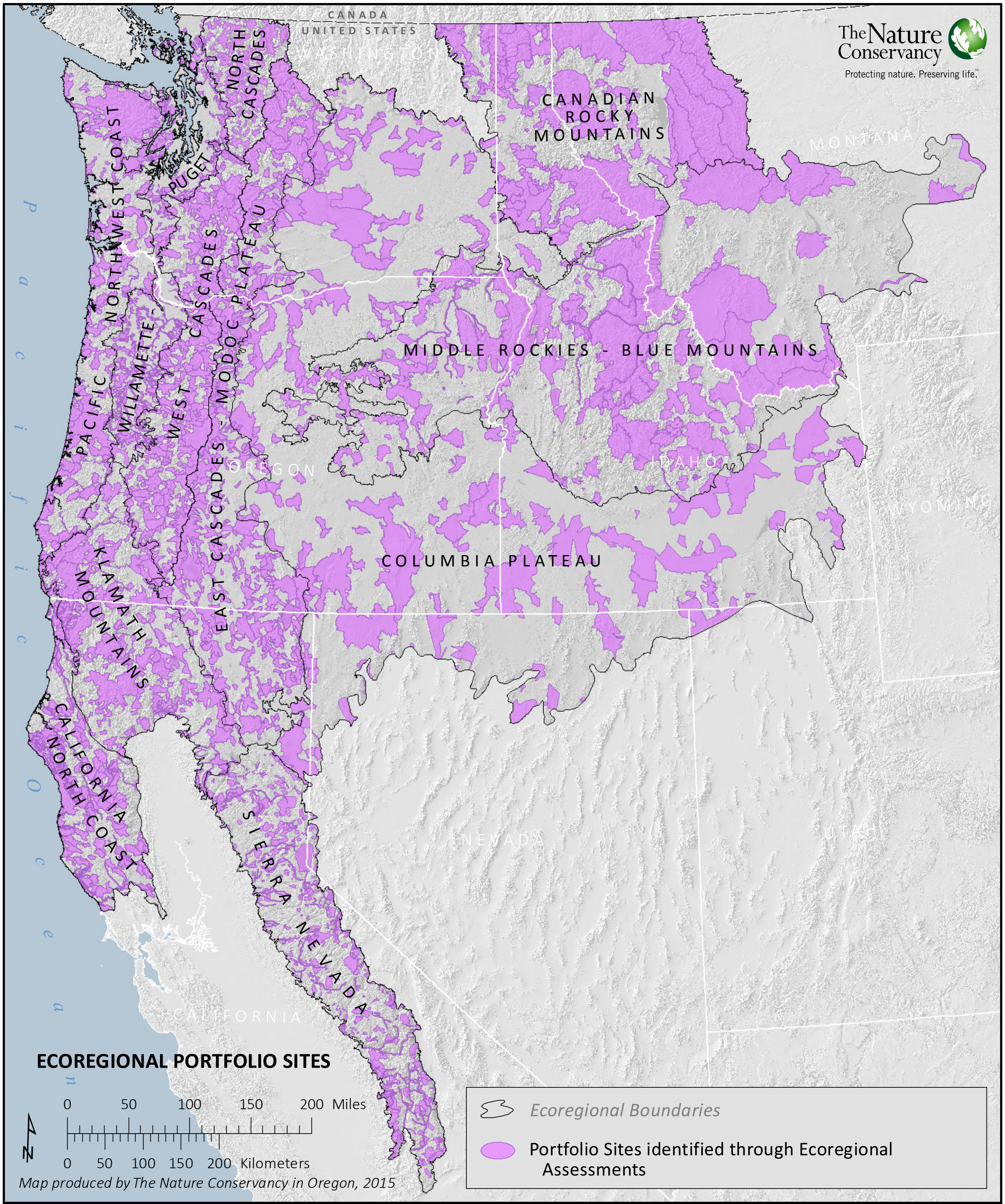
Conservation goals are set for the representation (number of occurrences and geographic distribution) of each target in the portfolio with the overarching goal being the long-term viability of each. These goals are based on the number of occurrences or amount of area occupied, the distribution of each target across the ecoregion, and target rarity and degree of endangerment.

The suitability of each assessment unit is described based on road density, GAP management status, land conversion/use and other factors related to the quality and condition of the area of the assessment unit. Overall, the suitability values denote the "cost" of conservation, or the impediments to conservation. The information used to define the land conversion portion of suitability is similar to that used in this project to estimate local permeability (Chapter 7).

Marxan optimization software (Ball and Possingham 2000) typically is used to identify a draft portfolio that meets target goals, minimizes the size of the overall portfolio, and maximizes the suitability of the portfolio sites for conservation and long-term sustainability.

One of the objectives of this terrestrial resilience project is to evaluate the current portfolio with respect to new information describing the potential resilience of each area to a changing climate. This will inform future priorities and updates to the portfolio (see Chapter 9).

Map 4.3: Ecoregional Assessment Portfolio Sites



Ecoregional assessments have been completed for all ecoregions in the study area. The purpose of each assessment was to identify priority areas for conserving the biodiversity of that ecoregion. The idea was to create a blueprint - a portfolio - of public and private landscapes that, if conserved or managed for biodiversity, would collectively protect the full biological diversity of an ecoregion. Assessments for these 11 ecoregions were completed between 1999 and 2012. *Data Source: The Nature Conservancy, 2013.*

Defining and Mapping the Stage

CHAPTER 5

A species' range and distribution is, in part, a function of climate, history, disturbance patterns, interactions with other species, and geophysical features including topography, geology and soils. For more than a century, ecologists have recognized that combinations of these geophysical features are primary drivers of vegetation patterns (Clements 1936). These unique combinations of geophysical features have been called geophysical settings, land facets, and the "stage" (Anderson and Ferree 2010, Beier and Brost 2010). We are using the practice common in the Western USA of calling these **land facets**.

Land facets hold promise for conservation planning because they are stable over ecological time periods and will remain unchanged under changing climates. These land facets are the templates upon which species and communities have evolved (Beier and Brost 2010) and will remain key as species respond, both ecologically and evolutionarily, to changing climatic conditions. In response to a changing climate, species will need to move as their habitats shift. As a result, ecological communities will disaggregate and their species reshuffle to form new associations. Yet, species are most likely to persist if they can respond to climate change by moving within, or among, occurrences of land facets to which they are adapted.

The Use of Land Facets as a Terrestrial Coarse Filter

The Nature Conservancy has traditionally used plant communities or ecological systems as a coarse filter to help inform our conservation priorities. The concept is that the conservation of geographically dispersed representative examples of each ecological system could conserve up to 90% of the ecoregion's species (Dobson 1996).In the past, the Conservancy has applied this reasoning to setting conservation priorities by identifying, ecoregion-by-ecoregion, those landscapes or sites that, if protected and managed appropriately, would effectively conserve all biodiversity. Over the past 15 years, these sites have represented the Conservancy's conservation portfolio and have been viewed as a blueprint for conservation (Groves 2003). In its original form, however, this blueprint did not explicitly consider climate change (Groves et al. 2012).

As described in Chapter 3, Anderson and Ferree (2010) showed that geophysical features not only influence patterns of biodiversity but also influence the biological richness in a region. In the Northeastern U.S. they demonstrated that the total number of species in a state could be accurately predicted using a combination of the state's elevation range, central latitude, amount of calcareous bedrock and the number of geologic types. The greater the number of combinations of these geophysical characteristics, each of which they referred to as a "geophysical setting," the larger the observed species richness.

It follows that protecting *geographically dispersed, representative examples* of each and every geophysical setting will likely protect areas that will foster a diversity of biota in the future – albeit a different biota than those areas would protect today. Our approach is to develop a system of land facets that represent the geophysical diversity of the region and to evaluate their use as a coarse filter for conservation planning.

Aggregation of Geophysical Features

To develop a system of land facets for the study area we needed to first identify an approach for aggregating geophysical features. A key criterion for this approach was that it should be easily applied by others in new geographies; we explicitly worked to avoid *ad hoc* approaches that would have been irrelevant outside of our study area.

Dr. Josh Lawler at the University of Washington was concurrently working on a project to classify land facets across 14 ecoregions in the Pacific Northwest and to test their sensitivity to data inputs and classification methodologies (Lawler 2013). At the onset, we worked closely with Dr. Lawler and his team to develop a common methodology. His team evaluated three approaches to aggregating geophysical factors:

1. A statistical clustering approach that designates land facets based on similarity in patterns across multiple continuous spatial variables.
2. A simple overlay method which combines the geographic distribution of each variable and identifies each unique intersection of factors on the landscape as a land facet. The overlay approach requires creating categorical breaks for each variable, e.g. elevation zones, and slope classes.
3. A hybrid approach that overlays some factors and clusters others.

Their findings demonstrated that each method had advantages and disadvantages. Yet, none was clearly best at reflecting the existing patterns of vegetation. The approaches reliant on statistical clustering produced "types" based on observable patterns in the spatial data, yet the facet boundaries created by this method were sometimes not ecologically meaningful, leading to facets that could not be easily described or linked to vegetation. In contrast, the overlay method was marginally better than the other two at reflecting vegetation pattern and, unlike the other two approaches, produced land facets that are easy to describe and name (e.g., mollisols on level terrain at high elevations). This system, however, is very sensitive to the number of categories developed. For example, a classification based on 3 elevation zones (low, medium, high) and 9 soil types would potentially create 27 land facets. Increasing the number of elevation zones to 6 would potentially result in 54 land facets. We say "potentially" because some combinations of soil types and elevation zones may not actually occur within the study area.

Geophysical Factors and Categorical Breaks

We set out to develop a taxonomy of land facets that best represents the existing mosaic of vegetation (ecological systems) and produces land facets at a scale and resolution that makes them useful as a coarse filter. To serve as a coarse filter for conservation there need to be enough land facets to reflect the heterogeneous nature of the study area and the existing mosaic of vegetation. For example, the fewer the land facets, the more internally heterogeneous each facet would be, each potentially containing more geophysical diversity and thus representing many different potential ecological systems under present or future climates. Thus, identifying areas to conserve within heterogeneous land facets would be a challenge. In contrast, the more facets, the more homogenous each would be. However, if there are too many facets, they cease to be effective coarse filters and might even become fine filters. In addition, as the number of facets increases so does the challenge of trying to describe and interpret each in terms of vegetation pattern and occurrence. There are 162 natural ecological systems classified and mapped within our 11 ecoregion study area (Comer et al. 2003). Traditional biological coarse-filter targets, including a geographically dispersed representative example (usually 30%) of each ecological system within our conservation portfolio, theoretically captures about 90% of all species (Dobson 1996). We reasoned that geographically dispersed, representative examples of a similar number of land facets could also capture most of the diversity of ecological systems and the study area's species diversity. Moreover, by capturing representative land facets we increase the probability that species diversity will be conserved in the future, even as communities dissolve and reassemble as species respond individualistically to climate change.

Appendix B: Selection of Land Facet Geophysical Factors and Category Breaks discusses how we selected the geophysical factors and identified the categorical breaks within those factors in 2014 for the eastside ecoregions, which were then used for the west side ecoregions as well. Taking previous approaches (e.g., Anderson et al. 2012, in the Northeast, Beier and Brost 2010 and Lawler 2013, in the West) as our starting point, we evaluated how well potential factors and categorical break combinations reflected the existing mosaic of ecological systems, and considered how many land facets various sets of categorical breaks would produce. Our final datasets and categories are described below.

Soil Order: Soil orders reflect both geology and time and are based largely on soil forming processes, including exposure to climatic factors and biological processes, as indicated by the presence or absence of major diagnostic horizons, and may reflect vegetation patterns in the western US better than geology. We used State Soil Geographic (STATSGO) soils data for the eastside ecoregions in Phase 1 of the project, and in Phase 2 for the relatively small portion of the westside ecoregions where finer-scaled Soil Survey Geographic (SSURGO) data were not available. The soil order data sources can be seen in Map 5.1, and the final soil layer is shown in Map 5.2.

Elevation: Elevation greatly affects vegetation pattern and distribution throughout our study area. Elevation within the study area ranges from sea level in the coastal and western ecoregions, to over 3,600 meters in the Idaho Rocky Mountains, Oregon Cascades, and California Sierras. This elevation range is twice that found in the Northeast and Mid-Atlantic regions and threefold that of the Southeast. The 600 meter elevation breaks used to create land facets are shown in Map 5.3.

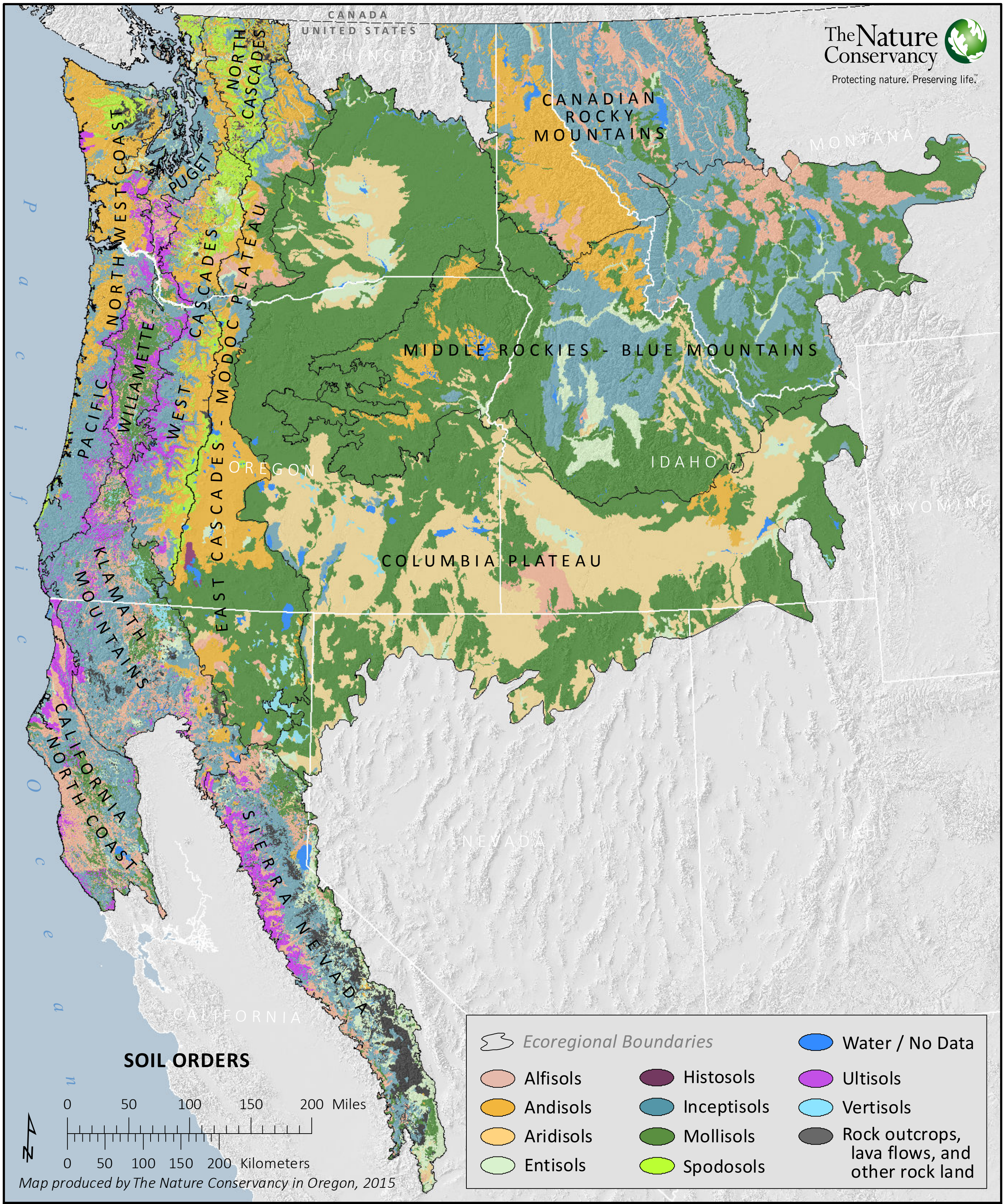
Slope: Slope was not included as a layer in the Geophysical Settings created in the Northeast and Mid-Atlantic (Anderson et al. 2012), however in this project, we used slope categories to help distinguish the flat, high elevation deserts and plateaus from high-elevation mountainous areas. The inclusion of slope also created more homogeneity within a land facet to better allow the comparison of resilience values. This allowed more meaningful comparison of resilience values in different settings because high scores in topographically complex mountainous areas would not overwhelm scores in flatter plateaus (See Chapter 8). The slope layer is shown in Map 5.4.

Map 5.1: Soil Data Sources

State Soil Geographic (STATSGO) soils data were used to identify soil orders (Map 5.2) for much of the study area, including the entirety of the Eastside project phase. Finer-scaled Soil Survey Geographic (SSURGO) data – generally more available in the western ecoregions – were used wherever they existed in the Westside project phase.

Data Sources: U.S. General Soil Map (STATSGO2), 2013; SSURGO Soil Map, 2013.

Map 5.2: Soil Orders Used for Land Facet Creation



Soil orders, based largely on soil forming processes, reflect both geology and time, and are recognized as major controllers on the ranges of many species, particularly plants. This is one of three datasets used in creating land facets for the PNW Landscape Resilience project.

Data Sources: U.S. General Soil Map (STATSGO2), 2013; SSURGO Soil Map, 2013.

Map 5.3: Elevation Zones Used for Land Facet Creation

In the Pacific Northwest, elevation greatly affects vegetation pattern and distribution. Elevation within the study area ranges from sea level in the coastal and western ecoregions to over 3,600 meters in the Idaho Rocky Mountains, Oregon Cascades, and California Sierras. *Data Source: National Elevation Dataset (NED), 2014.*

Map 5.4: Slope Categories Used for Land Facet Creation

Much of the landscape within the Pacific Northwest Terrestrial Resilience project area is flat; 46% of the area has a slope of 6 degrees or less. Slope categories were used to help distinguish flat valleys, deserts, and plateaus from rolling hills and more mountainous areas. The inclusion of slope also created more homogeneity within a land facet to better allow the comparison of resilience values. *Data Source: National Elevation Dataset (NED), 2014.*

Creation of Land Facets and Ecofacets

Land facets were created by overlaying 270 m resolution rasters of elevation (seven 600-m bands), soils (10 orders plus exposed rock) and slope (3 classes), resulting in 162 land facets within the study area (Map 5.5). There were a handful of additional land facet combinations that were very small and rare (less than 360 hectares, or 50 cells, in an ecoregion), and those were dropped from the summaries in this report, though they still exist in the associated GIS datasets. The soils data included non-soils in the “soil order” taxonomy, and we retained the widespread rock types (outcrops, lavaflows, etc.) in the western ecoregions, but discarded water, non-natural, and the small set of “other natural” data. Table 5.1 below lists the three factors and category breaks we used to create land facets.

Table 5.1. Factors and breaks used to create land facets. Summary of geophysical factors and the categorical breaks which were used in constructing geophysical units. The number of classes defined for each factor is indicated in parentheses, along with a description of how they were defined.

Soil Order (11, including exposed rock)	Elevation (7, with 600m breaks)	Slope (3, with 6 degree breaks)
Alfisols	0-600	0-6
Andisols	600-1,200	6-18
Aridisols	1,200-1,800	Over 18
Entisols	1,800-2,400	
Histosols	2,400-3,000	
Inceptisols	3000-3,600	
Mollisols	3,600-4,200	
Spodosols		
Ultisols		
Vertisols		
Rock		

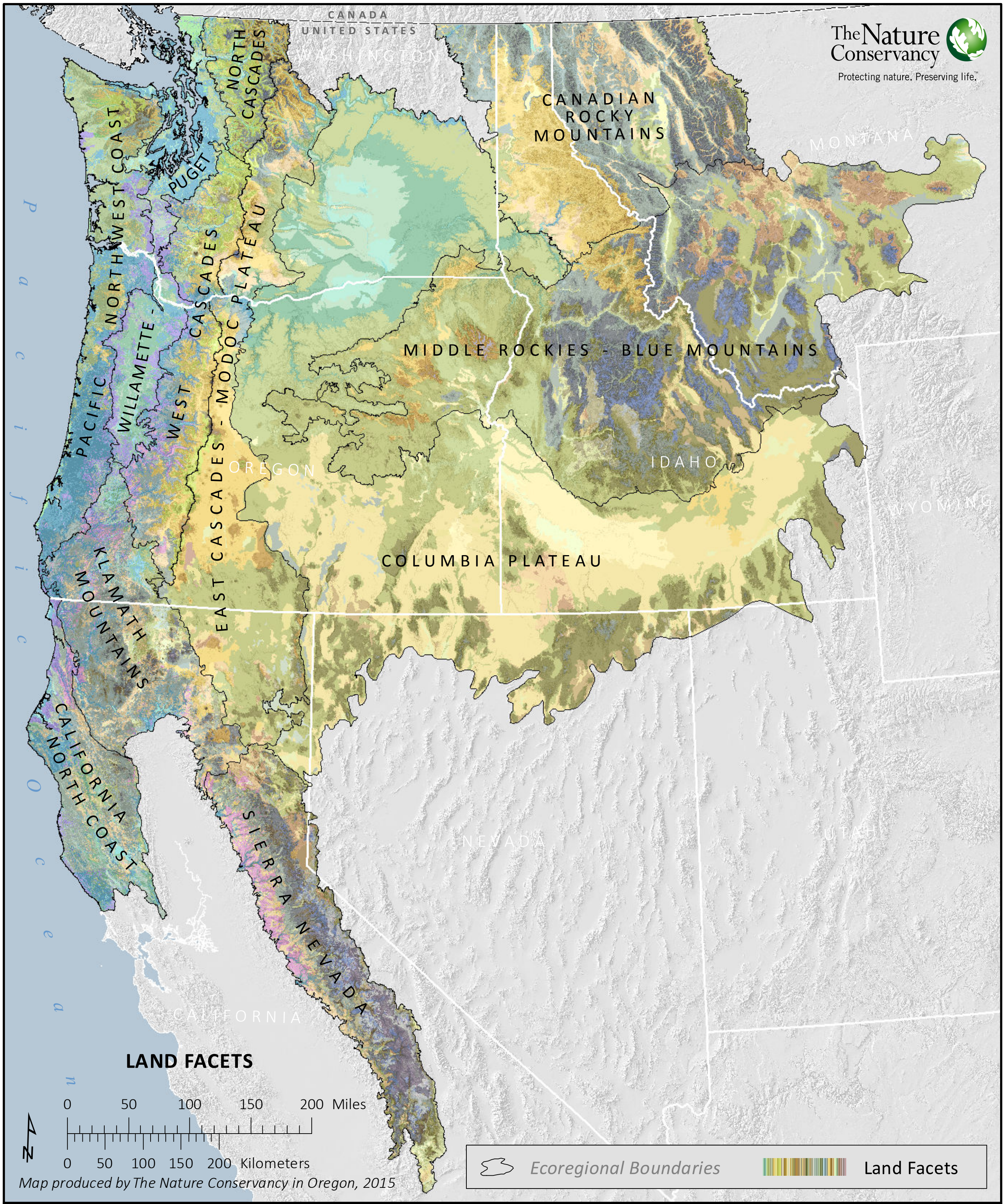
Appendix C: GIS Methods and the associated GIS metadata go into detail on the data sources for each of these factors and how the final 270 meter rasters were created using Python scripts.

We defined the portion of a land facet found within an ecoregion an **ecofacet;** each land facet was subdivided into ecofacets, which are the focus of the rest of this report. The 162 land facets become 794 ecofacets when stratified by the 11 ecoregions in the study area. These ecofacets range in size from millions of hectares of the flat Mollisols and Aridisols in the Columbia Plateau and Middle Rockies-Blue Mountains ecoregions to less than 1,000 hectares of rarer soils types such as Ultisols, Spodosols and Alfisols in the moderate and steeper portions of the West Cascades and Willamette Valley. Table 5.2 lists the number and size of ecofacets by ecoregion. *Appendix D, Ecofacet Statistics*, is a sortable Excel file which has more detailed summaries of each ecofacet, including its size, protection by GAP status, development, resilience, and Conservation Risk Index. See Chapters 6-8 for information on how resilience data were developed and stratified, and Chapter 9 for examples of how to use those data in conservation planning and priority setting.

Table 5.2. Number of ecofacets and natural terrestrial ecological systems by ecoregion. This list includes ecofacets only if there are at least 360 hectares of a particular facet in a particular ecoregion.

Ecoregion	Number of Ecofacets	Number of ecological systems
Columbia Plateau	76	108
Middle Rockies/Blue Mts.	86	74
East Cascades/Modoc Plateau	88	92
Canadian Rockies (US portion)	60	50
North Cascades (US portion)	48	32
Willamette Valley-Puget Trough	33	49
Pacific Northwest Coast	51	41
West Cascades	92	67
Klamath Mountains	96	81
California North Coast	53	42
Sierra Nevada	114	61
Study area (all 11 ecoregions)	162 Land Facets	162

Map 5.5: Land Facets



Land facets were created by combining 3 rasters: elevation (7 - 600-m bands), soil orders (11 classes) and slope (3 breaks) to produce a 270-m resolution grid. 162 land facets were created, ranging in size from over 9 million hectares in the plateaus of the Columbia Plateau to less than 1,000 hectares in steep, high elevation habitats. These 162 facets were stratified by ecoregions to produce 794 ecofacets which underlie the spatial distribution of biodiversity and the region's biological richness (premise #1).

Modeling Topoclimate Diversity

CHAPTER 6

With land facets mapped across all eleven ecoregions in the study area, we proceeded to evaluate the relative resilience to climate change of each 270m cell within each land facet type within each ecoregion (i.e., within each ecofacet). Our approach defines climate change resilience as a function of both a site's diversity of topoclimates (i.e., local climate conditions as influenced by topography) and the site's ability to support species movement (landscape permeability). Here, we posit that access to a variety of local topoclimates increases the likelihood that species can reach sites with suitable topoclimates, thus potentially providing localized refugia from the effects of a changing climate.

Below we describe the basic methods and tools for estimating topoclimate diversity at the local scale. Detailed methods, including GIS tools and equations are in *Appendix C: GIS Methods*.

Topoclimate Diversity

The climatic conditions experienced by an individual organism may vary widely from regional norms if that organism occurs in a location where fine-scale land surface features create different microclimates (Ackerly et al. 2010, Dobrowski 2011, Ackerly 2012). A south facing slope, for example, may experience higher daytime maximum temperatures than a north facing slope. Microclimate diversity connotes the range of temperature and moisture regimes available to species as local habitats: where this diversity is greatest, there is the most potential for some areas to deviate from the regional climatic norm, and to act as refugia under climate change scenarios (Dobrowski 2011). Areas rich in microclimatic niches may increase species diversity (Kerr 1997) and increase the likelihood for species persistence across multiple temporal scales (Luoto and Hekkine 2008, Weiss and Weiss 1988).

Microclimate diversity is expressed over multiple spatial scales. Whereas the micro-topography of a flat plain may include tiny swales and low hills that create microclimates at fine scales, the large elevation gradients and pronounced slope and aspect changes of rugged mountains affect microclimates across broader scales. Here, we are using topographic factors to estimate the diversity of microclimates at a site. We are not taking into account the vegetation at a site because vegetation will change over time, whether due to active management (such as clear-cutting a forest), natural disturbances, or the change in vegetation that will occur over time with climate change. For these reasons, we will use the term "topoclimate" throughout the remainder of this document. Areas with high topoclimate diversity should provide more localized occurrences of suitable habitat for dispersal by individuals of a species and eventual species-wide range shifts. High topoclimate diversity should also support greater biodiversity by providing more habitat niches and allowing more opportunities for the evolutionary processes of adaptation and speciation to occur.

Modeling Topoclimate Diversity in the Pacific Northwest

In the study of resilient sites for terrestrial conservation conducted for the northeastern United States, Anderson et al. (2012) modeled topoclimate diversity, which they termed 'landscape complexity,' based upon landform variety, elevation range, and wetland density. The approach began with a landform model delineating local environments with distinct combinations of moisture, insolation, and processes of soil formation. With local elevation variability factored in, wetland density was then incorporated to represent topographic diversity and patterns of freshwater accumulation in flat areas.

Several analytical considerations led the PNW team to develop an alternative approach to quantifying topoclimate diversity that relied upon continuous geomorphometric indices rather than the discrete classification of landforms. Chief amongst those was the difficulty in calculating 'landscape complexity' in flat areas. Landform modeling is not sensitive enough to discern any topographic diversity in flat landscapes, necessitating the inclusion of an additional metric, wetland density, in areas of low-relief. As 46% of the PNW project area is quite flat, and with much of the flat area being very arid (with few wetlands), this method was not appropriate for the PNW region.

As we developed our approach for modeling topoclimate diversity in the Pacific Northwest, key considerations informing our work were that the scale of analysis at which we measure topoclimate diversity should be commensurate with the scale of occurrence of the biodiversity we seek to conserve, the scale at which conservation actions will be taken, and GIS processing capabilities. Source data were available for the entire project area at a variety of scales. We selected data at a 30m resolution as the most appropriately scaled for the software used in our calculations of topoclimate metrics. Additionally, data at this resolution is often used for predictive species distribution modeling at landscape scales, and are well-matched to both the species occurrence and vegetation data used in TNC's Ecoregional Assessments. The resolution is also appropriate for evaluation of the vast areas (typically tens to thousands of hectares) across which TNC must prioritize its conservation actions, while still supporting meaningful comparisons between potential conservation acquisitions. Thirdly, 30m resolution may be the finest scale tenable given the extent of this project; raster analysis of the number of pixels required to describe this geography (n ~ 1,000,000,000) occurs near the upper limits in processing capability of most desktop computers using the standard ESRI suite of GIS tools.

We selected two indices to incorporate into a metric of topoclimate diversity, both derived from a 30m Digital Elevation Model (DEM): the first, *Heat Load Index* (HLI) provided a relative indication of temperature experienced on the ground, and the second, *Compound Topographic Index* (CTI) describes relative variation in water availability. These are briefly described below, with additional details in *Appendix* C: *GIS Methods*.

HLI has been shown to relate well to evapotranspiration rates and soil temperatures and is a direct measure of incident radiation (McCune and Keon 2002; Evans 2011). As implemented in the hli.py script (available as part of the PNW data downloads), aspect is “folded” so that southwest facing slopes have higher temperatures than southeast facing slopes, and northeast facing slopes are the coolest. This method also accounts for slope gradient, where steep, southwest facing slopes tilted at latitude (i.e., those receiving more tangential insolation) receive the highest HLI scores. This index can be applied appropriately anywhere in the mid-latitudes, from ~ 30º to 60º.

Our approach relies on HLI as an approximation of relative, local temperature (Figure 6.1). We anticipate species dispersal may occur along these temperature gradients in response to climate change.

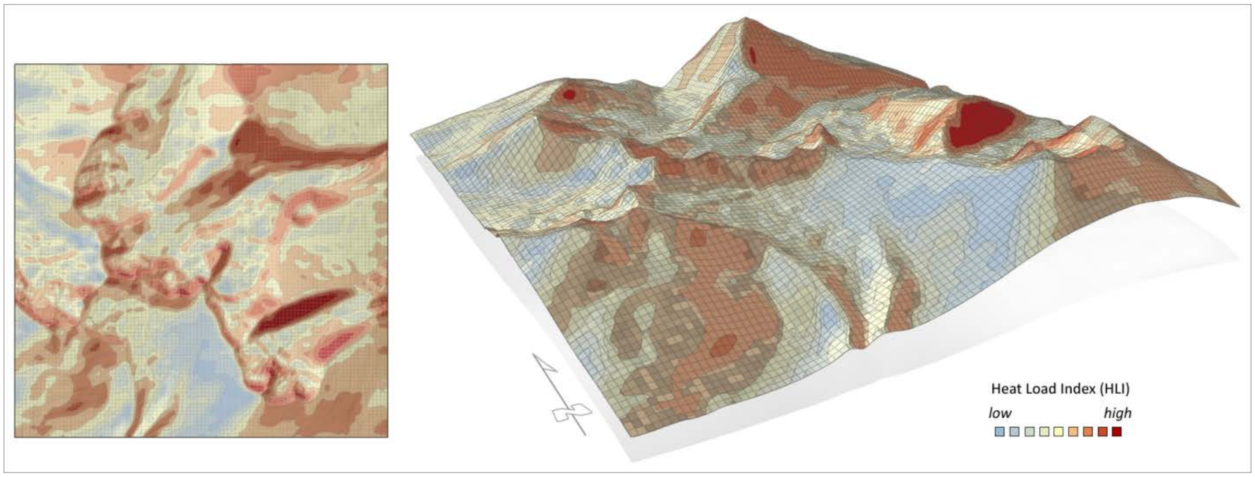


Figure 6.1. Heat Load Index (HLI), is a direct measure of incident radiation calculated from a Digital Elevation Model (DEM).

The second index that we calculated from our topographic data was CTI, a metric of potential ground wetness that is considered *steady-state*, or based on variables that remain relatively constant over time. CTI models water flow accumulation as a function of upstream contributing area and slope (calculated by percent rise). Prolonged exposure to water is a key factor in determining soil type, and CTI has been shown to have a strong correlation with many soil properties, including depth, texture, organic content and moisture (Gessler et al. 1995, Moore et al. 1993, Evans 2011). Smallest CTI values are typically found along ridgelines and largest values in valley bottoms and basins with large contributing areas.

Our method uses CTI as a measure of soil moisture potential (Figure 6.2). As future precipitation patterns change, many organisms - particularly plants - are likely to disperse along soil moisture gradients (Crimmins et al. 2011).

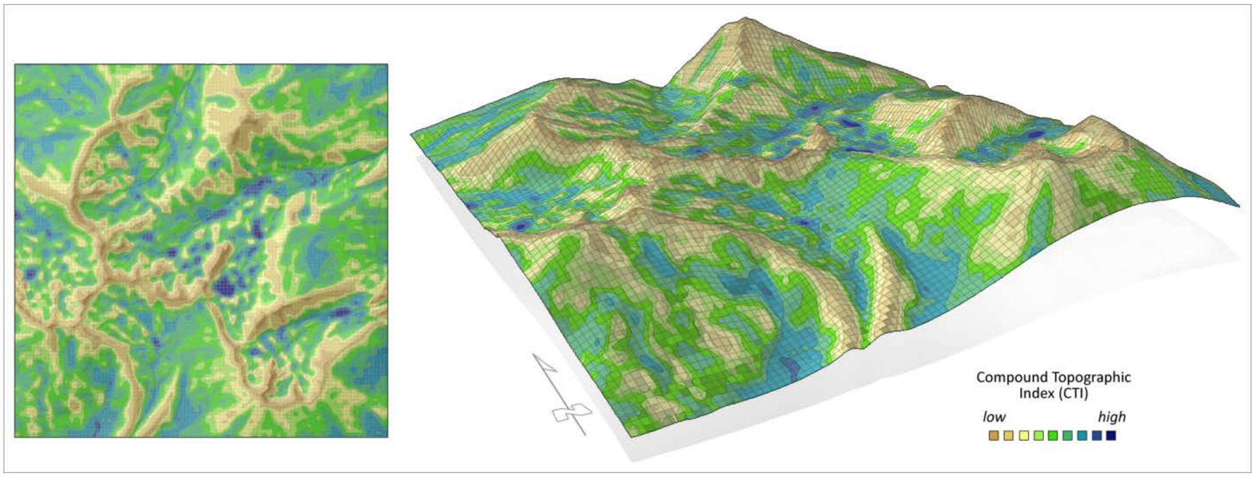


Figure 6.2. Compound Topographic Index (CTI), is a measure of soil moisture potential calculated from a Digital Elevation Model (DEM).

Both HLI and CTI are calculated directly from a digital elevation model (DEM) and produce topoclimate measures in nearly all terrain types. As the creation of these indices requires only a DEM and published software, they are easy to create, repeatable and objective.

Our next step was to relate the results of our index calculations to the process of species movement in response to climate change. We consider sites with the highest number of different topoclimates in close proximity to be most likely to play an important role in supporting species diversity over the long term. However, to calculate this type of metric, we first needed to assign a numeric value, or focal neighborhood, to define "close proximity." This focal neighborhood reflects a presumed dispersal distance organisms might traverse in the near-term to colonize areas with characteristics consistent with their climatic requirements. Dispersal distance is inherently a species-specific trait. As this project is not species-specific, selection of a neighborhood size entailed a balance in representing dispersal capabilities of many species. With little support in the available literature on an optimal search radius for representing the dispersal distances of species across many taxa, we opted for a moderate radius of 450m (compared to 358m in Anderson et al. 2012). This distance was an acceptable compromise between the needs of more sessile species – such as plants and small mammals – in shifting to nearby microclimatic niches, and distances large enough to be relevant for movements of wider-ranging species.

Using this 450 m distance, we calculated the Topoclimate Diversity Index (TDI) as a focal statistic combining our two extant indices, Heat Load Index (HLI), a metric of relative ground temperature, and Compound Topographic Index (CTI), a metric of relative variation in water availability. For each focal cell taken in turn, ranges in HLI and in CTI across its 450-m radius neighborhood were standardized from 0 - 1, then multiplied together to create the TDI value. For more specifics on these processing steps, please see *Appendix C: GIS Methods*.

Neighborhoods with a wide range of both soil moisture potential (as represented by CTI) and relative local temperature (as represented by HLI) have the highest TDI scores, while neighborhoods with narrow ranges in both indices have the lowest scores, and neighborhoods with disparate climate conditions (e.g., a wide HLI range and narrow CTI range) receive fairly low scores. The relative scoring under these generalized conditions is appropriate since a low score for either index would constitute a limiting factor, reducing the likelihood that an organism would locate both suitable temperature and moisture niches within its dispersal distance.

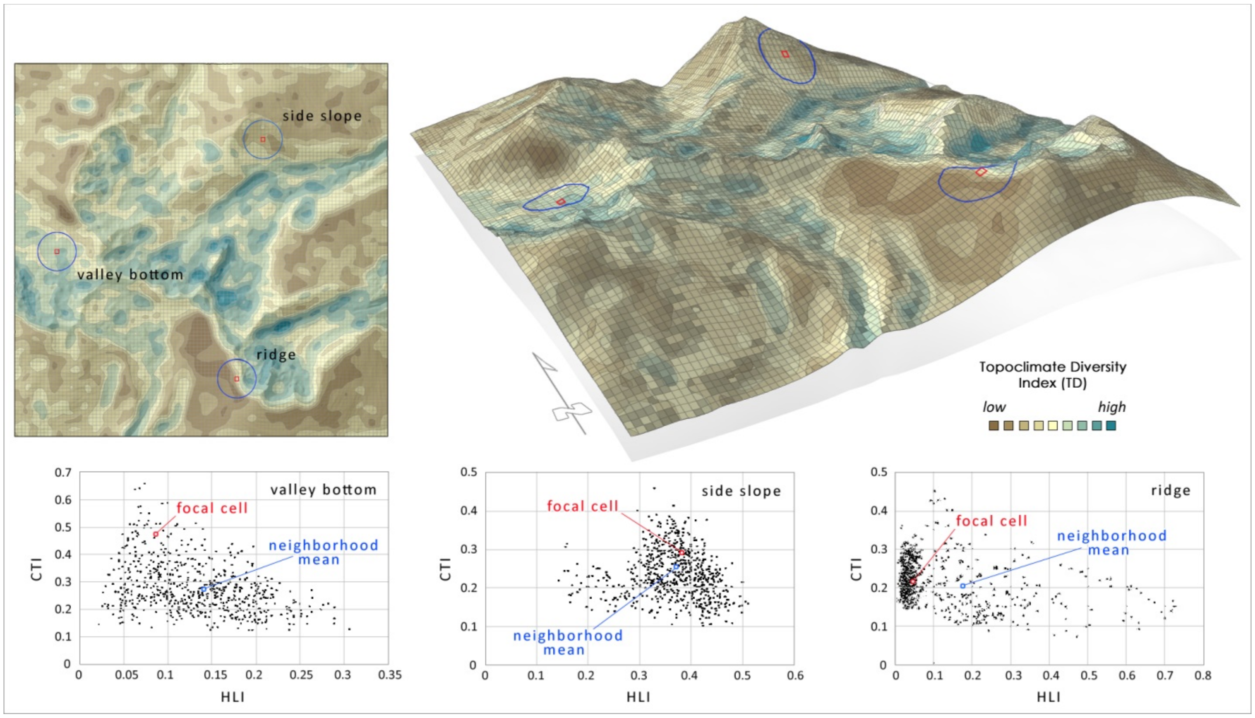


Figure 6.3. Topoclimatic Diversity Index (or TDI). Example focal statistics over three topographic feature types: valley bottom, side slope and ridge. The red boxes in each diagram indicate a focal cell, which is surrounded by a blue circle delineating the focal neighborhood. The graphs along the bottom plot the individual CTI and HLI values across each neighborhood, along with the location in environmental space of the focal cell value. The plots illustrate the spread of values that contributed to the final TDI rankings for the three highlighted locations.

The focal statistics over three topographic feature types (Figure 6.3) reveal patterns we might expect in CTI and HLI. In a west-facing valley bottom (left graph) with higher hydrologic flow accumulation and a low slope gradient, HLI is lower and CTI higher than across either of the other sites (note the differential ranges of the axes). On a south-facing side slope with a steep slope gradient, we see markedly higher HLI values due to more direct insolation and fairly low CTI values owing to higher runoff and lower soil deposition. Along a north-south running ridgeline with an angle acute to solar radiation, the plot's dominant cluster are of cells exhibiting low HLI due to indirect insolation and also low CTI due to little flow accumulation on the ridge itself.

The highest values of the final TD surface typically occur in the lower slope positions of valleys and canyons, particularly at river confluences. These findings underscore the importance of riparian corridors as refugia, both for diversity of topoclimates and as corridors between elevation zones.

The scatterplots also reveal the rich basis for additional statistics that might be calculated from these data. The relationship between the focal cell and the neighborhood x-y pairs, for example, might be used to predict how resilient a neighborhood would be in the face of a specific climate change scenario. The valley bottom scatterplot (Figure 6.3, left plot) shows the focal cell near the upper end of the neighborhood's CTI values (moister), and the lower end of the HLI neighborhood values (cooler). This implies that most of the environmental space available to a dispersing organism from that location is both drier and warmer. If we expect climate to become drier and warmer, with dispersing organisms seeking commensurately cooler and moister settings, this location might not provide as many suitable climatic niches as the side slope, where the focal cell is more centrally located relative to local HLI and CTI values.

Map 6.1 shows topoclimate diversity across the project area. As with all maps in Chapters 6-9 in this report, the reader can zoom into this map or access high resolution maps at http://nature.ly/resilienceNW

Map 6.1: Topoclimate Diversity

Topoclimate diversity connotes the range of temperature and moisture regimes available to species as local habitat refugia under climate change scenarios (Dobrowski 2010). Areas rich in topoclimatic niches may increase species diversity (Kerr et al. 1997) and increase the likelihood for species persistence across multiple temporal scales (Luoto et al. 2008, Weiss et al. 1988). We defined the Topoclimate Diversity Index (TDI) as a combination of two extant indices, Heat Load Index (HLI) and Compound Topographic Index (CTI), each measured as a focal statistic across a 450-m radius neighborhood.

Local Terrestrial Permeability

CHAPTER 7

Importance of Permeability

A highly permeable landscape is needed to maintain ecological processes, genetic diversity and adaptation potential of populations, and the ability of species to move as the climate changes. For species to take advantage of alternative locales, they need to be able to move across the landscape. In human-dominated landscapes, habitat conversion and fragmentation constrain the ability of many species to move even short distances. This inability to move and take advantage of newly available or alternative habitats may reduce the local diversity of native species in favor of habitat generalist species. Moreover, landscape and regional connectivity will be critical in allowing species to shift their ranges in response to climate changes (Heller and Zevaletta 2009) and to maintain species adaptive capacity by promoting gene flow (Sexton et al. 2011).

We are following the convention of Anderson et al. (2012) using the terms “permeability” and “connectedness” instead of “connectivity” and “corridors.” The conservation literature commonly defines “connectivity” as the capacity of individual species to move between blocks of habitat via corridors and linkage zones. As used here, permeability is not based on the needs of individual species, but is a measure of *the hardness of barriers, the connectedness of natural cover, and the arrangement of land uses* (Anderson et al. 2012). Meiklejohn et al. (2010) defined permeability as *the degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, will sustain ecological processes and are conducive to the movement of many types of organisms*.

Local permeability analyses measure how robust the structural connections are between natural systems within a local landscape. Roads, buildings, infrastructure, and the associated noise, disturbance, and other aspects of an altered landscape directly affect processes and create resistance to species movement by increasing the risk (or perceived risk) of harm. Estimating permeability is an important component of our resilience analysis because it indicates whether a process is likely to be disrupted or how much access a species has to alternative climate niches and vegetation types within its given neighborhood.

Permeability Methods

We used methods developed by Anderson et al. (2012) that map permeability as a continuous surface, not as a set of discrete core areas and linkages, the typical outputs of connectivity models. In line with our definition, we aimed for an analysis that quantified the physical arrangement of natural and modified terrestrial habitats, the potential connections between areas of natural habitat within the landscape, and the quality of the converted lands separating these fragments. Essentially, we wanted to create a surface that revealed the implications of the physical landscape structure with respect to the continuous flow of natural processes, including not only the short-distance dispersal and recruitment of plants and animals, but the rearrangement of existing communities. We use the term "ecological flow" or just "flow" to refer to both species movements and ecological processes.

Our permeability analysis evaluates the connectivity of a focal cell to its ecological neighborhood when the cell is viewed as a source; in other words, it asks the question: "to what extent are ecological movements outward from that cell impeded or facilitated by the surrounding landscape?" Thus, permeability analysis starts with a focal cell and looks at the resistance to ecological movement outward in all directions through the local neighborhood. As resistance increases, movement or flow is impeded or stopped altogether. Areas of no resistance allow the flow to proceed until a user-specified maximum distance is achieved. Therefore, cells grow further in directions of low resistance.

We used kernel analysis (Compton et al. 2007, http://www.umasscaps.org/) to map local permeability for the region. Each cell of a resistance grid is assigned a resistance value based on weights that the user assigns to each land cover and land use type. The modeled flow, or growth, outward from a focal cell is a function of the resistance values and distances to the neighboring cells out to a maximum distance of three kilometers. When each focal cell has grown to its maximum extent, it is scored by the number of neighborhood cells that it was able to grow into. Higher scores—larger numbers of cells a focal cell's resistant kernel—indicate the landscape is more permeable to movement from the cell. Each focal cell is assigned a permeability value based on the number of cells in its resistant kernel.

Importantly, higher resistant kernel scores also indicate high potential for flow into a cell from the surrounding landscape. This means that pixels with high scores can serve as destinations for local movements, bolstering the rationale for combining topoclimate and permeability scores to create a measure of site resilience (Chapter 8). Sites with high topoclimate diversity that are also accessible to neighboring sites receive high resilience scores because they can provide microrefugia for species responding to changing climates.

Resistance Data

Prior to developing new resistance surfaces, the team spent time evaluating resistance surfaces that had been developed independently by Dave Theobald (Theobald 2012, Theobald et al. 2012) and NatureServe (Comer and Hak 2012). Both surfaces were not a good fit for this project, primarily because we had no control over the resistance weightings assigned to each resistance feature. The resistant kernel algorithm is very sensitive to these weightings, and without the ability to test different weightings and their effects on the outputs we were concerned we would not be satisfied with the final product. Thus, we decided to create our own resistance weights using the values from the Washington Wildlife Habitat Connectivity Working Group (WHCWG 2012) and the values assigned by Anderson et al. (2012) in their work in the Southeastern US as starting points for our work. Because this is a terrestrially-focused analysis, we treated small waterbodies less than 90 meters wide as natural habitats (with a resistance of 1), but above that size we gave open water bodies resistance values that increased with their size. A detailed description of how we created the resistance surface is in Appendix C. The final resistance features and values used to calculate local permeability are shown in Table 7.1.

Table 7.1: Resistance values used to compile initial terrestrial resistance surfaces.

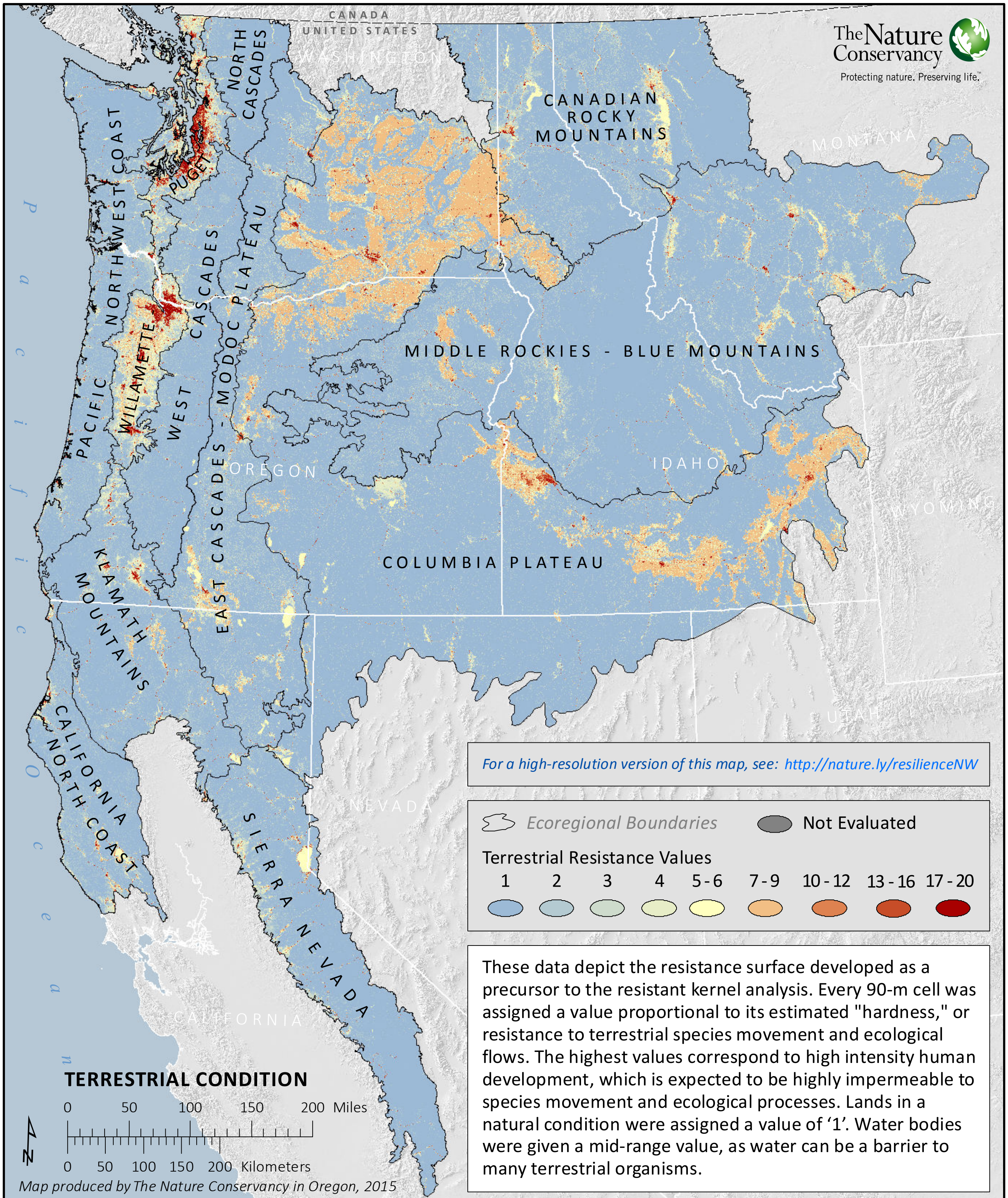
Data Layer	Class Description	Resistance
BHD2010	Undeveloped[1]	1
BHD2010	Residential - rural low (0.001-.0.006 dwelling units per acre)	1.2
BHD2010	Residential - rural (0.006-0.025 dua)	1.5
BHD2010	Residential - exurban low (0.025-0.1 dua)	2.5
BHD2010	Residential - exurban (0.1-0.4 dua)	4
BHD2010	Residential - low (0.4-1.6 dua)	7
BHD2010	Residential - med (1.6-10 dua)	16
BHD2010	Residential - high (>10 dua)	20
ENERGY	Wind Towers	10
ENERGY	Inner wind tower buffer (< 90m)	8
ENERGY	Outer wind tower buffer (90-180m)	6
ENERGY	Transmission line – Step-up -161 Volts	3
ENERGY	Transmission line - 230-287 Volts	4
ENERGY	Transmission line – 345-500 Volts	5
ENERGY	Transmission line - DC Line	5
ENERGY	Natural Gas Pipelines	3
NLCD	Open Water , 0 -90m	1
NLCD	Open Water , 90 -180m	2
NLCD	Open Water, 180 - 270m	3
NLCD	Open Water, 270 - 360m	4
NLCD	Open Water, > 360m	5
NLCD	Perennial Ice/Snow	2
NLCD	Developed, Open Space	4
NLCD	Developed, Low Intensity	9
NLCD	Developed, Medium Intensity	20
NLCD	Developed, High Intensity	20
NLCD	Barren Land (Natural)	1
NLCD	Deciduous Forest (Deciduous, Evergreen, Mixed)	1
NLCD	Shrub/Scrub	1
NLCD	Grassland/Herbaceous	1
NLCD	Pasture/Hay	4
NLCD	Cultivated Crops	7
NLCD	Woody Wetlands	1
NLCD	Emergent Herbaceous Wetlands	1
RAIL_ACTIVE	Actively used / maintained rail lines	5
RAIL_ACTIVE	Abandoned lines based on inspection[2]	3
TIGER_ROADS	Interstate, ramps[3]	20
TIGER_ROADS	State and local highways, major secondary roads[3]	20
TIGER_ROADS	City and rural streets, Unpaved and AWD (CA, NV, E OR, E WA)	3
ROADS – BLM	ALL BLM roads (not hwys) (CA, NV, W OR, W WA)	3
ROADS – USFS	All USFS roads, no distinction for road class (CA and NV)	3

ROADS – CA THP	All active California Timber Harvest Program roads (CA)	3
ROADS – CA THP	Proposed and Abandoned CA Timber Harvest Program roads[4]	1.5

[1]All lands with GAP 1, 2, or 3 protection status were considered undeveloped in housing density resistance calculations.
[2]Based on visual inspection these typically have new uses, such as dirt roadways.
[3]Interstates, Highways, and interchange ramps were widened by one cell in resistance calculations.
[4]Based on visual inspection these are often in use. Resistance score reflects likelihood of impacts.

The resistance values were calculated based on a 30 m grid. The resulting map of resistance is shown in Map 7.1 which is essentially a map of landscape condition.

Map 7.1: Terrestrial Condition



Data Sources: Ventyx Inc. EV Energy Map, 2013. Base Housing Density, Theobald, et.al. 2012. Tiger Line Files, U.S. Census Bureau, 2014. USGS NLCD, 2011. BLM Transportation Dataset, 2013. California USDA Forest Service Roads, 2014. CAL FIRE California Timber Harvesting Plan Roads, 2014. ESRI Online Railroads, 2014. Federal Railroad Dataset, 2013. ODOT Railroads, 2012. WDOT Railroads, 2012.

Local Terrestrial Permeability

To run the resistant kernel software on the resistance surface, we aggregated the 30 m cells to a 90 m grid by calculating their mean. This helped to remove erroneous gaps in barriers and reduce the influence of misclassified single-cell patches that can result from errors in classification of satellite data (WHCWG 2012). It also allowed us to run the analysis with a reasonable processing time because the software program is computationally intense.

Figures 7.1 and 7.2 illustrate the concepts behind resistant kernel modeling. Our resistant kernel analysis produced a map of local permeability (Map 7.2) with each 90 m cell receiving a permeability value between 0 (most constrained/least permeable) and 1 (least constrained/most permeable).

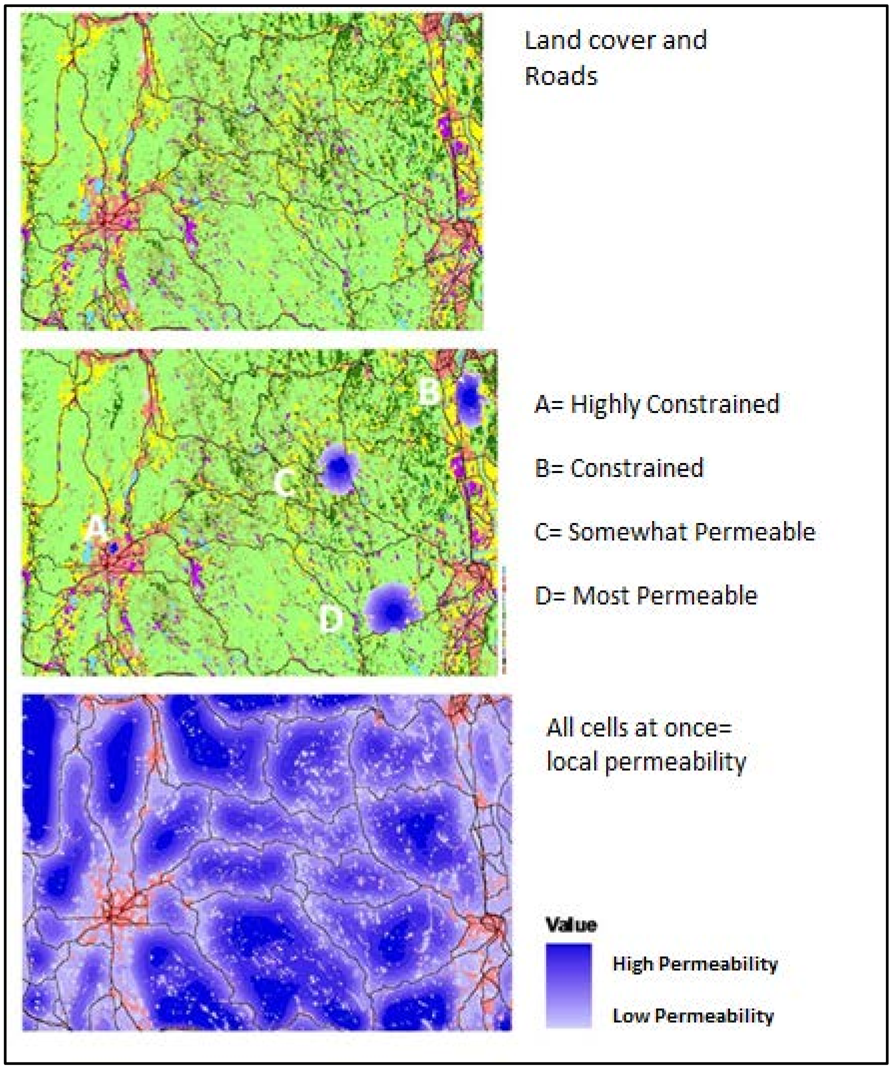


Figure 7.1. Examples of resistant kernel analyses. Each resistant kernel starts at a central, focal cell. The spread, or size, of the kernel is then a function the resistance and configuration of landscape features in the surrounding cells. The first panel shows land cover and roads, with

lines indicating roads, and all colors except green indicating non-natural land cover. The center panel focuses in on the resistant kernels associated with each of four focal cells (A-D) that represent a low-to-high gradient of surrounding natural cover. The score for each focal cell is calculated from the size of the kernel around the cell: kernel A is the least permeable, and D is the most permeable. The bottom panel represents the scores for all cells, summarizing local permeability patterns across the entire landscape (Figures from Anderson et al. 2012).

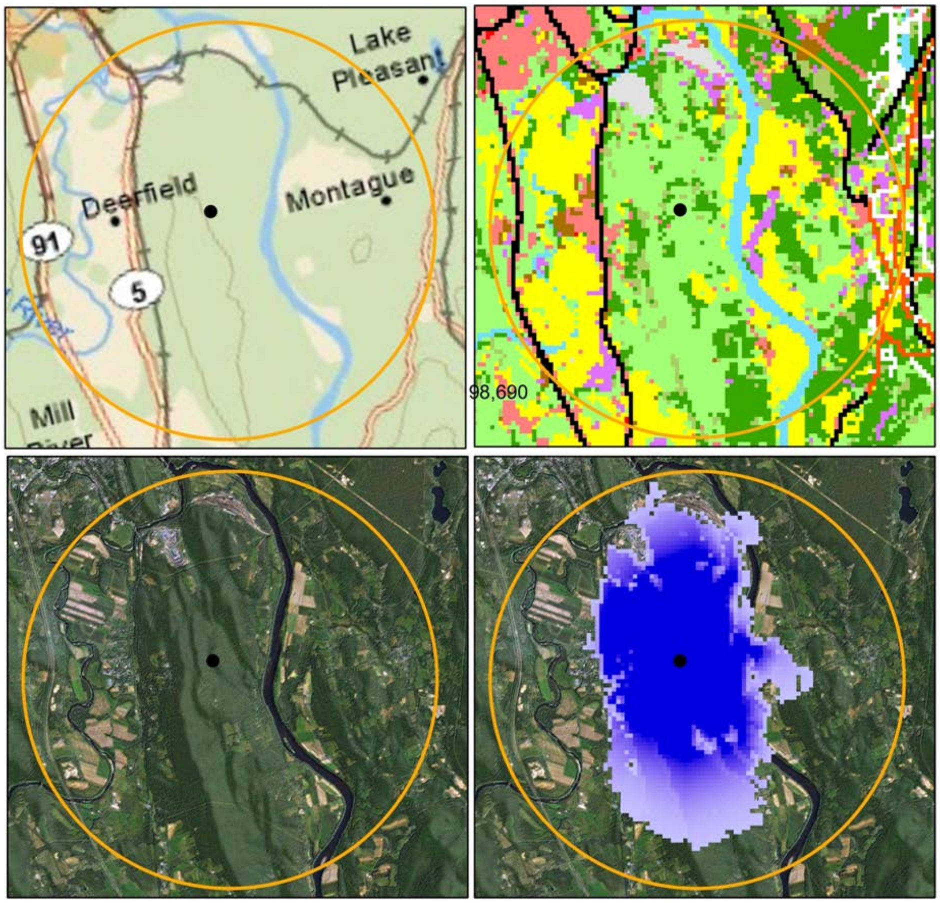
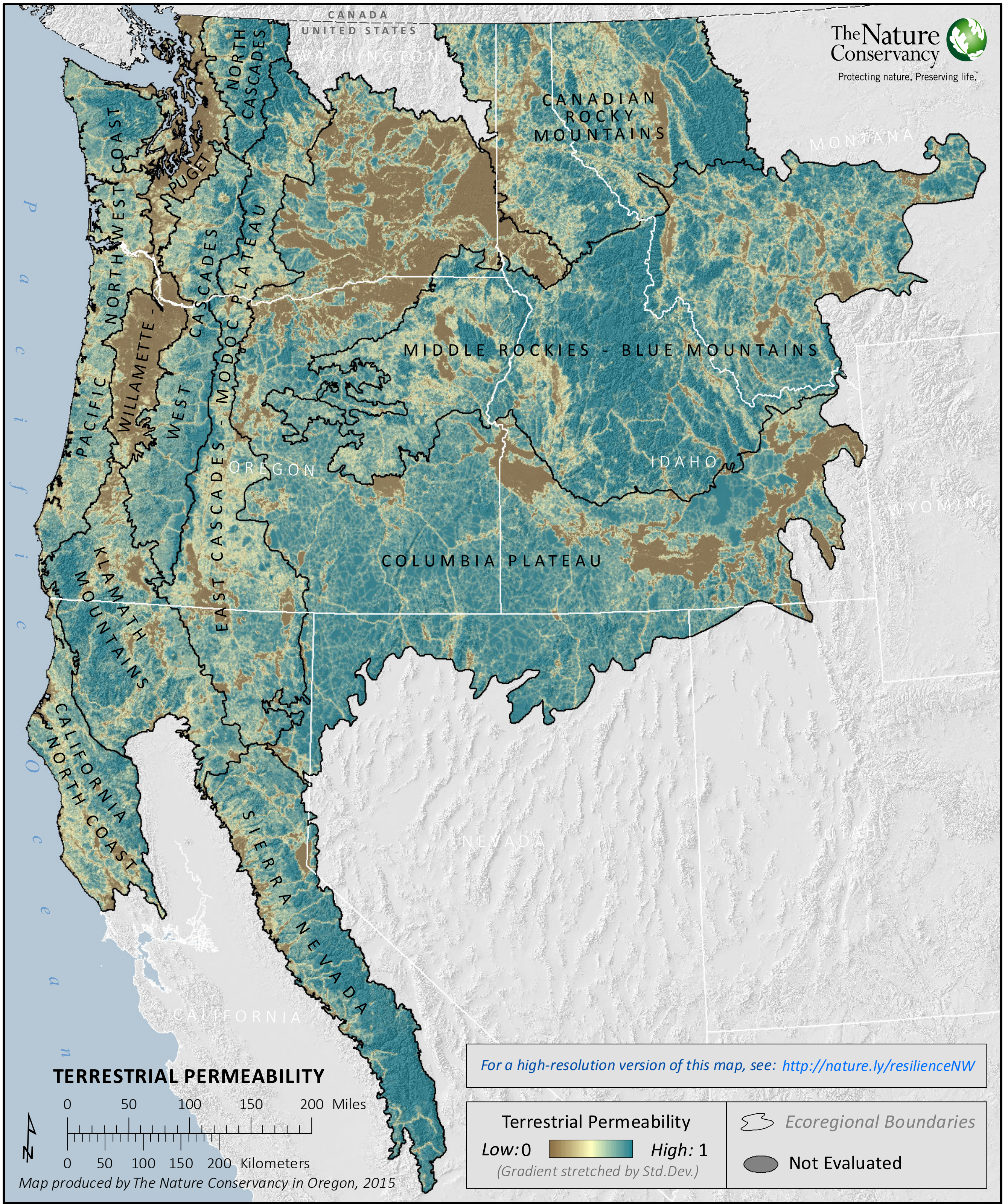


Figure 7.2. A detailed look at kernel B in Figure 7.1. All panels include the 3 km circular resistant kernel distance (yellow circle). The top left panel shows the kernel analysis area on topographic map, while the top right shows the land use grid associated with the same location. The bottom two panels show an aerial image for the same location, with the right panel showing the kernel spread calculated from resistance values that were developed based on the land cover information shown in the top right. Ecological flows from the focal cell are constrained on the west by roads and railroads and on the east by water and development. Flows are less constrained through the natural landscape in the north and south directions (Figures from Anderson et al. 2012).

Map 7.2: Terrestrial Permeability



Permeability refers to the degree to which a landscape sustains ecological processes and supports movement of many species by virtue of the structural connectedness of its natural systems (Meiklejohn et al 2010). We used resistant kernel analysis (Compton et al. 2007) to map permeability as a focal statistic based on the resistance data from the terrestrial condition dataset (Map 7.1). The analysis evaluates the capacity for ecological flow outward from each focal cell into its local neighborhood up to a maximum of 3-km, then combines the results into a final, study-wide surface.

Terrestrial Landscape Resilience

CHAPTER 8

Combining Topoclimate Diversity and Terrestrial Permeability

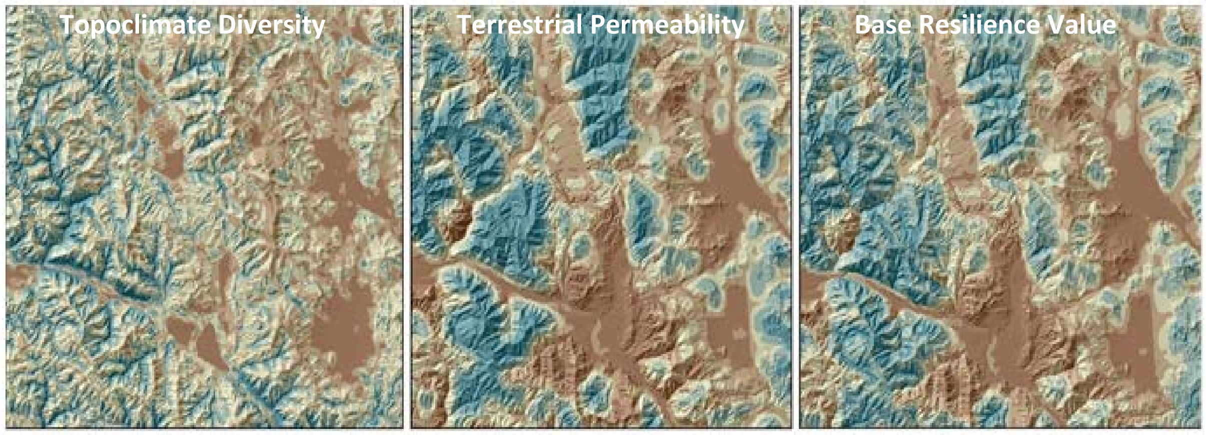
We've proposed in the previous chapters that areas of high topoclimate diversity (TD) and high terrestrial permeability should be most likely to retain and support diverse species assemblages as climatic conditions change. We refer to these areas as resilient sites. To estimate and compare site resilience, we developed a new terrestrial resilience metric by combining our metrics of local permeability and topoclimate diversity. This terrestrial resilience metric was first calculated for the entire region, then stratified within each ecoregion, and finally within each ecofacet.

Calculating Terrestrial Resilience

As previously described, we originally calculated local permeability at a 90 m resolution, whereas we calculated TD index values at 30 m resolution. To create a combined index, we first aggregated the 30 m TD data to 90 m to maintain a consistent resolution of the data sources. The new 90 m TD values were calculated by taking the mean of the nine 30 m cells nested within each 90 m unit. Both of these 90 m datasets were then scaled from 0 -1.

Our next step was to use the re-scaled TD and permeability metrics to create a measure of terrestrial resilience. A key concern in developing this new measure was to appropriately balance the two components. The PNW project area contains vast expanses of low-relief shrub-steppe. Many of these shrub-steppe systems are relatively intact with correspondingly high permeability values. These areas also host a broad suite of species that are adapted to these low-relief landscapes. The core team evaluated various weightings of the components to the resilience measure, and rejected the straight multiplication of the TD and permeability metrics, as the low TD scores were entirely overwhelming the high permeability values in intact shrub-steppe. The team also felt that impermeable landscapes should receive low resilience scores, and thus that low permeability scores should outweigh high TD values. To achieve this weighting, the TD data were rescaled from 0.2 – 1 (in effect, increasing the relative weighting of permeability), while permeability data remained scaled from 0 – 1. These final inputs were then multiplied together to generate a terrestrial resilience value for every 90 m cell across the project area (Figure 8.1).

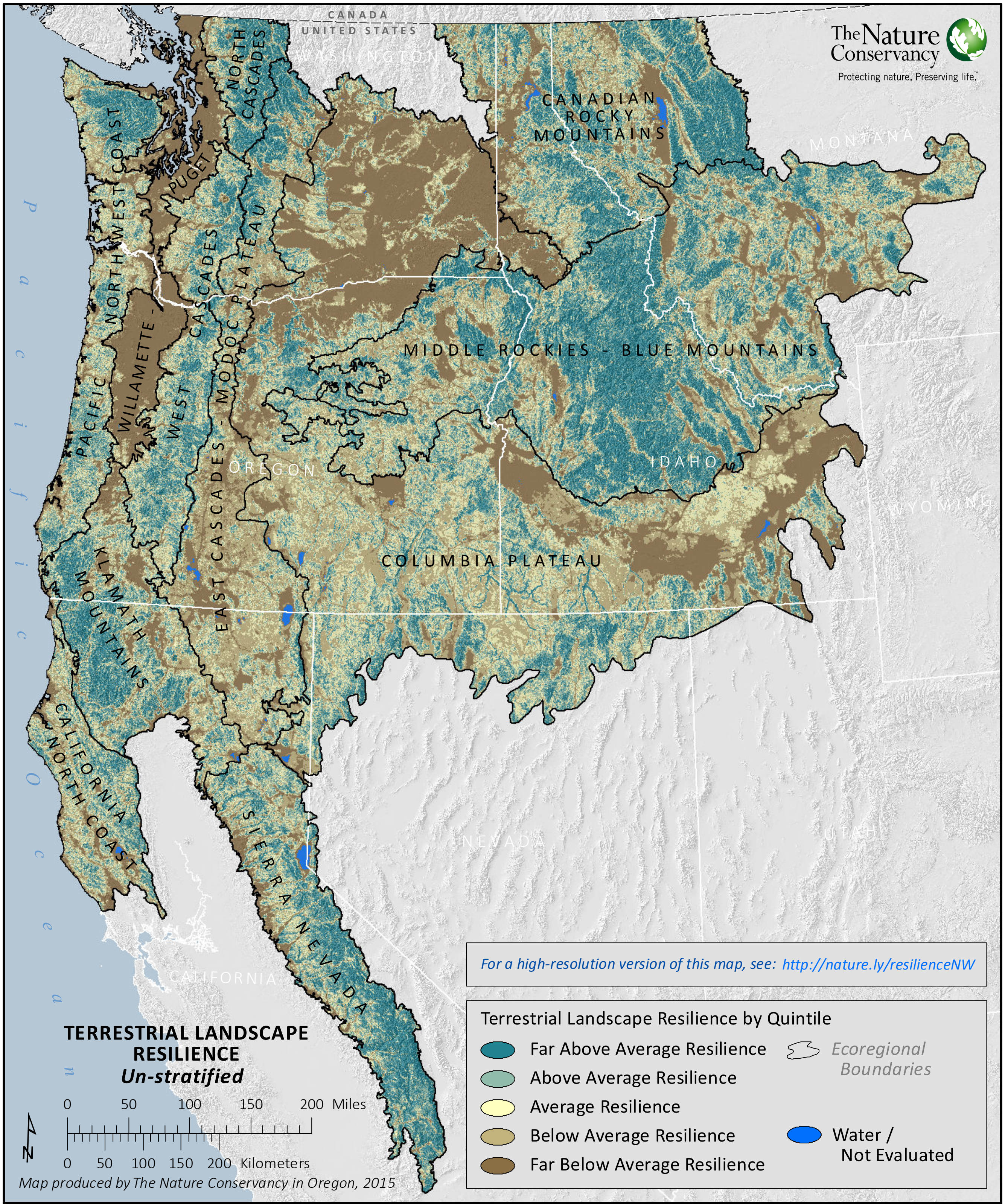
The terrestrial resilience values were in turn aggregated (again calculating the mean of the 9, 90 m cells) to 270 m cells to create resilience values that matched the resolution of our land facets. To facilitate visualization and prioritization of our results, we binned the base resilience values into quintiles (5 groups with approximately the same number of cells in each) for the entire study area. The two top quintiles were classified as more resilient, and the bottom two as less resilient (Map 8.1).



Examples of the data inputs and the Base Resilience metric at 1:250,000 scale, draped over shaded relief. Topoclimate Diversity was scaled from 0.2 – 1.0 and Landscape Permeability from 0.0 – 1.0. The two datasets were then multiplied together to create this resilience surface before stratifying by ecoregion and ecofacet.

Figure 8.1. Terrestrial resilience calculation from topoclimate diversity and permeability inputs.

Map 8.1: Terrestrial Landscape Resilience, Unstratified



This map depicts the resilience scores as calculated directly from topoclimate diversity x landscape permeability, not yet stratified by ecoregion or ecofacet. The values have been binned into quintiles. We have defined those cells in the upper two quintiles, 40% of the project area, as "more resilient". As expected, areas with high topographic diversity score better than low-relief plateaus and basins when the data are unstratified.

Stratification of Terrestrial Resilience by Ecoregions and Facets

Our topoclimate diversity index tends to identify areas that have more topographic relief (mountainous areas) as having higher topoclimate diversity. Also, the wall-to-wall permeability scores are largely a function of anthropogenic land use, and flatter terrain has been disproportionally impacted by conversion compared with steeper terrain. In order to make the resilience data more relevant to local geographies (and the species adapted to them), the resilience data were stratified by ecoregion and by ecofacet.

Ecoregions are defined as “relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change”(Olson, et al. 2001). Recognizing the distinct ecological nature of each of our 11 ecoregions, the core team determined that each ecoregion should be looked at independently. Therefore, each 270 m cell of the resilience surface was assigned to an ecoregion, and the base values were re-classified into quintiles based on the range of resilience values within that ecoregion (Figure 8.2), with cells in the top two quintiles representing the more resilient portions within each ecoregion.

Similarly, each ecoregion contains many disparate geophysical “stages”, as embodied in our land facet classification. Species adapted to flat, deep soils, for example, are not apt to fare well in steep rocky terrain. The core team therefore decided to also stratify the resilience values by ecofacet, where each resistance cell was assigned to an ecofacet (the combination of a land facet and ecoregion), then re-classified into quintiles based on the distribution of resilience values within that ecofacet (Figure 8.3). The cells in the top resilience quintiles in the ecofacet stratification represent the more resilient examples of each land facet within each ecoregion.

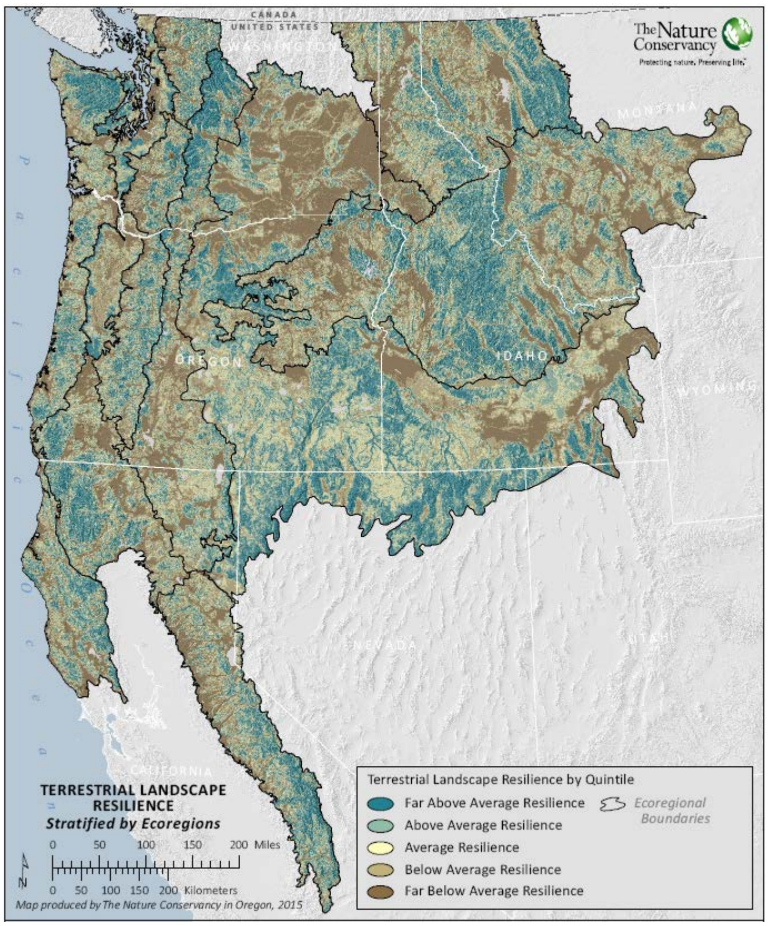


Figure 8.2 Terrestrial Landscape Resilience, Stratified by Ecoregion. This figure depicts the resilience scores stratified by ecoregion - each cell is only compared to other cells within the same ecoregion.

We used both the ecoregional and the ecofacet stratifications to create the final terrestrial resilience data. For example, the mountainous portions of the Canadian Rockies are relatively protected, undeveloped and topographically diverse; these are all qualities we associate with highly resilient landscapes. But viewed through the filter of the ecofacet stratification, the lower two quintiles of ecofacets representing this landscape would be considered less resilient. The ecoregional stratification was therefore utilized as an “override” to assure that cells with the highest resilience scores across the ecoregion were recognized as resilient in addition to the highest resilience scores within each ecofacet.

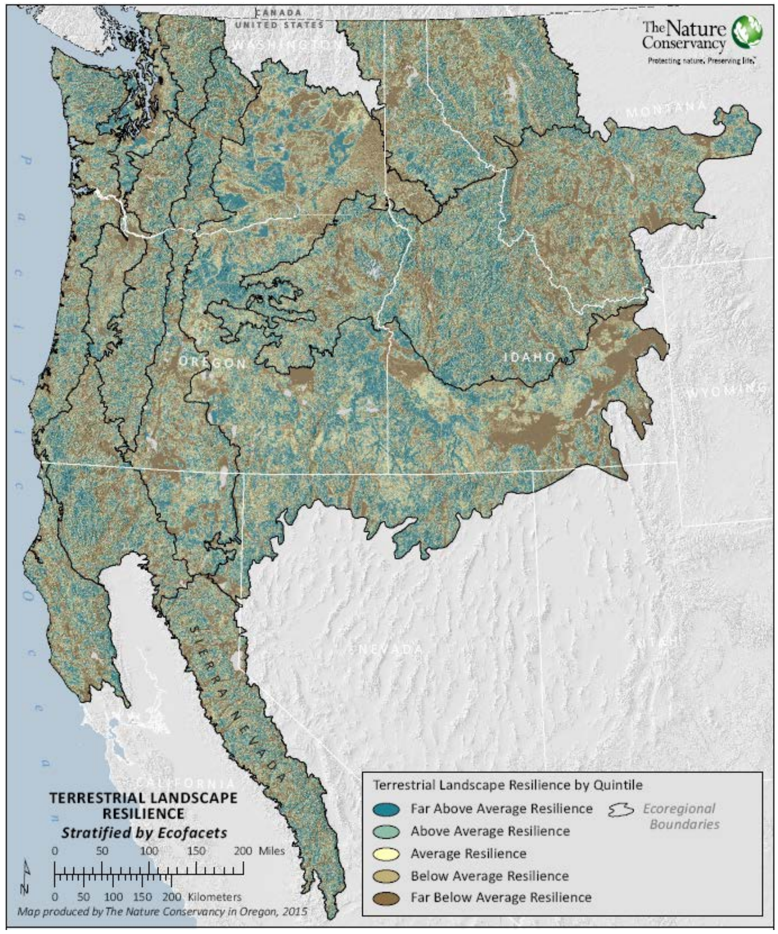
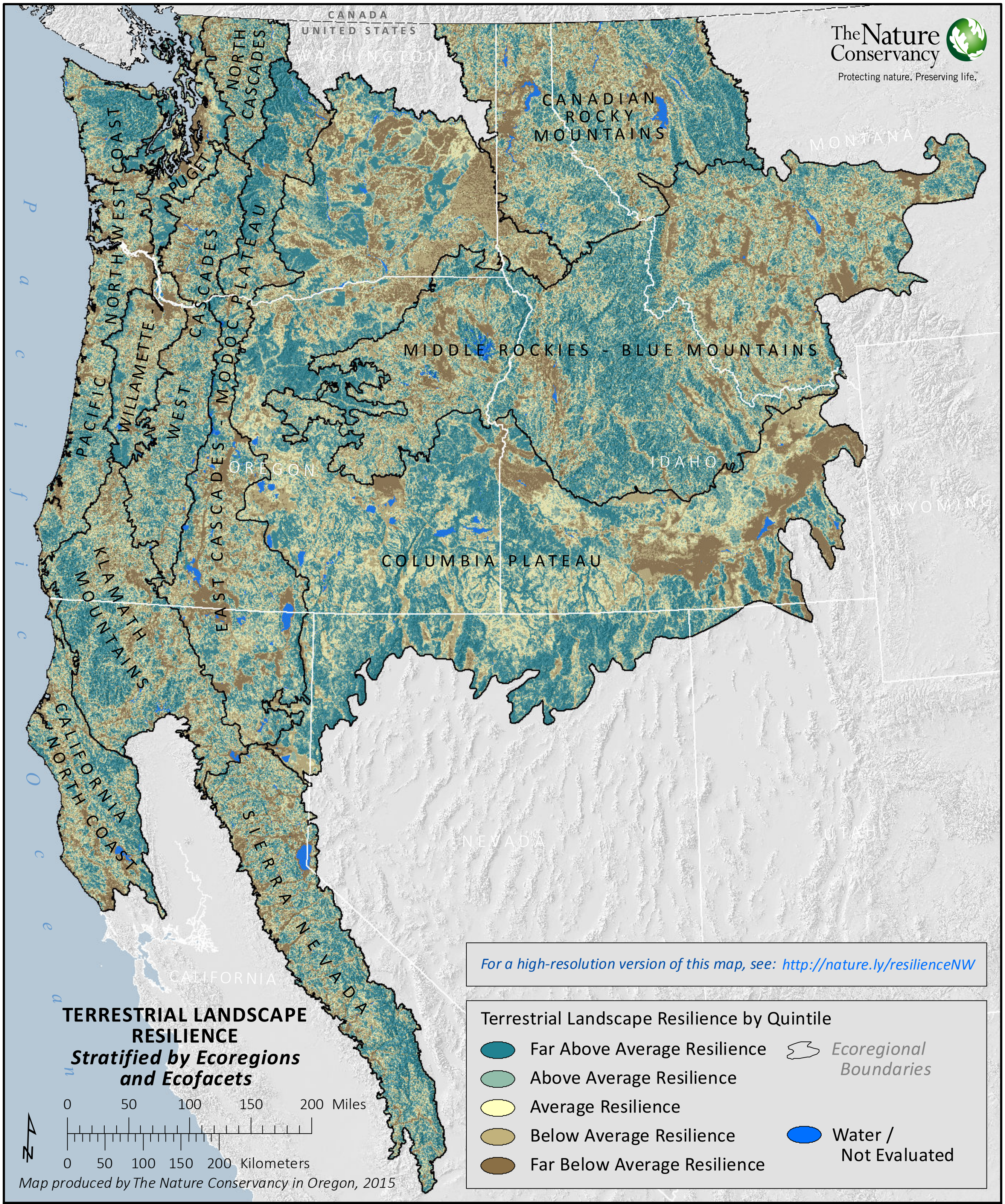


Figure 8.3 Terrestrial Landscape Resilience, Stratified by Ecofacet. This figure depicts the resilience scores stratified by ecofacet - each cell is only compared to other cells within the same ecofacet.

By contrast, low-relief landscapes, such as broad intermountain basins, tended to score in the lower resilience quintiles in the ecoregional stratification, suggesting that these areas were less resilient than other areas in the ecoregion. While these areas may be highly permeable, the adjacent mountains and canyons are also permeable, but have higher topoclimate diversity scores, placing them in the higher quintiles for the ecoregion. Consequently, the use of the ecofacet stratification was critical in identifying the more resilient examples of the land facets representing the low relief landscapes by allowing us to quantify and compare areas with flat slopes (0-6º) separately from those with moderate (6-18º) and steep slopes (above 18º).

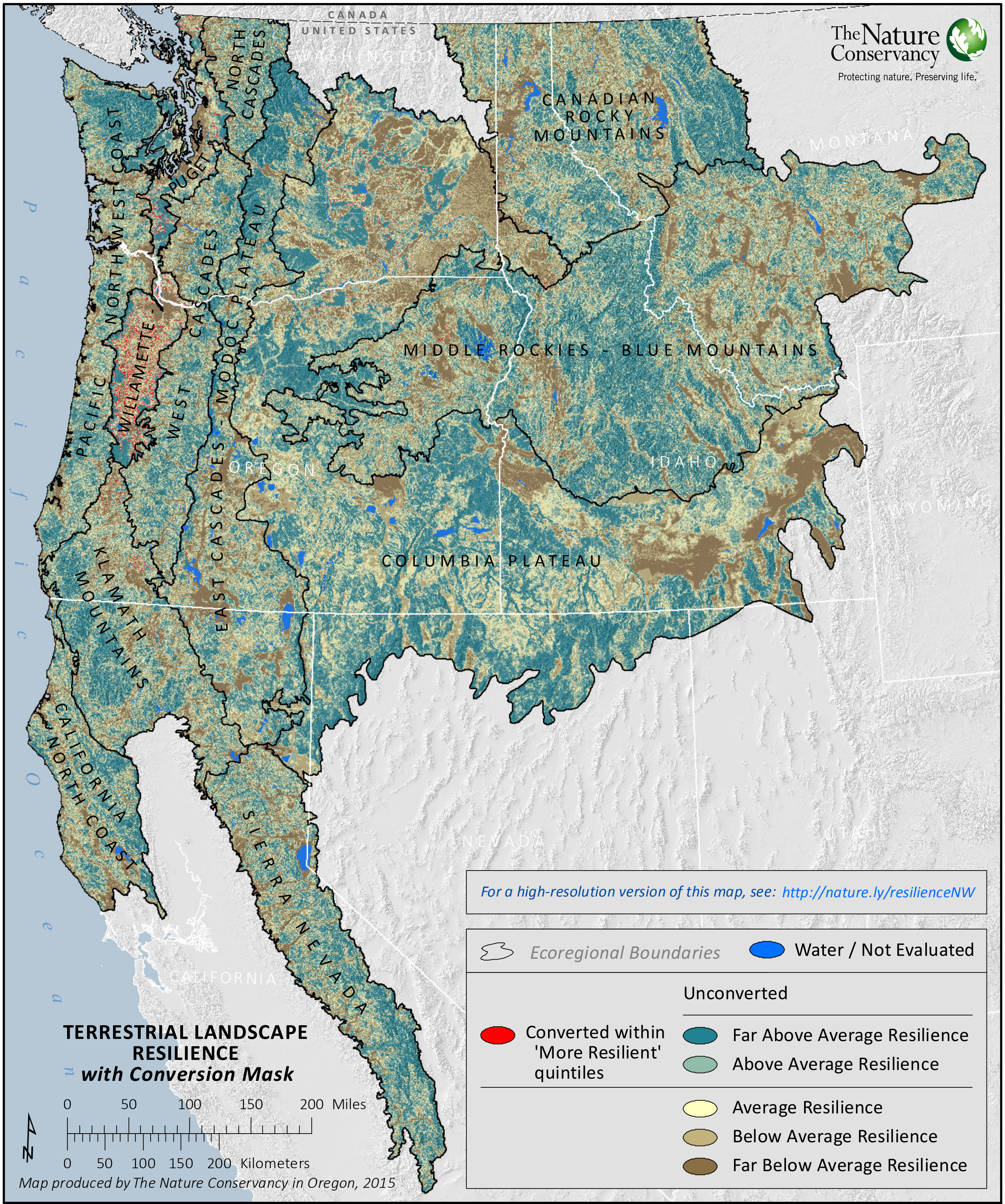
Calculated this way a cell will be more resilient if it falls in the top two quintiles of either the ecofacet or ecoregional stratification(Map 8.2). However, in some of the most developed and converted portions of our study area (such as agriculture in the Willamette Valley and northern Columbia Plateau), some cells which are already converted (especially those that are tilled) were in the “more resilient” categories. This was due to the fact that we were using quintiles, so by definition, 40% of the cells had to be in the top two quintiles. Therefore, we took a final step of identifying the 270 m land facet cells which NLCD data indicated were majority converted (all types of development, agriculture, and pasture/hay), and if those cells were previously identified as more resilient, we put them into a “majority converted class,” keeping in mind that they could be prioritized for restoration in the future. This accounted for a decrease of 1% in the total area of “more resilient” land facets in our study area, with the majority coming from the Willamette Valley – Puget Trough and Columbia Plateau Ecoregions. Accounting for this conversion, just over 50% the project area fell into the “more” resilient category (Map 8.3).

Map 8.2: Terrestrial Landscape Resilience, Stratified by Ecoregions and Ecofacets



This map depicts the resilience scores stratified by ecoregions and ecofacets, with the best score of the two retained as the final resilience score for each cell. These are the data used in subsequent analyses and prioritizations.

Map 8.3: Terrestrial Landscape Resilience, with Conversion Mask



In the Resilience Map Stratified by Ecoregions and Ecofacets (Map 8.2) the quintile statistical method places the same number of objects in each class. Because we used this method to derive our resilience classes, some non-natural areas within heavily converted Ecofacets (usually agricultural lands) have spilled into our “More Resilient” group. Only about 1% of our “More Resilient” hectares fall into this category.

The resilient areas shown on Maps 8.2 and 8.3 reflect the highest scoring cells within each ecofacet. We note that this is not an absolute measure of resilience to climate change. The map of unstratified resilience values (Map 8.1) shows that the highest absolute resilience scores are concentrated in the mountainous regions of the project area. Typically, the areas that scored more resilient in the flatter, low elevation ecofacets in the stratified map (Map 8.2) have lower absolute resilience scores (on Map 8.1) than their mountainous counterparts. It is important to note that all of these valuations are comparative; no absolute thresholds for resilience were identified. Rather, we chose to focus on those areas that are relatively more resilient when compared to other examples of their type. In this fashion we are identifying the most resilient examples of each stage, not simply the places with the most topoclimates and permeability regardless of soils, hydrology, etc.

We emphasize that these analyses are based on attributes that we believe are predictive of site resilience and that are of appropriate resolution to be used at a regional scale. The scientific community has a limited understanding of how climate-induced changes will play out within a landscape and influence the interaction of species on the ground. By conserving representative examples of all types of land facets and using site resilience criteria to inform conservation action, we may be able to expand the variety of species conserved and increase the odds of their persistence over time.

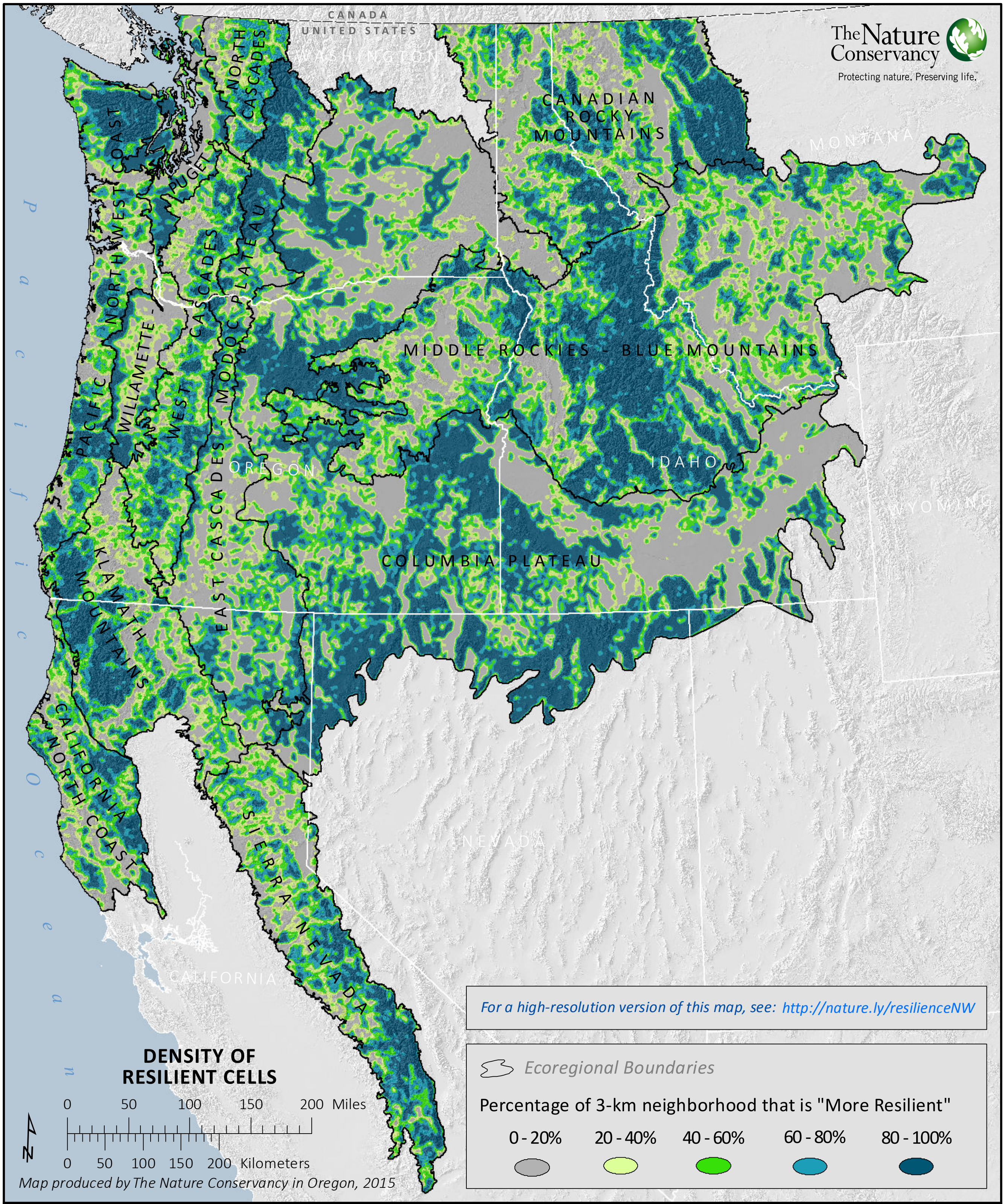
Density of Terrestrial Resilience

The individual cell-based stratifications are helpful, but a broader perspective can be attained when resilient areas are considered in context with each other. Our final way of describing terrestrial resilience is a neighborhood characteristic, i.e. the score represented in each cell on the map describes the entire area encompassing the cell, not just the cell value itself. This approach allows us to use these same core datasets in another way - to identify cells as resilient based upon the topoclimatic variation and terrestrial permeability of the landscapes in which they are embedded. Using these data without this broader perspective could result in conservation resources being expended in small, isolated islands of resilience that cannot support species over time.

To quantify resilience at this larger scale, we used a density function, where all cells classified in the final top resilience quintiles (Map 8.3, i.e. those which are “more” resilient and not predominately converted) were included in the density calculations, regardless of their underlying ecofacet, and all other cells were ignored. Looking out across a circular 3 km neighborhood from each resilient cell, we calculated the proportion of cells within that neighborhood that are “more” resilient. Neighborhoods with a higher proportion of resilient cells have higher density values than neighborhoods with lower proportions. These areas of high density occur in patches of varying size. As both patch size and density score increase, so too does the likelihood that conservation actions may provide enduring benefits.

See Chapter 9 for a discussion of how these and other data can be used in setting conservation priorities.

Map 8.4: Terrestrial Landscape Resilience Density



This map depicts the density of "More Resilient" cells (top two quintiles from Map 8.3) within a 3-km radius of every cell. This provides important additional context when making land protection or restoration decisions. Cells with higher density values are embedded in a larger resilient landscape. These areas are more likely to support biodiversity and ecological function over time in a changing climate.

Using Resilience Data to Inform Conservation Planning

CHAPTER 9

As stated in Chapter 3, the goal of this project was to identify areas in the Pacific Northwest that will, both individually and collectively, best sustain native biodiversity, even as the changing climate alters current distribution patterns. We believe that this information will provide a valuable guide for future conservation investment. This chapter looks at different ways the products of this assessment might be used to accomplish this goal.

Appropriate Use

There are, of course, limitations to the use and interpretation of these data. Maps are produced at a resolution of 270 square meters, but conservation planning decisions should not be made at this scale. The scale of the geophysical data used to derive land facets was at times very large, 1:250,000 in the case of STATSGO soils data. These data should be used with these scale issues in mind.

In addition, we need to emphasize again that this is an assessment of terrestrial resilience. Aquatic resources such as rivers and lakes should not be evaluated with these data. Near-shore marine areas including estuaries and small islands should also not be evaluated with these data, as tides, oceanic climate and sea-level rise may confound analyses built upon terrestrial data inputs and assumptions.

Land Facets as Surrogates for Biodiversity

In regions lacking high-quality biodiversity data, planners may be able to use geophysical data as a surrogate. Anderson and Ferree (2010) showed that, in the northeastern United States, states with high geophysical diversity also supported high species biodiversity. This relationship between geophysical diversity and biodiversity should apply not only to existing conditions, but also future conditions under a changing climate. Developing a portfolio of sites that includes dispersed and representative examples of resilient sites for each land facet may be a good first step at protecting biodiversity into the future.

In North America, biodiversity data are available from Natural Heritage Programs and other sources, and have been assessed and summarized through the ecoregional planning process. When biodiversity data are available they should be used with the resilient landscape results to help ensure that sites selected for conservation attention are not only of above average resilience, but also important for existing biodiversity. When conserving nature’s stage we should also make sure we have included the full suite of actors.

Representation of Land Facets and Resilient Areas in TNC's Portfolio

The ecoregional planning process described in Chapter 4 is a key component for ensuring the selection of resilient, biodiverse sites. The Nature Conservancy has completed ecoregional assessments for each of the eleven ecoregions within the project area. The purpose of an ecoregional assessment is to identify an efficient suite of conservation sites (the conservation portfolio) that will contribute to the survival of all viable native plant and animal species and ecological systems/natural communities in the ecoregion.

A number of analyses can be done using resilience data to both prioritize conservation activity within the existing biodiversity-based portfolio and to modify that portfolio to include a representative suite of resilient ecofacets.

Once our terrestrial resilience data were completed, the first question we asked was, "how well does our existing biodiversity-based portfolio capture resilient[1] occurrences of ecofacets?" For each ecofacet, and its resilient examples, we set a 30% inclusion goal. In other words, we identified those ecofacets that have at least 30% of their total area within the existing portfolio. We also identified those ecofacets that have at least 30% of their more resilient portions within the existing portfolio.

The 30% goal is based on species-area curve relationships used in each of our ecoregional plans and described by Groves (2003). Species-area curves show the relationship between the percentage of habitat loss and the percentage of the number of species likely to be remaining after that habitat loss. Based on this curve, ecoregional assessments set coarse-filter conservation goals of 30% of the existing extent of each community to capture between 80 and 90% of all species. If we consider ecofacets to be an additional coarse filter, setting a 30% goal for each is reasonable.

We overlaid the existing portfolio sites and ecofacets and found that, as a whole, ecofacets and resilient examples of them were well represented in nine of the eleven ecoregions; 79% of all ecofacets met a 30% goal and 81% met the 30% goal for resilient ecofacets (Table 9.1). All ecoregions except the Columbia Plateau and Sierra Nevada had at least 75% of their ecofacets and 75% of the resilient examples of those ecofacets meeting a 30% goal. The Columbia Plateau recently had a partial update (Buttrick et al. 2014) that will result in a new portfolio in southeastern Oregon. The Sierra Nevada and Columbia Plateau results reflect the data available at the time (1999), and, for the Columbia Plateau, the fact that coarse-filter goals were set at only 10 to 20% for the ecoregion (as opposed to the 30% goal for the other ecoregions). Those two ecoregional portfolios also covered the lowest percent area of their respective ecoregions. The Canadian Rockies ecoregion did very well, even meeting most of the 30% ecofacet goals just with resilient examples (68%), but its portfolio also had the highest percent area of any assessment, covering 62% of the ecoregion. The Willamette Valley – Puget Trough portfolio

[1] We use the term "resilient" here to refer to cells that have been mapped as "above average" and "far above average" resilience relative to the range of resilience values for pixels within an ecofacet.

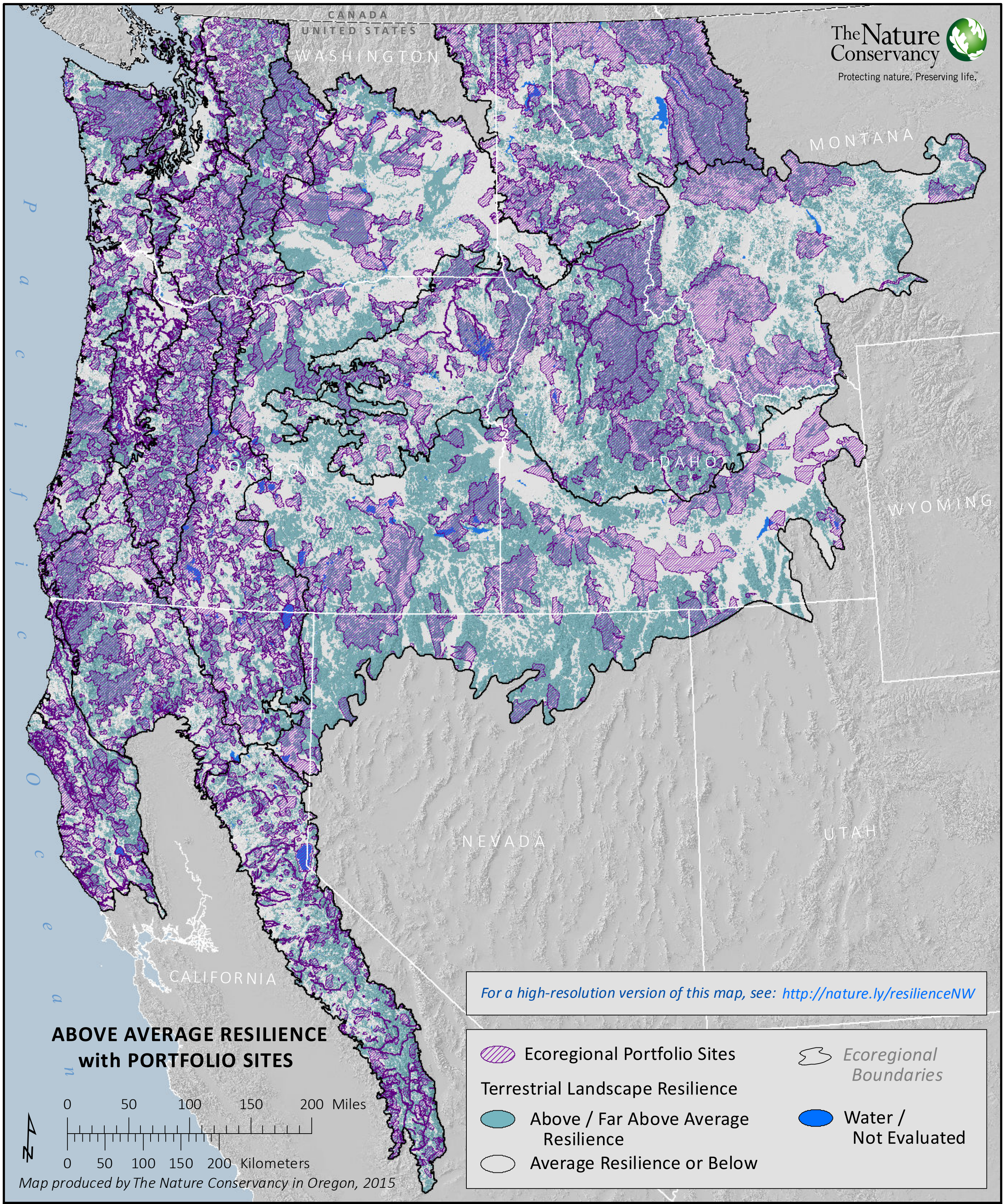
was very efficient for resilient pixels, meeting 30% goals for almost all the resilient ecofacets, and thus 84% of all ecofacets there had their goals met with just resilient pixels. Part of the reason for this is that the ecoregion is highly converted, and thus there are fewer resilient ecofacets (due to the lack of areas with high permeability), and the areas the assessment identified as being best for biodiversity are also those with high permeability scores in our analysis.

We can use the results of these calculations to identify both ecofacets, and above-average-resilience occurrences of ecofacets, that are underrepresented in our conservation portfolio (Map 9.1).

Table 9.1 The Nature Conservancy's portfolio capture of ecofacets and resilient examples of ecofacets. This table uses all portfolio sites as of 2012, and a benchmark of 30%. Appendix D lists the details for each ecofacet.

Ecoregions	Number of Ecofacets	% of Ecoregion in the Portfolio	% of Total Resilient Ecofacet ha that are in the Portfolio	# of Ecofacets with at least 30% of their area in the Portfolio	# of Ecofacets with at least 30% of their more resilient hectares in Portfolio	# of Ecofacets where the 30% ecofacet goal is reached with resilient ecofacets.
Canadian Rockies	60	62%	71%	60	60	41
West Cascades	92	57%	64%	88	90	51
East Cascades	88	48%	56%	77	79	50
CA North Coast	52	47%	52%	44	45	19
PNW Coast	50	45%	53%	42	45	24
Klamath Mountains	96	44%	52%	79	79	22
North Cascades	48	42%	45%	37	37	5
Mid Rockies/Blue Mtns.	86	39%	46%	74	75	50
Willamette V. - Puget T.	32	31%	51%	25	30	21
Columbia Plateau	76	27%	28%	52	51	30
Sierra Nevada	114	26%	28%	47	50	6
All Ecoregions	**794**	**38.5%**	**44%**	**625**	**641**	**319**

Map 9.1: Above Average Resilience and Ecoregional Portfolio Sites



This map depicts the upper two resilience categories (per map 8.2) with The Nature Conservancy's ecoregional portfolio superimposed. Note that the portfolio sites were selected to conserve both terrestrial and aquatic biodiversity.

Assessing the Resilience of the Existing Portfolio Sites

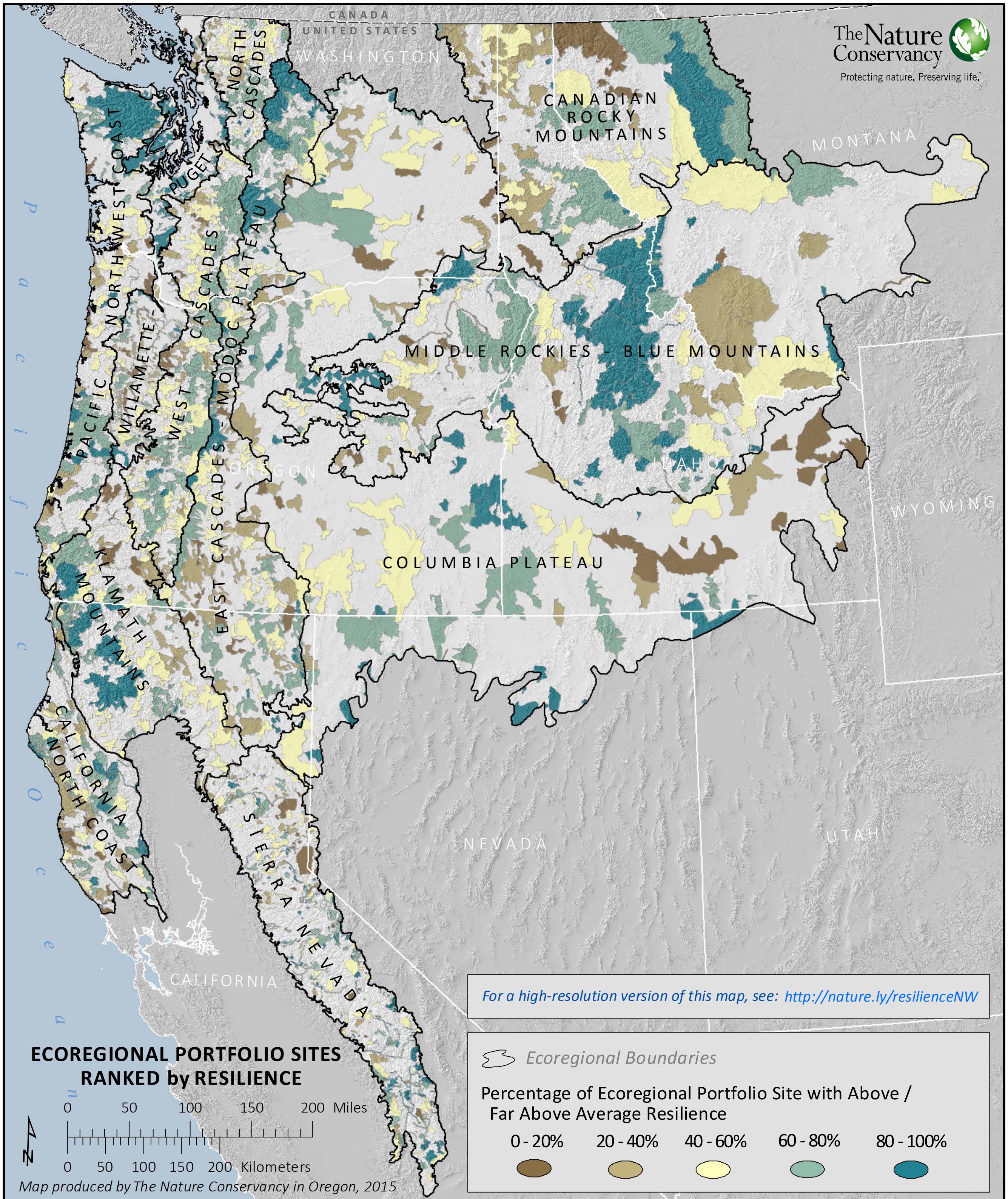
Because our terrestrial resilience methods are meant to identify those sites, for every ecofacet, that are most likely to retain species and ecological functions longer under a changing climate, it can be combined with biodiversity-based analyses to increase confidence in the importance of existing portfolio sites (Map 9.2, with a larger version accessible at the website for this project: http://naturel.ly/resilienceNW). It's important to note that these ecoregional assessments included all biodiversity – terrestrial, freshwater, coastal, and estuarine, so a terrestrial resilience filter or lens cannot tell the whole story. Some portfolio sites were also identified in part for their restoration potential, so those areas might not score well in the permeability analysis. There is more discussion regarding how to use the resilience and conversion information to identify restoration needs and opportunities later in this chapter.

Sixteen percent (293 sites) of the portfolio sites in the project area (totaling 3.4 million hectares) are at least 90% resilient, and 58% of sites (totaling 21.9 million hectares) are at least 50% resilient (Maps 9.1 and 9.2 and Appendix E). The results also help to identify portfolio sites of high biodiversity value but low resilience suggesting that we may want to find the same biodiversity values in more resilient landscapes.

Eight percent of all portfolio sites (totaling 1.2 million hectares) are under 10% resilient. Ecofacets (and portfolio sites containing those ecofacets) that are highly converted and have limited opportunities for additional protection of highly resilient ecofacets present an especially challenging situation. However, they likely include areas which have low permeability scores but are still restorable with increased effort (e.g., those classified as crops, hay, or pasture) and thus could be a priority for restoration and protection. Future work by The Conservancy on identifying priority sites and barriers to connectivity will help identify these for restoration.

The results might also encourage conservation planners to evaluate the biodiversity value of the ecoregion's most resilient landscapes that are underrepresented in existing conservation portfolios or plans.

Map 9.2: Ecoregional Portfolio Sites Ranked by Resilience



This map depicts The Nature Conservancy's ecoregional portfolio sites by the percentage of each that contains cells classified as "above average resilience" or "far above average resilience." See the high resolution online version of this map for site numbers and names.

Incorporating Resilience in Ecoregional Planning

Ideally, the development or update of an ecoregional plan or any conservation assessment would be done with an eye not only to biodiversity significance but also resilience to climate change. Including geophysical targets as well as biodiversity targets in an ecoregional plan is an effective and efficient way to increase the likelihood of conserving both present and future biodiversity. Chapter 8 in Buttrick et al. (2014) describes the process and results of updating the ecoregional assessment for the southeast Oregon portion of the Columbia Plateau, originally completed in 1999. Buttrick et al. (2014) incorporated land facets, and the more resilience occurrences of the land facets, as targets in addition to updated species and community occurrence data that have become available since 1999.

The conservation goal for coarse-filter targets (land facets, more resilient occurrences of land facets, ecological systems, freshwater habitats) was set at 30% for reasons described earlier in this chapter. Results showed that meeting all goals for the biodiversity targets required 39% of the land area. To meet all goals for all targets, biodiversity and land facets, required only 2% more area or 41% of the entire assessment area. The resulting portfolio met the 30% goal for all ecofacets with resilient examples of those types.

Finally, individual components of the resilience analysis might also be used as inputs to an ecoregional planning exercise. As mentioned above and in Chapter 4, the resistance data developed as a precursor to the permeability analysis could be used as one part of a suitability index. The resistance data would provide good estimates of the degree of conversion within each assessment unit. Similarly, the permeability data would provide good estimates of the local connectivity within each assessment unit, and connections to the local neighborhood of adjacent assessment units.

Prioritizing Land Facets: Incorporating Threat in Conservation Planning

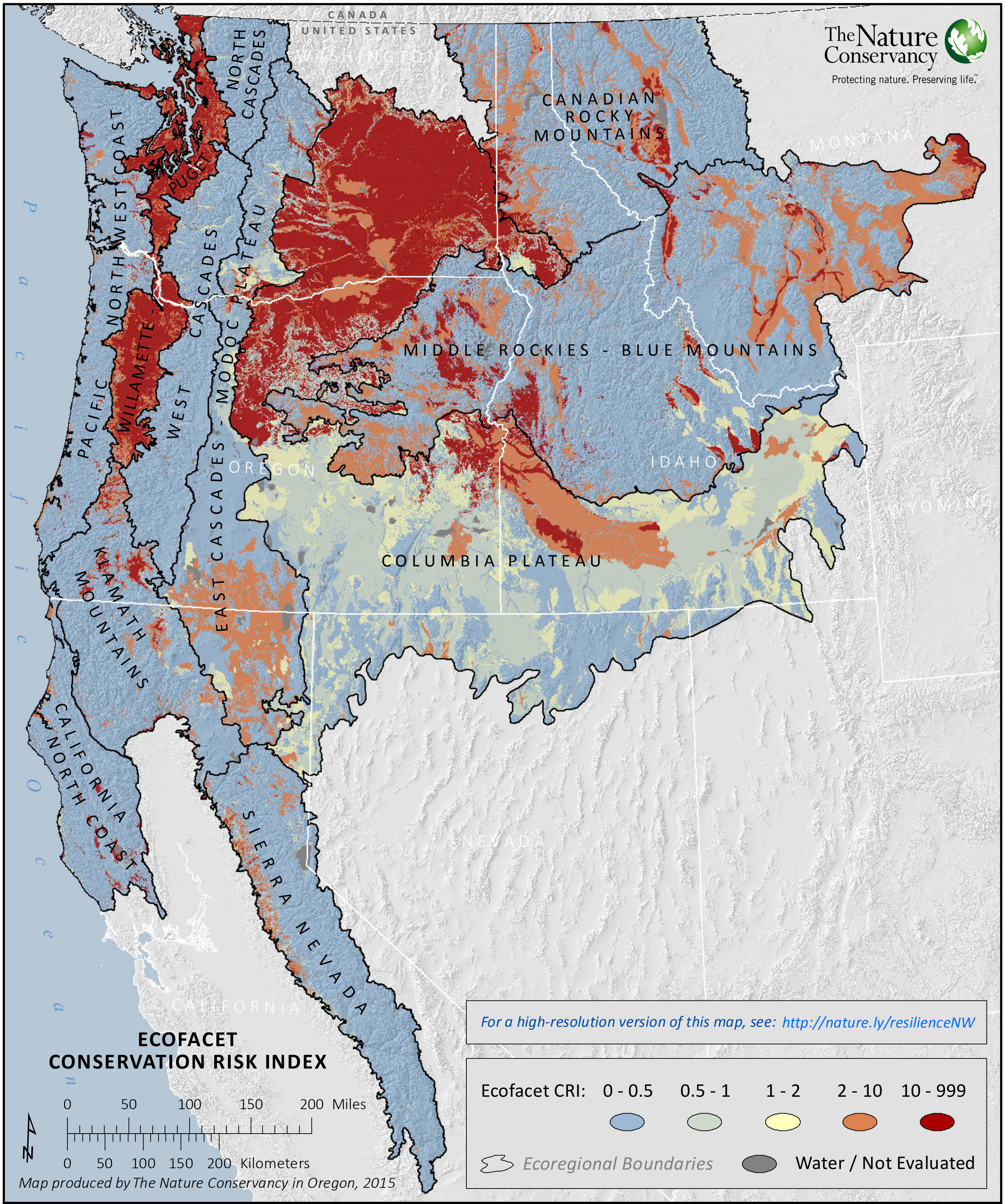
Focusing conservation resources on the most resilient sites is one approach to prioritizing conservation action. But, it does not address the *need* for conservation; it does not address how threatened a site or landscape is. Based on the geophysical characteristics of elevation, soil and slope, some ecofacets are more converted or under a greater threat of conversion than others. For instance, 54% of low elevation mollisols on level terrain have been converted to agriculture in our study area. Similar ecofacets at higher elevations are often at less risk of conversion and more protected than their lower-elevation counterparts.

We used an approach to rank and prioritize ecofacets based on levels of protection and conversion called a Conservation Risk Index (CRI; Hoekstra et al. 2005). Originally developed to assess the conservation risk of biomes, this index is the ratio of percent area “converted” to percent area “protected”. We used NLCD information on all developed classes, agriculture, and pasture/hay to estimate conversion (as in Map 4.1 and Chapter 7), and GAP status (Map 4.2) to estimate protection. When applied to ecofacets, a risk index greater than one indicates that more of that ecofacet is converted than protected. A risk index less than one represents more land protected than converted. We calculated CRI for two different levels of protection. First we considered all lands with GAP status of 1, 2 or 3 as protected. GAP 3 lands are primarily public lands managed for multiple use. Some may call these protected because they are unlikely to be converted to other uses, and the underlying geophysical factors defining the facet will remain intact even with natural resource extraction. We also calculated CRI using GAP status 1 and 2, a stricter definition of "protected", as GAP status 3 lands are not managed for biodiversity.

Map 9.3 shows CRI values based on GAP 1 and 2. If we consider an ecofacet with a CRI value greater than one as at high risk, 148 of the 794 ecofacets (or just under 19%) are at high conservation risk. The areas at the highest risk are those that have already experienced a high rate of conversion, particularly the Willamette Valley and lands around the Puget Sound, which are heavily populated. Areas with high levels of agricultural conversion in the Columbia Plateau also scored above 1 for CRI. Local planners will also want to examine areas in other ecoregions, all of which had at least some ecofacets at high conservation risk. See Appendix D (Ecofacet Descriptive Statistics) and the GIS data posted online for CRI scores for every ecofacet.

The CRI could allow planners to focus attention on those landscapes which have above average resilience and high conservation risk.

Map 9.3: Ecofacet Conservation Risk Index



A Conservation Risk Index (CRI) is calculated for each ecofacet and represents the ratio of the ecofacet area that is converted to the area of the ecofacet that is protected (GAP 1 or 2). If more land is converted than protected, the CRI is greater than 1. If more land is protected than converted, the CRI is less than one. The higher the CRI, the greater the conservation risk.

Resilience Density

The output of the resilience density analysis described and mapped in Chapter 8 can provide an especially intuitive framework for decision makers (Map 8.4). An NGO looking to conserve examples of a specific land facet might be faced with deciding between several locations where that facet occurs. In this case, they could use the density information to select the example that is embedded within a high (and perhaps large) concentration of resilient areas (regardless of ecofacet). This gives additional assurance that the investment will provide value over time and contribute to a larger whole. Similarly, a land management agency may use the density information to identify areas where long term terrestrial resilience to climate change is most likely, and within those areas, see where their other conservation priorities can be met. Doing conservation work in an area that is more likely to be resilient to climate change can be a value-added priority, whether the original purpose was protection of a single endangered species or restoration of riparian habitat.

Selecting Protection Priorities - an example

An approach that an NGO could take to develop protection priorities would be to calculate a CRI for the study area based on GAP 1 and 2 protection status. Focusing on the ecofacets that score greater than 1, they could select only the areas with above average resilience and overlay on them areas of important biodiversity (State Wildlife Action Plan priorities, Nature Conservancy portfolio sites, etc.). Looking at these resilient priority areas through a density filter would show how these at risk, resilient landscapes within important biodiversity-based sites fit into larger more resilient landscapes and map out areas within which to search for conservation opportunities.

Please visit the website for this project (http://nature.ly/resilienceNW) for updates to this Terrestrial Resilience project, including implementation tools and opportunities.

Data Products

CHAPTER 10

A great deal of data, both spatial and tabular, were created during the course of this project. Those data are included in a small suite of files available for download from http://nature.ly/resilienceNW along with any updates to this report. The files are broken into individual packets to decrease download times and to allow the user to select the pertinent information for their needs.

Report, Appendices and Maps

Three files are available which include:

1. The main report and written appendices.
2. The electronic appendices, in excel format –
    a. Range-wide descriptive statistics for each ecofacet, including the proportion of each by GAP protection category, landuse, etc.
    b. Statistics on the resilience characteristics of each TNC Portfolio site.
3. High resolution versions of the report maps, with additional geographic data and orienting features.

Scripts

Draft scripts, used for many of the geoprocessing tasks required for the analyses, are available as a downloadable file with the geodatabase. These are production scripts developed during the course of the project, not polished software certain to run on any machine, and should be viewed as merely a starting point for future software development. Those scripts include:

1. **0Duke_CA_Facet_Source_Layer_Prep.py** – Derives elevation and slope classes for our land facet classification from 1 arc second DEMs. Calls functions contained in Duke_CA.py module.
2. **1Duke_CA_PNW_EcoFacets_x_Condition_x_GAPSts.py** – Creates land facets, ecofacets, and calculates protection status and land use statistics for each facet/ecofacet. Calls functions from Duke_CA.py.
3. **Cti.py** – Calculates *Compound Topographic Index* from 1 arc second DEMs.
4. **Duke_CA.py** – Module with set of functions called for processing steps in 0Duke_CA_Facet_Source_Layer_Prep.py and 1Duke_CA_PNW_EcoFacets_x_Condition_x_GAPSts.py.
5. **Hli.py** - calculates *Heat Load Index* from 1 arc second DEMs.
6. **NLCD_Duke.py** – Processes USGS NLCD data as a precursor to construction of the resistance surface.

7. **SSURGO_taxorder.py** – Builds soil orders for land facets from NRCS SSURGO data.
8. **STATSGO2_taxorder.py** - Builds soil orders for land facets from NRCS STATSGO2 data.
9. **traverse_BHM.r** – This script is written in 'R', implements the *traversability* algorithm across an area.

In addition to these scripts, the *Resistance and Habitat Calculator of Gnarly Landscape Utilities* (McRae et al. 2013) can be downloaded from: http://www.circuitscape.org/gnarly-landscape-utilities.

Geodatabase

The File Geodatabase, 'PNW_RESILIENCE_20150201.gdb' is available in a 15 GB zip file that also includes the 'PNW Scripts' folder at http://nature.ly/resilienceNW.

The processing steps used to derive many of these datasets are described in *Appendix C: GIS Methods*. Each of the datasets listed has extensive metadata describing how it was derived, attribute definitions, etc.

The following is a comprehensive list of the data included in the geodatabase.

CTI_ALL_ECOREG - CTI is a steady-state wetness index. As a function of slope and upstream contributing area, CTI is a metric similar to Topographic Convergence Index (TCI), wherein the former measures slope by its tangent and the latter calculates slope by percent rise (Wolock and McCabe 1995). CTI has been shown to have a strong correlation with many soil properties, including depth, texture, organic content and moisture (Gessler et al. 1995; Moore et al. 1993; Evans 2011). Smallest CTI values are typically found along ridgelines and largest values in valley bottoms and basins with large contributing areas.

We calculated Compound Topographic Index as an approximation of relative, local soil moisture. This is a smoothed (Low Pass filter) version of the raw geoprocessing output.

CTI_FOCAL_NORM - Using 'CTI_ALL_ECOREG' as the input, a focal statistic, 'Range', was calculated for each 15 cell circular neighborhood. This range was then standardized from 0 - 1. These standardized data were then used in the final calculation of topoclimate diversity.

ECO_RAST_ALL_ECOREG - These data are a 270m raster representation of the ecoregions that are the primary stratification and reporting units for the PNW Climate Resilience Project. This version includes portions of ecoregions that were added to satisfy the data needs of additional partners after the project began.

ECOFACET_ALL_ECOREG - These data represent a land facet classification created for the PNW Climate Resilience Project. Each Land Facet has been stratified by terrestrial ecoregions -

essentially defining each combination of soil order, elevation zone and slope class as unique from that same combination in another ecoregion. Most of the ecofacet related statistics included in the report are derived from attributes in the raster tabular data.

ECOFACET_RESIL_QUINT_ALL_ECOREG - These data represent Ecofacets combined with resilience data. Each Ecofacet is attributed with its membership in both resilience stratifications (by ecofacet and by ecoregion as described in chapter eight of the report), as well as the highest value of the two stratifications.

ECOREGIONS_ALL_ECOREG - These data are a vector representation of the ecoregions that are the primary stratification and reporting units for the PNW Climate Resilience Project. This version includes portions of ecoregions that were added to satisfy the data needs of additional partners after the project began.

ESYST_LF_ALL_ECOREG – Existing vegetation, circa 2010, as mapped by LANDFIRE. These data are cross-walked to four existing vegetation classifications including NatureServe's Ecological Systems. We used the Ecological Systems when comparing facet distributions to vegetation patterns.

FACETS_ALL_ECOREG - Because species distributions are tightly correlated with physical characteristics of the land, especially geology and elevation, conserving a variety of geophysical settings, such as limestone valleys or granite summits, could offer a robust and efficient approach to protecting biodiversity under future climate scenarios (Anderson and Ferree 2010, Beier and Brost 2010). These data represent such a geophysical classification created for the PNW Climate Resilience Project. We call these combinations of geophysical factors 'Land facets'.

GAP_ALL_ECOREG - This is the final GAP Protection Status layer, based upon USGS PADUS data and modified by The Nature Conservancy for the PNW Climate Resilience Study. All TNC Lands, fee and easement, have been included and status codes for some features have been changed to better standardize the categories across the project area. In addition, this dataset has also been "flattened", such that only the highest protection status is retained in areas with overlapping management designations.

HLI_ALL_ECOREG - Heat Load Index(HLI) has been shown to relate well to evapotranspiration rates and soil temperatures and is a direct measure of incident radiation (McCune and Keon 2002; Evans 2011). Aspect is "folded" so that southwest facing slopes have higher temperatures than southeast facing slopes, and northeast facing slopes are the coolest. This method also accounts for slope gradient, where steep, southwest facing slopes tilted at latitudes (i.e., those receiving more tangential insolation) receive the highest HLI scores. The index can be applied appropriately anywhere in the mid-latitudes, from ~ 30º to 60º.

We calculated Heat Load Index as an approximation of relative, local temperature. This is a smoothed (Low Pass filter) version of the raw geoprocessing output.

HLI_FOCAL_NRM - Using ‘HLI_ALL_ECOREG’ as the input, a focal statistic, 'Range', was calculated for each 15 cell circular neighborhood. This range was then standardized from 0 - 1. These standardized data were then used in the final calculation of topoclimate diversity.

NLCD_ALL_ECOREG - These data are extracted from the 2011 National Land Cover dataset for the PNW Climate Change Resilience study area. These data were a principal component of the resistance surface that was the basis of our terrestrial landscape permeability surface.

PERM_90_ALL_ECOREG - These data are the final landscape permeability data developed for the PNW Climate Resilience project. Permeability refers to the connectivity of a focal cell to its ecological neighborhood when it is viewed as a source; in other words, it asks the question: “to what extent are ecological flows outward from that cell impeded or facilitated by the surrounding landscape?” Thus, permeability starts with a focal cell and looks at the resistance to ecological flow outward in all directions through the local neighborhood. As resistance increases, flow is impeded or stopped altogether. Areas of no resistance allow the flow to proceed until a user-specified maximum distance is achieved. Therefore, cells grow further in directions of low resistance. This process is repeated for every cell across the analysis extent, and the results are combined to create this final surface.

PORT_ALL_ECOREG - This Feature Class represents TNC's official ecoregional portfolio for the areas covered by the PNW Climate Resilience project. TNC's Ecoregional Portfolio Core Data Set was downloaded in June of 2013, and clipped to the PNW project area. Updates from neighboring states were obtained in cases where their portfolio modifications had not yet been incorporated to the core dataset. These updates were incorporated into this product.

Ecoregional Assessments are used to prioritize the places where The Nature Conservancy and our conservation partners should focus our work among the lands and waters in each ecoregion. They provide information that can help guide conservation strategies and help assess the value of conservation actions, including spatial "portfolios" of recommended conservation areas that are aggregated into this data set.

RESIL_90_ALL_ECOREG - We have defined resilience as a function of both a site’s diversity of topoclimates and the site’s ability to support species movement, or terrestrial landscape permeability. Here, we posit that topoclimates provide species localized refugia from the direct effects of a changing climate, whereas landscape permeability reflects the ability of the landscape mosaic to facilitate terrestrial species movement to and between topoclimates as they shift in response to their respective climatic envelopes.

90 m topoclimate data, scaled from 0.2 – 1, were multiplied with terrestrial landscape permeability data, scaled from 0 – 1, to generate a resilience value for every 90 m cell across the project area.

A 270m resolution version of this data is also included; ‘RESIL_270_ALL_ECOREG’.

RESIL_DENS_ALL_ECOREG - Resilience, as calculated for the PNW Climate Resilience Project, is a neighborhood characteristic, i.e. it is a description of the area encompassing a cell, not of the cell itself. We have identified cells as resilient based upon the topoclimatic variation and permeability of the landscapes in which they are embedded. Using these data without a broader landscape view could result in conservation resources being expended in small, isolated islands of resilience that cannot support species over time.

To quantify terrestrial landscape resilience across the broader landscape, we used a density function, where hectares (cells) classified in the top resilience quintiles (i.e. those which are “more” resilient) were included in the density calculations and other hectares were ignored. We used a 3 km radius for the density calculation; however, the radius could be modified to evaluate resilience at multiple spatial scales. Higher density areas are those which contain a higher number of “more resilient” hectares, and represent portions of the landscape which we would expect to be more resilient to climate change.

RESIST_90_ALL_ECOREG - The resistance surface is the basis for the landscape permeability analysis and has a great deal of influence on the final terrestrial landscape resilience scores. As such, great pains were taken to make this dataset as reflective of actual ground condition as possible. Each dataset used was evaluated at several locations, and multiple draft versions of the resistance surface were produced until reviewers were satisfied with the data.

Each cell has been assigned a value, or weighting, representing its hardness/ impermeability to species movement and ecological flows. Higher values are more difficult to cross, while lower values are easier. Natural lands are assigned a value of 1, meaning the cost to move across the pixel is equal to the Euclidean distance, allowing relatively free flow of ecological processes at that location.

Some of the data used in the creation of this surface are proprietary. We cannot, therefore, release those datasets as part of this data package. They are described under the ‘Data Sources’ portion of the metadata document for the resistance surface.

TOPOCLIMATE_ALL_ECOREG - These are the topoclimate diversity data developed for the PNW Climate Resilience Project*.* They are a focal statistics output (450 m radius from each focal cell), describing the range of temperature and moisture settings within the neighborhood. These data are scaled from 0.2 - 1.

Glossary

Assessment unit or AU: The area-based polygon units used in the optimal site-selection algorithm Marxan, and attributed with the conservation suitability and amount of all targets located within each AU. Most assessments in the Pacific Northwest used 12 digit, 6th field hydrologic units.

Biodiversity: The full range of natural variety and variability within and among organisms, and the ecological complexes in which they occur. This term encompasses multiple levels of organization, including genes, subspecies, species, communities, and ecological systems or ecosystems.

Biological richness: The number of different biological species represented .

Cell: We use cell as synonymous with pixel and is our unit of mapping. We used cells that are 270 meters on a side to map resilience values.

Climate envelope: The range of climatic conditions suitable for a species which may be used to predict its current and future distribution.

Coarse filter: Traditionally the coarse filter is the set of communities, ecological systems, or habitats which often include modeled data, and are mapped across the study area. For this project we added land facets as a coarse filter.

Compound Topographic Index (CTI): A steady state wetness index, quantified as a function of slope and upstream contributing area, providing a measure of soil moisture potential. Calculated from a digital elevation model (DEM) with the Geomorphometric and Gradient Metrics Toolbox (Evans 2011). CTI is combined with HLI to estimate microclimatic diversity.

Conservation targets: Elements of biodiversity (plants, animals, ecological systems) that are used in Ecoregional Assessments to represent the full range of biodiversity in an ecoregion, and which are considered when defining goals which are used to prioritize areas for conservation. In this report, we added Land Facets to the target list.

Cost: A component of the MARXAN algorithm that encourages MARXAN to minimize the area of the portfolio by assigning a penalty to factors that negatively affect biodiversity, such as proximity to roads and development. In the SE Oregon Columbia Plateau assessment, costs were assigned to each assessment unit in the planning area. Used synonymously with “suitability,” which is actually the inverse of the cost.

Conservation portfolio: See Portfolio

Distribution: In ecoregional assessments, distribution is thought of relative to the ecoregion and used as a guide to establish numeric differentials in goal setting (higher with endemic species, to lower with peripheral species).
Endemic = >90% of global distribution in ecoregion
Limited = <90% of global distribution is within the ecoregion, and distribution is limited to 2-3 ecoregions
Disjunct = distribution in ecoregion quite likely reflects significant genetic differentiation from main range due to historic isolation; roughly >2 ecoregions separate this ecoregion from other more central parts of its range
Widespread = global distribution >3 ecoregions
Peripheral = <10% of global distribution in ecoregion

Ecofacet: The combination of a land facet and an ecoregion. We stratified land facets by ecoregions, creating 298 ecofacets over the four ecoregions.

Ecofacet resilience: The range of resilience values for all pixels within an ecofacet. We selected the top two 5ths of all pixels as more resilient.

Ecological flow: The movement of species and ecological processes between two cells and across the landscape.

Ecological system: *A group of plant community types (associations) that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients* (Comer et al. 2003). For this project, only Terrestrial ecological systems are considered.

Ecoregion: A large area of land with similar environmental conditions, especially landforms, geology and soils. At a continental scale, an ecoregion has a distinct assemblage of natural communities and species. As defined by Bailey (1995) and modified by TNC.

Ecoregional Assessment: A conservation planning method and product which identifies geographic priorities based on the status of biodiversity, habitat condition, threats, and conditions in an ecoregion.

Ecoregion resilience: The range of resilience values for all pixels within the ecoregion. We selected the top two 5ths of all pixels as more resilient.

Element occurrence (EO): A term originating from the methodology of the Natural Heritage Network that refers to a unit of land or water on which a population of a species or example of an ecological community occurs.

Fine-filter: Species of concern or aggregations that complement the coarse filter data and targets, helping to ensure that a conservation portoflio adequately captures the range of viable, native species and biological communities. Endangered or threatened, declining, vulnerable, wide-ranging, very rare, endemic, and keystone species are some potential fine filter targets.

Fragmentation: The degree to which landscapes are increasingly subdivided into smaller units, resulting in increased insularity as well as losses of total habitat area.

GAP status code: GAP refers to the USGS National GAP Analysis Program which characterizes land ownership and stewardship on public lands in to 5 GAP status codes:

1 = Managed for biodiversity - disturbance events proceed
2 = Managed for biodiversity - disturbance events suppressed
3 = Managed for multiple uses, including resource extraction
4 = No known mandate for protection (primarily Tribal or Military lands)
0 = Private lands with no PADUS protection status

Geophysical diversity: The degree of geophysical variation represented

Geophysical features: Characteristics used to describe the earth's surface, including topography, geology, and soils

Geophysical setting: See Land facet

Goal: As used in in ecoregional assessments, a numerical value associated with a species or system that describes how many element occurrences (for species populations) or how much area (for modeled and coarse filter targets) the portfolio should include to represent each target. Goals are often stratified by sections within a planning area to better represent genetic diversity and hedge against local extirpations. **30% goal:** We set a representation goal of 30% for most coarse filter targets, including each ecofacet and the resilient examples of it.

Heat Load Index (HLI): A measure of direct incident radiation which relates to evapo-transpiration rates and soil temperatures. Calculated from a digital elevation model (DEM) with the Geomorphometric and Gradient Metrics Toolbox (Evans 2011). HLI is combined with CTI to estimate microclimatic diversity.

Habitat: A group of ecological systems, combined based on the plant associations and communities that make up the ecological systems.

HUC6: A 6th field, or 12 digit Hydrologic Unit, as mapped by the USGS's National Hydrography Watershed Boundary Dataset. We used these as the basis for our planning units in most Ecoregional Assessments.

Land facet: Land facets are geophysical units that we have defined by soil order, elevation zone and slope that repeat across the landscape. The combination of these three geophysical features creates 162 different land facets within the PNW Terrestrial Resilience study area. Land facets are also referred to as 'geophysical setting' or the 'stage'.

Local Permeability: *The degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, will sustain ecological processes and are conducive to the movement of many types of organisms* (Meiklejohn et al. 2010). Local permeability is also referred to as 'Connectivity'.

Landscape Resilience: See Resilience

Marxan: Marine Reserve Design Using Spatially Explicit Annealing. Software consisting of computerized optimal site selection algorithms that select conservation sites based on their biological value and suitability for conservation. This tool is used to select draft portfolios in Ecoregional Assessments. URL: www.ecology.uq.edu.au/marxan.htm

Microclimate: Local area temperature and moisture patterns, affected by topography, vegetative cover.

Topoclimate Diversity: The amount of variation in local climates represented. Quantified by combining Compound Topographic Index (CTI) and Heat Load Index (HLI).

Occurrence: Spatially referenced locations of species or systems. May be equivalent to Natural Heritage Program element occurrences, or may be more loosely defined locations of targets, like an example of a land facet.

Permeability: see Local Permeability

Permeable landscape: A permeable landscape is free of barriers to species movement and/or ecological flows – a landscape in a semi-natural condition. Human modifications to the landscape, including agriculture and development, decrease permeability.

Pixel: The unit of mapping, as in a raster file. We used pixels that are 270 meters on a side to map ecofacets and resilience values.

Portfolio: Areas prioritized for conservation by an Ecoregional Assessment

Resilience: A measure of the degree of opportunities provided for *species within an* area to respond to changes in temperature and moisture (changes in climate). In this report we quantified resilience by combining the degree of topoclimate diversity and local permeability of the area. A resilient system is one that allows adaptive responses by species and is less likely to change its species composition.

Resilience value: A combination of local topoclimate diversity and landscape permeability assigned to each pixel that ranks it as more or less resilient.

Resilient Cells: Cells (or pixels) that fall in the top two 5ths of all cells within an ecofacet (ecofacet resilience) or an ecoregion (ecoregion resilience) based on their resilience values. These are also referred to in the report as cells or ecofacets that are “more resilient” or ones with “above average” resilience.

Resistance: The degree to which movement of organisms to nearby areas is impeded by dissimilar structural characteristics and condition of the surrounding landscape. Resistance is modeled as a raster surface where each cell is given an integer value (resistance weight) ranging from 1-20, with 20 assigned to cells representing areas most converted from natural condition (most developed).

Resistant Kernel: Refers to both a software algorithm, and the method used in the algorithm, to model local permeability for each cell in an input raster using supplied resistances (Compton 2012). A permeability score ranging from 0 to 1 is computed for each pixel, where0 represents the least permeable areas and 1 the most permeable areas.

Site resilience: see Resilience

Suitability: see Cost

Target(s): see Conservation Target

Terrestrial ecological system: see Ecological system

Topoclimate: Topoclimate (Thornthwaite, 1953) refers to local temperature and moisture conditions that result from underlying topographic properties such as slope, aspect, landform shape, elevation, etc. Topoclimate is an important component of the climatic conditions an organism might encounter at a given location. We consider “microclimate” to include the local effects of vegetation cover. Topoclimate is an enduring property of the landscape, and has a profound influence on the potential species which might inhabit a specific locale.

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Appendix A: Lessons Learned and Changes from 2014

As with any complicated project, methods and data evolve over time. In this case, ideas for modifications began after publication of the phase 1 PNW Resilient Landscapes project (Buttrick et al 2014) in March of 2014. Key GIS tools and datasets were updated around that time, including USGS' *2011 National land Cover Dataset* and modified scripts to calculate *Heat Load Index* and *permeability*. Also, we realized that our methods and goals were more aligned with using "topoclimate diversity" as the term to describe the diversity of habitats created by topographical variation in a local neighborhood, rather than "microclimate diversity," as used in the 2014 report. Microclimate measurements can be interpreted as including current local temperature measurements, which are influenced by existing vegetation. We are interested in the diversity of microclimates regardless of the existing vegetation (since vegetation will change over time as the larger climate changes), thus "topoclimate" is the more appropriate term.

A second major realization, which drove many of our methodological changes, occurred when reviewing draft permeability surfaces for the western project area. The western ecoregions are more modified and parcel sizes are smaller. Our draft permeability surface, based upon the resistance weightings we had used for the sparsely populated eastern ecoregions, made obvious some ramifications of our earlier decisions that had gone unnoticed in large expanses of semi-natural landscape. Modifications were therefore proposed to our base resistance surface. Those included:

- *Block Housing Density* (BHD) data was clipped to private lands. Population densities are low enough in the eastern ecoregions we hadn't noticed that many of the BHD polygons overlapped with public lands, erroneously increasing their resistance.
- Resistance values were reduced for some of the Block Housing Density classes to be more representative of actual densities in those classes, particularly 'Rural Low' and 'Rural'. Most of the land within those classes is, in fact, semi-natural.
- We did not "expand cells" for minor roads, as that overestimated impacts from logging roads and other lightly used routes. Areas adjacent to those roads may be ecologically degraded, but they do not present a hard barrier to terrestrial species movement.
- We reduced the resistance values for all roads **except** Interstates and State/Local Highways, as the majority of those roads were lightly travelled and our previous resistance values overestimated their impacts.
- We slightly increased the resistance values assigned to "Pasture/Hay" and lowered "Cultivated crops" to make them more similar, as these are poorly differentiated in NLCD.
- "Open water" was broken into more classes representing distance to shore to allow for a more gradual ramping up of values as distance from shore increased.

The full list of resistance value changes are shown below in Table 1. Also refer to Chapter 7 and the GIS Methods Appendix for more information on resistance and permeability.

Other resistance input data were also modified. Almost immediately after publication of our results from the first phase of this project for the eastside ecoregions, the USGS released an update version of NLCD reflecting ground conditions circa 2011. This dataset was subsequently used as the basis for our phase 2 resistance surface.

The first of several scripts written, or modified, to assist with this project was used to pre-process the NLCD data. This script performed a "shrink" function on the "Developed" classes to remove linear development features such as roads, and replace them with the class that is most frequent in their immediate neighborhood. Another departure from the previous work was that shrunken pixels were assigned the average of their pre- and post-processing resistance values. This step acknowledged that narrow strips of developed pixels represented human modifications of some sort, even if they were misclassified. It was agreed that this better represented the impacts of those pixels than merely giving them the value of the surrounding pixels. The script also created the "distance from shore" open water classes, in 30m bands, allowing us to easily modify resistances of different distance bands.

Road data, too, were scrutinized quite heavily. One consistent critique of the first phase results was that road resistances were over estimated. The road data we had used, though widely considered the best available, included many dirt routes which were barely used, if at all. We therefore evaluated several road datasets, and selected the dataset with the most realistic depiction of active roadways for every subset of each project area. The full list of those datasets can be found in the GIS Methods Appendix. Railroads were similarly treated.

Table 1: **Changes in resistance weightings between Phase 1 (East) and Phase 2 (West).**

Data Layer	Class Description	East Side	West Side
BHD2010	Residential - rural low (0.001-.0.006 dua)	2	1.2
BHD2010	Residential - rural (0.006-0.025 dua)	2	1.5
BHD2010	Residential - exurban low (0.025-0.1 dua)	3	2.5
BHD2010	Residential - low (0.4-1.6 dua)	9	7
BHD2010	Residential - med (1.6-10 dua)	20	16
NLCD	Open Water , 0 -210m	1	NA
NLCD	Open Water, 210 - 420m	3	NA
NLCD	Open Water, > 420m	5	NA
NLCD	Open Water, 0 – 90m	NA	1
NLCD	Open Water, 90 – 180m	NA	2
NLCD	Open Water, 180 – 270m	NA	3
NLCD	Open Water, 270 – 360m	NA	4
NLCD	Open Water, >360 m	NA	5
NLCD	Pasture/Hay	3	4
NLCD	Cultivated Crops	8	7
RAIL_ACTIVE	Abandoned lines based on inspection[1]	NA	3
TIGER_ROADS	Roads on public lands	5	NA
TIGER_ROADS	City and rural streets (California and Nevada)	9	3
ROADS – BLM	ALL BLM roads, no distinction for road class	NA	3
ROADS – USFS	All USFS roads, no distinction for road class (CA and NV)	NA	3
ROADS – CA THP	All active California Timber Harvest Program roads (CA)	NA	3
ROADS – CA THP	Proposed and Abandoned CA Timber Harvest Program roads[2]	NA	1.5

[1]Based on visual inspection these typically have new uses, such as dirt roadways.
[2]Based on visual inspection these are often in use. Resistance score reflects likelihood of impacts.
'NA' indicates the input data, or data class, was not used in that phase.

New snapshots of the Ventyx EV Energy infrastructure data were obtained, and GNARLY tools were once again used to compile the resistance layer from the full suite of inputs. Permeability results obtained from these modified data appeared much more reflective of ground conditions to our reviewers.

The creation of the permeability surface in the phase 1 work was contracted to University of Massachusetts. The 'Permeability' routine is very computationally intensive, and exceeded the capabilities of our desktop computers. The results obtained from UMass also required post-processing to assign permeability scores that included permeability of the focal pixel. For the phase 2 work, Brad McRae modified the permeability script to deal with this post-processing, and was able to successfully create permeability surfaces for subsets of the project area in house. We therefore split the project area into tiles, analyzed each independently, and re-assembled the tiles for a continuous permeability surface. One limitation with this script, however, is that it must be run on computers with ArcGIS 10.0 installed. Running permeability analyses in-house allowed us to use a more iterative approach, creating draft products and revising them based on review.

These results were then compared to the phase 1 results along the overlapping buffer region between the two project footprints. The differences were so stark it was quickly agreed that the resistance and permeability data for the phase one ecoregions would need to be redone. This entire process was therefore repeated for the full phase 1 project area for this 2015 report. This change also necessitated revisiting the other processing steps for phase 1 to ensure the ultimate resilience information accurately reflected the improvements to the base data.

An additional lesson learned between the two phases involved resampling the native 1 arc second DEM. The native cell size of the DEM varies with latitude, and across our data extent averaged ~ 34m. We resampled those data to 30m to match our other data inputs, but noticed that process introduced striping artifacts into the resampled DEM. Those artifacts could potentially bias our topoclimate indices, so we changed the order of operations to minimize this issue. Rather than resample the native DEM and then calculate our topoclimate indices, we completed the full suite of topoclimate analysis before resampling the final topoclimate surface.

The script that calculates Heat Load Index (HLI) was modified after phase 1 and just before phase 2. An error was corrected in one of the script functions. This error had caused problems in our phase 1 analysis, requiring us to standardize each HLI tile before we could assemble a project-wide HLI surface. Comparing results from the new and old scripts did show small differences, enough that the team agreed that HLI should also be re-calculated for the phase 1 geography. Therefore, when we calculated our topoclimate indices for phase 2, we ran the indices across the combined phase 1 and 2 geographies. These outputs did not require standardization.

The methods to produce land facets didn't change, but finer-scale soils data (SSURGO) were incorporated into the west side facets. This is an improvement from the soil order mapping completed for phase 1, where the coarser STATSGO data were used. SSURGO data is not mapped wall-to-wall (though it is more complete for the western ecoregions), so STATSGO data were still used to fill data gaps. Another script was compiled to populate a soil order attribute to each polygon, using the NRCS component tables. One additional soil order and four additional non-soil classes ('non-natural, ' 'other natural,' 'glaciers,' and 'rock') were added to our west side facet classification as a result of the inclusion of the SSURGO data.

A script was written for the phase 2 analyses that used the final soil data, along with DEM, GAP protection status, ecoregional boundaries, land use and our landscape resilience information, to:

- Build land facets,
- Create ecofacets,
- Calculate the percent of each facet/ecofacet within each GAP protection category,
- Calculate the percent of each facet/ecofacet within converted lands,
- Calculates the resilience quintiles for each facet/ecofacet and for each ecoregion.

Though we did not modify the soils data for the eastside ecoregions from phase 1, we did run this script across the full project extent so that all statistics were calculated in the same fashion.

We added an additional reporting metric in phase 2. Using amount converted (NLCD data) and amount protected (GAP1 GAP2 and GAP3) we calculated a Conservation Risk Index (Hoekstra et al. 2005) for every ecofacet. This and other uses of the data are discussed in Chapter 9.

Appendix B: Selection of Land Facet Geophysical Factors and Category Breaks

This Appendix is revised from the "Methods" section in Chapter 4 of the 2014 Buttrick et al. report, and represents how decisions were made for the four eastside ecoregions. The same factors and category breaks were also used to develop land facets for the west side ecoregions in 2015.

Selection of Geophysical Factors and Categorical Breaks

Researchers in the West have variously used geophysical factors including elevation, slope, geology and soils to create geophysical units (Beier and Brost 2010). Unique combinations of geophysical factors have been called "geophysical settings," "land facets," and the "stage" (Anderson and Ferree 2010, Anderson, et al. 2012). Taking these previous approaches as our starting point, we evaluated how well various geophysical factors and categorical break combinations reflected the existing mosaic of ecological systems and the number of land facets they would produce.

We evaluated elevation, geology and soils, which as a product of both geology and local site conditions and may better reflect vegetation patterns than geology. We also tested slope as a way to create more homogeneity within facets; steep landscapes tend to support different ecological systems than flat areas. Josh Lawler (2013) and his team used 4 slope breaks to create land facets (0-6, 7-12, 13-18, and 18-90 degrees). Our Steering Committee suggested a combination of slope and aspect (0-6, 6-10 N+E, 6-18 S+W, >18 N+E), >18 S+W). We also tested three slope breaks (0-6, 6-18, and 18 degrees and above). Table B.1 shows the geophysical features, and the number of classes for each tested to determine the appropriate groupings to define land facets.

When considering which categories for each geophysical feature to use in an overlay method, we compared the results for each category in two ways. Both methods relied on the proportion of each ecological system that fell within each category of the abiotic factor, and utilized crosstabs. A crosstab is created by overlaying a map of ecological systems with the map of the factor/category combination being tested and displaying the result in a table where the columns reflect the categories and the rows the ecological systems. The cells then show the proportion of each ecological system within in each factor category.

Table B.1. Factors and breaks assessed for land facets. Summary of the geophysical factors and the categorical breaks which were assessed for use in constructing land facets for the four ecoregions east of the Cascade crest. The number of classes defined for each factor is indicated in parentheses, along with a description of how they were defined.

Soil Order (9)	Geology (9)	Elevation (10 breaks)	Elevation (6 breaks)	Slope (3 breaks)	Slope (4 breaks)	Slope and Aspect (5 combinations of 2 slope breaks and 2 aspects)
Alfisols	Acidic sed.	0-300 m	0-600 m	0-6 deg	0-6 deg	Flats
Andisols	Acidic shale	300-600 m	600-1200 m	6-18 deg	6-12 deg	Northerly aspect, 6 - 18 degrees
Aridisols	Calc.	600-900 m	1,200-1,800 m	Over 18 deg	12-18 deg	Southerly aspect, 6 - 18 degrees
Entisols	Mod. Calc.	90-1,200 m	1,800-2,400 m		Over 18 deg	Northerly aspect, 18 - 90 degrees
Histosols	Acidic granitic	1,200-1,500 m	2,400-3,000 m			Southerly aspect, 18 - 90 degrees
Inceptisols	Mafic	1,500-1,800 m	Above 3000 m			
Mollisols	Ultramafic	1,800-2,100 m				
Spodosols	Course sed.	2,100-2,400 m				
Vertisols	Fine sed.	2,400-2,700 m				
		Above 2,700 m				

Each crosstab has 155 rows, one for each ecological system, and as many columns as there are class breaks in the factor. In the geology factor example below (Table B.2), there are 9 classes (excluding water). The greater the proportion in a crosstab cell, the stronger the association between the system and the factor. In the example below, 82% of the first vegetation type co-occurs with the first geology category, a very strong relationship.

Table B.2. Cross-tab example of ecological systems X geology. An example showing a portion of the cross-tab table generated to quantify the relationship between ecological systems and geology. The full cross tab contains 155 rows, one for each ecological system, and a column for each of the 9 geology factor classes. The numeric values are the proportion of each ecological system's full extent falling into each geology class.

Ecological System	Geology (9 classes; five shown)				
	Mafic	acidic granitic	acidic sedimentary	fine sedimentary	coarse sedimentary
North Pacific Dry Douglas-fir Forest and Woodland	0.816	0.011	0.125	0.037	0.010
North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	0.874	0.007	0.005	0.025	0.087
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	0.850	0.081	0.036	0.007	0.025
... remaining types					

To further investigate the strength of association between a factor and ecological systems, the average for each factor class was computed (i.e. a column average), indicating overall how tightly that factor class is associated with all the vegetation types with which it co-occurs. The average across all factor classes (i.e. the mean-of-means) provided a measure of association for all factor categories. This **mean-of-means measure of association** was computed for each abiotic factor. Facet factors with higher mean-of-mean values are more tightly associated with vegetation; therefore, we expect that a land facet classification built using the factors with the largest measures of associations will also have the strongest association with current vegetation.

Because these measures of association included ecological systems of vastly different spatial extents, we also created an **area-weighted association measurement** (Table B.3). This was done by comparing the expected amount vs. observed amount for each vegetation/land facet combination in the crosstab. The expected amount for an ecological system is the amount expected to occur within a category if the ecological system were randomly distributed across the study area. For example, "mollisol" soils cover 50% of the project area and would thus be expected to contain 50% of each ecological system. The magnitude of the difference between the expected and observed amount is a measure of the strength of association (or disassociation) between the category and the ecological system. Calculating these metrics for each category and each ecological system allowed us to compare levels of association between each factor and existing vegetation.

Table B.3. Example of area-weighted association calculation. An example of the area-weighted association measure for veg types (ecological systems) and soil order. A) Expected amount (cell count) for each veg type (ecological system) and soil order class combination based on the proportion of the soil order class in the study area. B) Observed amount for each combination; and C) The difference between expected and observed for each combination. Positive numbers indicate that the veg type occurs more often than expected within the soil order class (a positive association) and negative numbers indicate that the veg type occurs less than expected within the soil order class (a negative association). The larger the number (positive or negative), the stronger the association.

A)

Soil Order	Mollisols	Aridisols	Inceptisols	Entisols	Alfisols	Vertisols	Andisols	Histosols	Spodosols	TOTAL
Proportion of Duke Area	0.4710	0.1524	0.1743	0.0278	0.0632	0.0040	0.1023	0.0002	0.0048	1.0000
Expected Amounts of Veg Type in Duke Area by Soil Order										
Inter-Mountain Basins Playa	12,944	4,189	4,790	765	1,736	110	2,810	5	133	27,482
North Pacific Oak Woodland	297	96	110	18	40	3	64	0	3	630
Northern Rocky Mountain Western Larch Savanna	4,867	1,575	1,801	288	653	41	1,057	2	50	10,333
Rocky Mountain Aspen Forest and Woodland	31,584	10,220	11,687	1,866	4,237	268	6,857	13	324	67,056
Rocky Mountain Bigtooth Maple Ravine Woodland	652	211	241	39	88	6	142	0	7	1,385
Columbia Plateau Western Juniper Woodland and Savanna	102,701	33,233	38,001	6,068	13,777	870	22,298	43	1,053	218,043
East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	26,635	8,619	9,855	1,574	3,573	226	5,783	11	273	56,548
Great Basin Pinyon-Juniper Woodland	13,509	4,371	4,998	798	1,812	114	2,933	6	138	28,680
Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	29	9	11	2	4	0	6	0	0	62
Total of All Soil Types	3,395,485	1,098,750	1,256,398	200,613	455,488	28,760	737,200	1,428	34,800	7,208,922

B)

Soil Order	Mollisols	Aridisols	Inceptisols	Entisols	Alfisols	Vertisols	Andisols	Histosols	Spodosols	TOTAL
Proportion of Duke Area	0.4710	0.1524	0.1743	0.0278	0.0632	0.0040	0.1023	0.0002	0.0048	1.0000
Observed Amounts of Veg Type in Duke Area by Soil Order										
Inter-Mountain Basins Playa	4,287	16,268	6,133	15	41	729	9	-	-	27,482
North Pacific Oak Woodland	63	-	566	-	1	-	-	-	-	630
Northern Rocky Mountain Western Larch Savanna	7,473	-	233	-	54	-	2,518	-	55	10,333
Rocky Mountain Aspen Forest and Woodland	53,103	962	7,702	1,141	3,575	24	536	-	13	67,056
Rocky Mountain Bigtooth Maple Ravine Woodland	1,368	7	-	7	-	3	-	-	-	1,385
Columbia Plateau Western Juniper Woodland and Savanna	200,576	9,937	663	1,024	1,150	817	3,873	3	-	218,043
East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	5,269	1,797	9,747	966	11,642	-	23,951	-	3,176	56,548
Great Basin Pinyon-Juniper Woodland	23,300	3,607	-	1,033	128	468	144	-	-	28,680
Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	62	-	-	-	-	-	-	-	-	62
Total of All Soil Types	3,395,485	1,098,750	1,256,398	200,613	455,488	28,760	737,200	1,428	34,800	7,208,922

C)

Observed-Expected Amounts	Mollisols	Aridisols	Inceptisols	Entisols	Alfisols	Vertisols	Andisols	Histosols	Spodosols
Inter-Mountain Basins Playa	(8,657)	12,079	1,343	(750)	(1,695)	619	(2,801)	(5)	(133)
North Pacific Oak Woodland	(234)	(96)	456	(18)	(39)	(3)	(64)	(0)	(3)
Northern Rocky Mountain Western Larch Savanna	2,606	(1,575)	(1,568)	(288)	(599)	(41)	1,461	(2)	5
Rocky Mountain Aspen Forest and Woodland	21,519	(9,258)	(3,985)	(725)	(662)	(244)	(6,321)	(13)	(311)
Rocky Mountain Bigtooth Maple Ravine Woodland	716	(204)	(241)	(32)	(88)	(3)	(142)	(0)	(7)
Columbia Plateau Western Juniper Woodland and Savanna	97,875	(23,296)	(37,338)	(5,044)	(12,627)	(53)	(18,425)	(40)	(1,053)
East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	(21,366)	(6,822)	(108)	(608)	8,069	(226)	18,168	(11)	2,903
Great Basin Pinyon-Juniper Woodland	9,791	(764)	(4,998)	235	(1,684)	354	(2,789)	(6)	(138)
Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	33	(9)	(11)	(2)	(4)	(0)	(6)	(0)	(0)
Amount More Than Expected	2,605,341								
Amount Less Than Expected	2,605,341								
Percent of Duke Area (7,208,922)	72.2%								

We chose our factor categories considering both association metrics described above, and if there was not a large difference, we always chose the one that would result in the fewest land facets. We found a large difference in the relationships between ecological systems and geology, versus that with soils (TableB.4). Soil order had a stronger association as measured by the area-weighted measure of association; therefore, we chose soil over geology to create land facets. Additionally, the measures of association were strongest for the factor with 3 slope breaks compared to the other slope factors, and 6-600m elevation breaks compared to the 10-300m breaks, so we selected those factors for use in creating facets.

Table B.4. Results of measure of association and area-weighted association. Measures of association used to describe the strength of the relationship between ecological systems and each of the seven geophysical factors tested. The relationship between ecological systems and elevation was stronger when elevation was divided in to 6 classes, rather than 10. The relationship between systems and slope was strongest when slope was described using 3 breaks, rather than 4, and when aspect was not included.

Geophysical Factor	Mean-of-means	Area-Weighted
Soil Order (9 classes)	0.15	0.72
Geology (9 classes)	0.12	0.54
Elevation (10 – 300m breaks)	0.14	0.67
Elevation (6 – 600 m breaks)	0.44	0.63
Slope (3 degree breaks)	0.27	0.50
Slope (4 degree breaks)	0.25	0.49
Slope and Aspect (5 combinations of 2 slope breaks and 2 aspects)	0.18	0.50

Describing Land Facets with Ecological Systems

By overlaying the maps of ecological systems and habitats on the land facet map we calculated the proportion of each land facet covered by each ecological system or habitat (showing the composition of each facet) (Table B.5). Additionally, we calculated the proportions of each ecological system or habitat in each facet (a measure of the importance of that facet for the conservation of each ecological system or habitat) (Table B.6). Similar proportions were calculated for agricultural and pasture land uses, plus areas of human development. Spreadsheets containing these data are found in Buttrick et al. 2014, Appendix 3.1: Conserving the Stage.xlsx, tabs *Ecosys_Prop_Veg, Ecosys_Prop_Facet, Habitats_Prop_Veg, and Habitat_Prop_Facet.* This report can be found at http://nature.ly/resilienceNW.

Table B.5. Proportion of habitats within each land facet. An example of the summary table providing the proportion of habitats within each land facet. For the complete table and color scheme used below see Appendix 3.1: Conserving the Stage.xlsx, tab *CrossTab_Notes*.

Facet Name	Aridisols; 1200 - 1800 m; 0 - 6 deg	Inceptisols; 0 - 600 m; 6 - 18 deg	Inceptisols; 0 - 600 m; over 18 deg	Mollisols; 0 - 600 m; 0 - 6 deg
Facet ID	131	212	213	1011
Habitat Name / Facet Hectares	6,910,210	76,509	13,917	2,371,090
Alkali and Desert Grasslands	0.012	0.000	0.000	0.002
Alpine and Subalpine Habitats	0.000	0.001	0.001	0.000
Aspen Forests and Woodlands	0.000	0.000	0.001	0.000
Big Sagebrush Shrublands and Steppe	0.630	0.118	0.085	0.211
Canyon and Montane Shrublands	0.001	[illegible]	0.007	[illegible]
Chaparral	0.000	[illegible]	[illegible]	[illegible]
Cliff and Canyon	0.000	[illegible]	[illegible]	[illegible]
Interior Lowland Grasslands and Prairie	0.018	[illegible]	[illegible]	[illegible]
Deserts, Playas and Ash Beds	0.017	[illegible]	[illegible]	[illegible]
Dunes	0.002	[illegible]	0.000	0.000
Forest/Shrub Swamps	0.000	0.000	0.000	0.000
Interior Lowland and Foothill Riparian Woodlands and Shrublands	0.002	0.003	0.001	0.003
Juniper Woodlands and Savanna	0.010	0.006	0.000	0.004
Lakes and Ponds	0.000	0.000	0.000	0.000
Lava Flows	0.010	0.000	0.000	0.000
Lodgepole Pine Forests and Woodlands	0.000	0.000	0.000	0.000
Low, Black and Rigid Sagebrush Steppe	0.052	0.030	0.003	0.013
Marshes, Bogs and Emergent Wetlands	0.001	0.000	0.000	0.000
Mixed Conifer Forests	0.002	0.146	0.220	0.001
Mixed Hardwood-Conifer Forests	0.000	0.018	0.098	0.000
Montane Grasslands and Meadows	0.000	0.000	0.003	0.000
Montane Riparian Forests and Shrublands	0.000	0.008	0.003	0.001
Oak Woodlands	0.000	0.036	0.026	0.000
Oak-Conifer Forests and Woodlands	0.000	0.121	0.054	0.005
Ponderosa Pine Forests and Woodlands	0.000	0.100	0.104	0.004
Salt Desert Scrub	0.030	0.000	0.000	0.001
Silver Fir - Mountain Hemlock Montane Forests	0.000	0.000	0.000	0.000
Sparsely Vegetated Systems	0.001	0.000	0.000	0.000
Subalpine Forests and Woodlands	0.000	0.000	0.000	0.000
Douglas-fir Hemlock Forests	0.000	0.053	0.229	0.000
Whitebark Pine Subalpine Woodland	0.000	0.000	0.000	0.000
Agriculture	0.090	0.031	0.004	0.539
Open Water	0.002	0.036	[illegible]	0.008
Exotics/Introduced	0.071	0.004	[illegible]	0.073
Pasture/Hay/CRP	0.017	0.028	[illegible]	0.077
Non-specific Disturbed	0.000	0.000	[illegible]	0.000
Harvested Forest	0.000	0.022	[illegible]	0.000
Recently Burned	0.021	0.003	0.020	0.004
Developed	0.009	0.024	0.022	0.023

64% of this land facet is Big Sagebrush Shrublands and Steppe

Land Facet name and total hectares within study area.

54% of this land facet is in agriculture.

Table B.6. Proportion of land facets within each habitat. An example of the summary table providing the proportion of land facets within each habitat. For the complete table and color scheme used below, see Appendix 3.1: Conserving the Stage. Xlsx, tab *CrossTab_Notes*

Facet Name	Aridisols; 1200 - 1800 m; 0 - 6 deg	Inceptisols; 0 - 600 m; 6 - 18 deg	Inceptisols; 0 - 600 m; over 18 deg	Mollisols; 0 - 600 m; 0 - 6 deg
Facet ID	131	212	213	1011
Habitat Name / Facet Hectares	6,910,210	76,509	13,917	2,371,090
Alkali and Desert Grasslands	0.386	0.000	0.000	0.020
Alpine and Subalpine Habitats	0.001	[illegible]	[illegible]	0.000
Aspen Forests and Woodlands	0.001	[illegible]	[illegible]	0.000
Big Sagebrush Shrublands and Steppe	0.236	[illegible]	[illegible]	0.027
Canyon and Montane Shrublands	0.010	[illegible]	[illegible]	0.002
Chaparral	0.000	0.000	0.000	0.000
Cliff and Canyon	0.018	0.003	0.001	0.004
Deserts, Playas and Ash Beds	0.375	0.000	0.000	0.001
Douglas-fir Hemlock Forests	0.000	0.056	0.044	0.007
Dunes	0.148	0.000	0.000	0.007
Forest/Shrub Swamps	0.000	0.000	0.000	0.000
Interior Lowland and Foothill Riparian Woodlands and Shrublands	0.006	0.000	0.000	0.004
Interior Lowland Grasslands and Prairie	0.031	0.004	0.000	0.016
Juniper Woodlands and Savanna	0.038	[illegible]	[illegible]	0.005
Lakes and Ponds	0.000	[illegible]	[illegible]	0.000
Lava Flows	0.198	[illegible]	[illegible]	0.000
Lodgepole Pine Forests and Woodlands	0.000	[illegible]	[illegible]	0.000
Low, Black and Rigid Sagebrush Steppe	0.163	[illegible]	[illegible]	0.014
Marshes, Bogs and Emergent Wetlands	0.075	0.000	0.000	0.009
Mixed Conifer Forests	0.002	0.001	0.000	0.000
Mixed Hardwood-Conifer Forests	0.000	0.350	0.350	0.000
Montane Grasslands and Meadows	0.001	0.000	0.000	0.000
Montane Riparian Forests and Shrublands	0.029	0.005	0.000	0.016
Oak Woodlands	0.000	0.585	0.075	0.035
Oak-Conifer Forests and Woodlands	0.000	0.062	0.005	0.076
Ponderosa Pine Forests and Woodlands	0.000	0.003	0.001	0.004
Salt Desert Scrub	0.368	[illegible]	[illegible]	0.005
Silver Fir - Mountain Hemlock Montane Forests	0.000	[illegible]	[illegible]	0.000
Sparsely Vegetated Systems	0.270	[illegible]	[illegible]	0.000
Subalpine Forests and Woodlands	0.000	0.000	0.000	0.000
Whitebark Pine Subalpine Woodland	0.000	0.000	0.000	0.000
Agriculture	0.096	0.000	0.000	0.196
Developed	0.085	0.003	0.000	0.078
Exotics/Introduced	0.259	[illegible]	[illegible]	0.092
Harvested Forest	0.000	[illegible]	[illegible]	0.000
Non-specific Disturbed	0.000	[illegible]	[illegible]	0.000
Open Water	0.045	[illegible]	[illegible]	0.068
Pasture/Hay/CRP	0.072	[illegible]	[illegible]	0.115
Recently Burned	0.151	0.000	0.000	0.010

39% of Akali and Desert Grasslands are on Aridisols at moderate elevation in areas of flat slope.

75% of Mixed Hardwood-Conifer Forests are on Inceptisols at low elevation and relatively steep slopes.

59% of Oak Woodlands are also on Inceptisols at low elevation and relatively steep slopes.

26% of Exotics/Introduced habitat is on Aridisols at moderate elevation and areas of flat slope.

Appendix C: GIS Methods

Extensive GIS processing was required to build and analyze the datasets outlined in this report. This chapter gives an overview of the data inputs and processing steps. Many portions of the processing have been scripted in Python or R programming languages. Those nine scripts are available for download with the project geodatabase, and the processing steps they cover are highlighted in gray. These are production scripts developed during the course of the project, not polished software certain to run on any machine, and should be viewed as merely a starting point for future software development. All referenced scripts are included with the data download package, within the 'PNW Scripts' folder.

All data were originally developed out to a 5 km buffer on the project area, except along the Canadian border.

The datasets described in this appendix include:

- 30m Heat Load Index
- 30m Compound Topographic Index
- 30m Topoclimate diversity
- 30m Resistance surface
- 90m Permeability surface
- 270m Land Facets
- 270m EcoFacets
- 270m Landscape Resilience

Descriptions of the data processing steps used to produce each of these datasets follow. Prior to processing, we established a standard projection (USA Contiguous Albers Equal Area Conic USGS version) for the project, and created nested 30, 90 and 270m snap rasters and raster masks for the project extent. All data were projected to the project standard and most geoprocessing results (with the exception of Heat Load and Compound Topographic indices, as noted below) were snapped and masked to the corresponding snap and mask rasters.

Heat Load Index

Heat Load Index(HLI) has been shown to relate well to evapotranspiration rates and soil temperatures and is a direct measure of incident radiation (McCune and Keon 2002; Evans 2011). Aspect is "folded" so that southwest facing slopes have higher temperatures than southeast facing slopes, and northeast facing slopes are the coolest. This method also accounts for slope gradient, where steep, southwest facing slopes at higher latitudes (i.e., those receiving more tangential insolation) receive the highest HLI scores. The index can be applied appropriately anywhere in the mid-latitudes, from ~ 30º N to 60º N.

The constituent datasets for HLI included:

- USGS NED 1 arc second DEM
- Analysis tiles, derived from the polygon of project area

The script used to calculate HLI was modified in March of 2014 from the version available in the *Geomorphometric and Gradient Metrics Toolbox* (Evans 2011), to fix a math error. That modified version is included in the 'PNW Scripts' folder included in the data download which contains the PNW geodatabase. Other portions of this workflow have not been scripted, primarily as they require many subjective decisions from the planning team.

HLI is calculated directly from digital elevation data. We therefore downloaded 1 arc second DEM data from NED. The native pixel size of the 1 arc second data is slightly larger than 30 m. However, we did not resample the data to match our other 30m data, as that process would introduce striping into the outputs, affecting subsequent calculations. Instead, we ran through the entire calculation of topoclimate diversity before resampling any DEM derived data to 30m. All geoprocessing outputs were snapped to the native NED DEM.

HLI is sensitive to latitude, and latitude is a user input to the script. This means that for each implementation of the HLI tool in any given geography, the southwest facing slopes tilted at the user specified latitude will receive the highest values. This wouldn't introduce any noticeable error into a local analysis, but across large landscapes, such our PNW Project area (which covers ~14º of latitude) the errors created by using a single latitude value across the entire geography would have been unacceptable. Additionally, the memory demands of a single HLI run across an area of this size are too much for a standard desktop computer. For these reasons the project area was split into 13 tiles (Figure 1), each spanning about 2º of latitude. There is no limit on longitudinal spread as HLI is only sensitive to latitude.

Each of these 13 tiles was buffered by 3,000 meters (*Analysis Tools.tbx > Proximity > Buffer*).

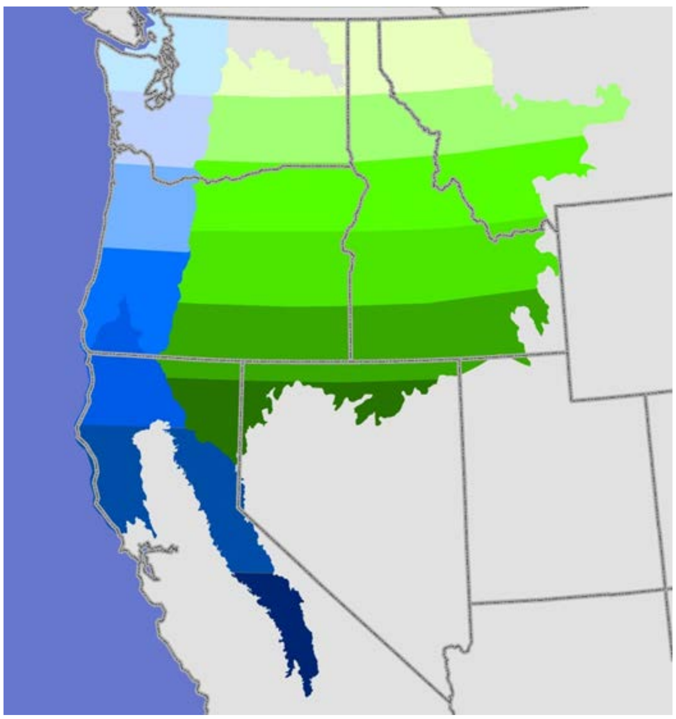


Figure 1: HLI Processing Tiles

These buffered tiles were each given a unique id and attributed with their centroid's latitude (decimal degrees). The buffered tiles were then used to extract portions of the DEM (*Spatial Analyst Tools.tbx > Extraction > Extract by Mask*) for HLI calculations.

The HLI.py script was then used to calculate HLI for each DEM tile, using the latitude that was earlier attributed to each buffer tile.

Once HLI was calculated for all tiles, the original latitude tiles were again buffered, this time by 1,000 meters. This version of the tiles was used for extracting each of the HLI outputs in preparation for creating seamless data for the entire project area. By reducing the extent of each HLI output by 2,000 meters, any edge effects were removed but enough overlap remained between tiles to prevent data gaps. The extracted HLI tiles were then mosaicked (*Data Management Tools.tbx > Raster > Raster Dataset > Mosaic to New Raster*) into a complete HLI surface, using 'Mean' as the *Mosaic Operator*.

Finally, a 3x3 low pass filter was run across the HLI surface (*Spatial Analyst Tools.tbx > Neighborhood > Filter)* to remove any residual striping/artifacts. This output was used in calculations of the topoclimate surface.

Compound Topographic Index

CTI acts as a steady-state wetness index. As a function of slope and upstream contributing area, CTI is a metric similar to Topographic Convergence Index (TCI), except that the former measures slope by its tangent and the latter calculates slope by percent rise (Wolock and McCabe 1995). CTI has been shown to have a strong correlation with many soil properties, including depth, texture, organic content and moisture (Gessler et al. 1995; Moore et al. 1993; Evans 2011). Smallest CTI values are typically found along ridgelines and largest values in valley bottoms and basins with large contributing areas.

The constituent datasets for CTI included:

- USGS NED, 1 arc second DEM
- Analysis tiles, derived from U.S. Department of Agriculture, Natural Resources Conservation Service 4 digit HUCs

The script used to calculate CTI is available as part of the *Geomorphometric and Gradient Metrics Toolbox* (Evans 2011). The script is also included in the 'PNW Scripts' folder included in the data download which contains the PNW geodatabase. Other portions of this workflow have not been scripted, primarily as they require many subjective decisions from the planning team.

CTI is calculated directly from digital elevation data. The CTI calculations were therefore based on the same native NED 1 arc second DEM used in the HLI calculations. All geoprocessing outputs were snapped to the native NED DEM under the "Environment Settings" tab of the tool.

CTI is not sensitive to latitude. However, memory requirements to calculate CTI across the entire project area exceed the capabilities of standard desktop computers. Therefore, the project area was broken into 5 tiles.

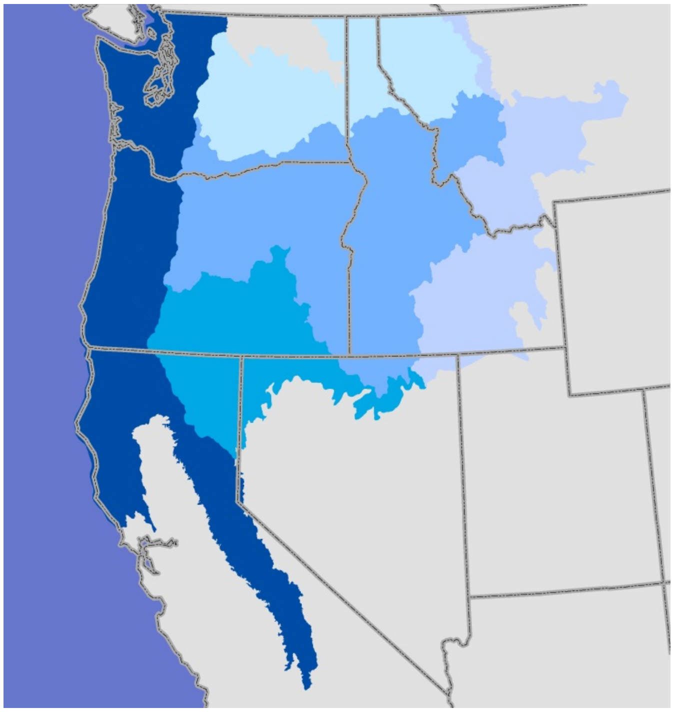


Figure 2: CTI Processing Tiles

CTI values accumulate from ridgelines, starting at ‘0’ at the crest, with values increasing as contributing area expands downhill. Splitting a drainage mid-slope would introduce error into the analysis by separating the headwaters from the remainder of the basin, lowering the ultimate CTI values downstream. To avoid this, tiles were created from aggregations of 4 digit HUCs. These watersheds generally follow ridgelines, minimizing the impact to CTI calculations that might otherwise result from splitting the project area into analysis tiles (Figure 2). Each tile was buffered (*Analysis Tools.tbx > Proximity > Buffer*) by the minimum amount to avoid data gaps; 100 meters (~ 3 pixels) was deemed sufficient.

The buffered tiles were then used to extract portions of the DEM (*Spatial Analyst Tools.tbx > Extraction > Extract by Mask*) for CTI calculations.

The CTI.py script was then used to calculate CTI for each DEM tile. The CTI tiles were then mosaicked (*Data Management Tools.tbx > Raster > Raster Dataset > Mosaic to New Raster*) into a complete CTI surface, using ‘Maximum’ as the *Mosaic Operator*.

Finally, a 3x3 low pass filter was run across the CTI surface (*Spatial Analyst Tools.tbx > Neighborhood > Filter)*. CTI is calculated along individual flowpaths, so smoothing makes the raw output more ecologically realistic by averaging the values from adjacent flowpaths (Evans, personal communication, 2013). This output was used in calculations of the topoclimate surface.

Topoclimate Diversity

We used HLI and CTI to derive a metric representing a surrogate for topoclimate diversity. Areas with diverse topoclimates are more able to provide proximal areas of suitable habitat to species whose current locations are no longer within their climatic envelope due to climate change impacts.

The constituent datasets for the topoclimate analysis included:

- HLI and CTI surfaces, previously described.
- The 2011 National Land Cover Dataset.

All geoprocessing outputs (except the NLCD reclassify) were snapped to the native NED DEM under the “Environment Settings” tab of the tool.

Both HLI and CTI data were standardized from 0 – 1 using the following equation in the Raster Calculator (Spatial Analyst Tools.tbx > Map Algebra > Raster Calculator):

((Raster Value – Minimum value) / (Maximum raster value – Minimum raster value))

The 2011 NLCD data, clipped to the PNW project area, were reclassified (*Spatial Analyst Tools.tbx > Reclass > Reclassify)* to change 'Open Water' or 'Developed, High Intensity' pixels to 'NoData', while all other pixels were valued at '1'. The output was saved as 'TC_AnalysisMask'. This mask was used in the subsequent focal statistic calculations to prevent inclusion of HLI or CTI values in areas which cannot contribute topoclimates accessible to terrestrial species. This is especially important with CTI, as large water bodies create large CTI values which can bias scores on adjacent terrestrial lands.

Focal statistics (*Spatial Analyst Tools.tbx > Neighborhood > Focal Statistics)* were then performed on the standardized CTI and HLI surfaces. The neighborhood was defined as a 15 cell (~ 450 m) circular neighborhood. The 'Focal Statistic' was set to 'Range', and 'TC_AnalysisMask' was specified as the analysis mask in the tool "Environments Settings."

Both HLI range and CTI range outputs were then standardized from 0 – 1 using the following equation in the Raster Calculator (*Spatial Analyst Tools.tbx > Map Algebra > Raster Calculator)*:

((Raster value – Minimum raster value) / (Maximum raster value – Minimum raster value))

The standardized HLI and CTI range rasters were then multiplied together using the Raster Calculator (*Spatial Analyst Tools.tbx > Map Algebra > Raster Calculator*) to produce 'TC_BASE' .

The final landscape resilience data are the product of (topoclimate * landscape permeability). As high landscape permeability can confer a degree of resilience to an area despite low topoclimate diversity, the topoclimate values were standardized from 0.2 – 1. Therefore, 'TC_BASE' was standardized from 0.2 – 1 using the following equation in the Raster Calculator (*Spatial Analyst Tools.tbx > Map Algebra > Raster Calculator)*:

(((TC_BASE– Minimum TC_BASE value) * (0.8/(Maximum TC_BASE value – Minimum TC_BASE value)))+ 0.2

Resistance Surface

The resistance surface is the basis for the landscape permeability analysis and has a great deal of influence on the final landscape resilience scores. As such, great pains were taken to make this dataset as reflective of our best understanding of how different landscape features affect species' movement abilities as possible. Each input dataset used was evaluated at several locations, and multiple draft versions of the resistance surface were produced until reviewers were satisfied with these data.

Each cell in the resistance surface was assigned a value, or weighting, representing its hardness/ impermeability to species movement and ecological flows. Higher values are more difficult to cross, while lower values are easier. Natural lands are assigned a value of 1, meaning the cost to move across the pixel is equal to the Euclidean distance, allowing relatively free flow of ecological processes at that location.

The constituent datasets for the resistance surface included:

- 2011 National Land Cover Dataset, produced by the U.S. Geological Survey, used to map development classes, agriculture, natural lands, and open water across the project area.
- Publication transportation dataset (roads), produced by the U.S. Bureau of Land management, used across Oregon, Nevada and Washington west of the Cascade crest. Based on visual

inspection against NAIP imagery, this dataset captured roads on private timberlands much better than TIGER.

- 2014 TIGER roads and highways, produced by the U.S. Census Bureau, were used throughout most of the remainder of the project area. Exceptions are noted in the additional datasets listed below.
- California USDA Forest Service roads data, used on USFS administered lands in California.
- California Timber Harvesting Plan data for private timberland roads data from CAL FIRE.
- EV Energy Map layer, produced by Ventyx Inc. (proprietary subscription service), was used to map all significant transmission lines, wind towers and natural gas pipelines across the project area.
- ESRI online railroads were used for the California North Coast, Sierra Nevada and the Klamath Mountain ecoregions. Abandoned lines were identified by visual inspection against NAIP imagery.
- 2012 Railroads, digitized at 24k by the Oregon Department of Transportation, were used for the remaining portions of Oregon west of the Cascade crest. Abandoned lines are flagged.
- The 2013 Federal Railroad dataset, produced by the U.S. Railway Administration, was used for all ecoregions east of the Cascade crest. Abandoned lines are flagged. Scale is 1:100k or better, though on visual inspection against NAIP imagery the data aligned well with the state-based railroad data at 24k. This dataset was chosen as it covered the 5 state area with a single data standard.
- 2012 Railroads, digitized at 24k by the Washington State Department of Transportation, were used for all portions of Washington west of the Cascade crest. Abandoned lines are flagged.
- The 2010 *Population and Housing Unit Counts* Report, produced by the U.S. Census Bureau, were used in conjunction with census tract polygons (clipped to private lands) to calculate 8 classes of ‘Block Housing Density' (BHD) on private lands across the study area. These data, obtained from David Theobald (Conservation Science Partners), were included to represent the non-specific impacts associated with increasing human densities. These impacts include noise, pollution, predation by household pets, modification of native vegetation, etc.

Development of the Resistance surface began with processing of the NLCD 2011 dataset. Two primary modifications were made; removing linear developed features (such as roads), and assigning increasing resistance values in water bodies as distance from shore increased.

The following geoprocessing tasks are included in the script NLCD_Duke.py.

Distance from shore was calculated for all water bodies, with new classes representing different distance bands replacing the original open water class.

Roads and developed classes within NLCD are poorly differentiated. Road pixels are often classified as “Developed, high intensity,” though many roads do not appear at all. The first modification was to remove roads entirely from NLCD, following work by the Washington Wildlife Habitat Connectivity Working Group (WHCWG 2013). This was accomplished with the ‘Shrink’ tool (*Spatial Analyst Tools.tbx > Generalization > Shrink*), shrinking all developed classes by 1 pixel and replacing those cells with their nearest neighbor values.

We developed expert-based resistance scores for all classes in each input dataset, representing the resistance to movement created by each landscape feature (Table XXX). These data were input into the Resistance and Habitat Calculator of Gnarly Landscape Utilities (McRae et al. 2013, http://www.circuitscape.org/gnarly-landscape-utilities.) The resulting raster represented the maximum resistance across all input layers at a 30m pixel size. We then used the Raster Cell Size Coarsener in Gnarly Landscape Utilities to aggregate these data to 90m. We took the mean of all pixels within each 90m pixel, using the option to smooth input data before aggregating.

These 90m data were used in the calculation of Landscape Resilience, described later in this document.

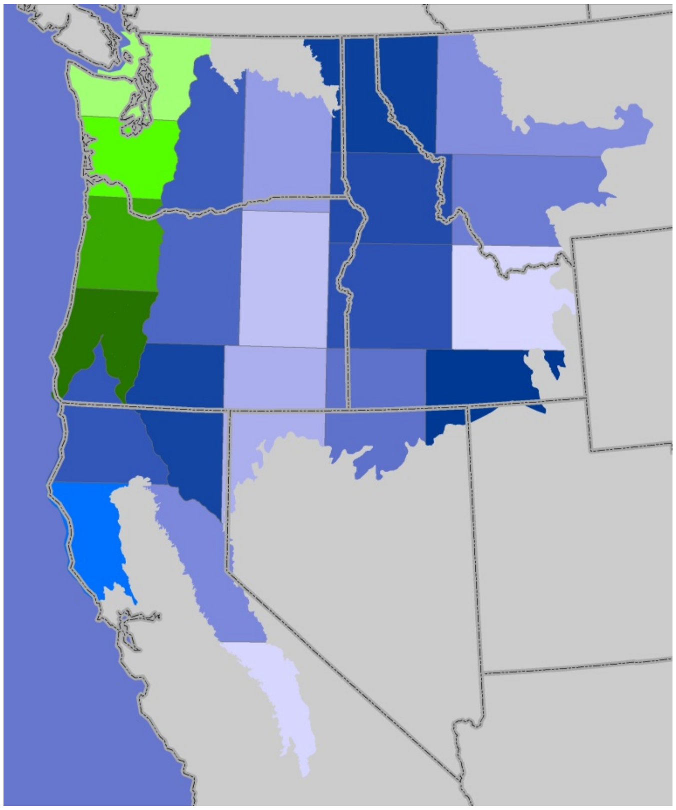
Permeability Surface

Permeability refers to the connectedness of a focal cell to its ecological neighborhood when it is viewed as a source; in other words, it asks the question: "to what extent are ecological flows outward from that cell impeded or facilitated by the surrounding landscape?" Thus, permeability starts with a focal cell and looks at the resistance to ecological flow outward in all directions through the local neighborhood. As resistance increases, flow is impeded or stopped altogether. Areas of no resistance allow the flow to proceed until a user-specified maximum distance is achieved. Therefore, cells grow further in directions of low resistance. This process is repeated for every cell across the analysis extent, and the results are combined to create the final surface.

The constituent datasets for the permeability surface included:

- Resistance surface, previously described.
- Analysis tiles, derived from polygon of the buffered project area.

The method used to map local permeability for the region, *traversability,* was calculated using a resistant kernel algorithm described in Compton et al (2007) and McGarigal et al (2012). A script, provided by Brad Compton and subsequently modified by Brad McRae (*traverse_BHM.r)*, was used to implement the algorithm across the study area. Due to the computational intensity of the traversability calculation, the analysis area was split into tiles. The buffered project area polygon was put into edit mode and split into 22 tiles (Figure 3). Each of these tiles was less than 6,000,000 hectares, the maximum allowable area for calculation of traversability using the traverse.r script.



Each tile was then buffered (*Analysis Tools.tbx > Proximity > Buffer*) by 4,000 meters. As the ‘bandwidth’ used in the traversability calculation translates to ~ 3,000 meters, it was important to run the analysis at least that far beyond each tile to avoid edge effects.

The 90m resistance data were then extracted for all 22 buffered tiles (*Spatial Analyst Tools.tbx > Extraction > Extract by Mask*).

Traversability was then calculated for each tile using the following settings:

- resist = FALSE
- window = NULL
- focal = 20
- search = 3
- focalresist = TRUE

Figure 3: Traversability Processing Tiles

Once traversability was calculated for all the buffered tiles, the original tiles were again buffered, this time by 1,000 meters. This version of the tiles was used for extracting each of the traversability outputs in preparation for creating seamless data for the entire project area. By reducing the extent of each HLI output by 3,000 meters, any edge effects were removed but enough overlap remained between tiles to prevent data gaps. The extracted permeability tiles were then mosaicked (*Data Management Tools.tbx > Raster > Raster Dataset > Mosaic to New Raster*) into a complete permeability surface, using ‘Maximum’ as the *Mosaic Operator*.

Land facets

Current approaches for assessing resilience focus on species, using models that relate species ranges to habitats and climates, and predict where species are likely to turn over or remain relatively stable, but they are hampered by the sheer number of species that need to be modeled. Because species distributions are tightly correlated with physical characteristics of the land, especially geology and elevation, conserving a variety of geophysical settings, such as limestone valleys or granite summits, could offer a robust and efficient alternative approach to protecting biodiversity under future climate scenarios (Anderson and Ferree 2010, Beier and Brost 2010).

We developed a ‘Land Facets’ classification scheme to represent the representation of geophysical settings in our study area. Land facet occurrences were scored by topoclimate diversity and landscape permeability to identify examples of each that would be most resilient to a changing climate.

The constituent datasets for the Land Facets included:

- USGS NED, 1 arc second DEM
- USDA-NRCS STATSGO2 Soils
- USDA-NRCS SSURGO Soils

Soil Data - Soil taxonomic orders for the study area were extracted from Soil Survey Geographic (SSURGO) databases where available and from U.S. General Soil Map (STATSGO2) data in the eastern portion of the study area and portions of the west where SSURGO data was not available. Taxonomic order data from the two sources were combined to create a continuous soil taxonomic order name feature class of the study area. This feature class was clipped to the study area for use in creating Land facets.

SSURGO and STATSGO2 data were retrieved in June, 2014 from the US Department of Agriculture Natural Resource Conservation Service Geospatial Data Gateway.

After the SSURGO data were obtained from the Geospatial Data Gateway, the source files were manually unzipped. A python geoprocessing script , *SSURGO_taxorder.py*, was executed to populate a file geodatabase with SSURGO map unit polygon feature classes and extract the required soil property data from the source text files. The script performed the following general steps:

1. create an empty file geodatabase to hold a states' soil data,

2. import the soil map unit polygons into a single feature class,

3. add columns to the soil map unit polygon feature class to hold soil taxonomic data,

    a. The python geoprocessing script first created a file geodatabase component taxonomic order table with the following data columns:

    b. map unit key ("mukey"; a foreign key identifier, linking a component record to a map unit spatial record),

    c. component key ("cokey"; the unique key identifier of a component record),

    d. component name ("compname"; the name assigned to the component based on its range of properties),

    e. component kind ("compkind"; identifies the kind of component of the mapunit, examples are series and miscellaneous areas),

    f. component representative percent of the map unit ("comppct_r"; the representative value of the percentage of the component of the mapunit), and

    g. component taxonomic order name ("taxorder"; the highest level of the soil taxonomy).

4. create and populate a taxonomic order data table -

Populating the soil component table was accomplished using native python file reading and string parsing functions. Each survey area component source file was opened and the data record lines in the file were sequentially copied into a python list variable. Data corresponding to the five fields above were extracted from the list and inserted into the file geodatabase soil component table using an ArcGIS insert cursor. This read and insert process was repeated until the all component tables for a state were completely read.

5. create and populate an aggregated taxonomic order table -

The aggregated taxonomic order table was then joined to the map unit spatial data in ArcMap and relevant taxonomic information was transferred to the corresponding column in the map unit spatial data. The spatial data were then converted into a raster grid for use creating Land Facets. For those component records that did not have data in the taxorder value field, the data in the compname field was copied into the taxorder field.

For the purposes of these data, the taxonomic order name for a map unit was determined using the dominant condition aggregation method. In the case of a tie in dominant condition, the dominant component value was used.

The taxonomic order table was created using the python geoprocessing and included these columns:

a. map unit key ((“mukey”; a foreign key identifier, linking a taxonomic order record to a map unit spatial record),

b. four fields (“tax_01”, “tax_02”, “tax_03” and “tax_04”) to hold the names of the four most extensive taxonomic orders,

c. four fields (“pct_01”, “pct_02”, “pct_03” and “pct_04”) to hold the four largest total component percent composition for each taxonomic order

d. four fields (“dcd_01”, “dcd_02”, “dcd_03” and “dcd_04”) to hold the four largest individual component percentages,

e. the taxonomic order determined to be the most representative of a map unit.

The script retrieves all map unit keys (***mukey***) in ascending sort order from the component table using a search cursor and stored the mukeys in a python list data structure.

For each map unit key, the script retrieves all of the component records associated with a map unit key from the geodatabase component table and inserted the component record key value (***cokey***) into a python list structure.

The script iterates over the list of cokeys to retrieve the component’s taxonomic name and component percentage composition, summing the percent composition. Using a python dictionary data structure, the script stores the taxonomic order name as the dictionary key and the summed component percent composition as the dictionary key value.

As the taxonomic values are accumulated, the largest component percentage is stored in a python dominant condition dictionary, using the taxonomic name as the dictionary key. (See Appendix 1 for an explanation of SSURGO aggregation methods).

Using the dominant condition dictionary, the script extracts taxonomic order and percent composition and sorts the list in descending order by percent composition. The list is scanned and the taxonomic order names and component percentages of the four largest components are inserted into the taxorder table.

To determine the dominant component taxorder value, the value of the taxorder field were manually calculated with the contents of the first (largest) taxonomic order name field. Next, select where largest percent component is equal to the percent component of the next largest value, for those records, inspect for the largest component value and assign that to the taxonomic order name field. If the component percentages are equal and the largest component percentages are equal, assign the first one. This method introduces some bias into the process, but because assignment of equal total component percentages is random, the overall bias effect should be largely masked.

Determining the dominant condition taxonomic order name and dominant component for STATSGO2 Data was essentially identical to the SSURGO data, using the script *STATSGO2_taxorder.py*. The main difference was there fewer data records to process.

To create the required continuous feature class of soil taxonomic order values (or assigned non-soil descriptors) these steps were followed in ArcGIS:

1. Create a SSURGO coverage that excludes soil map unit polygons without a taxorder value or were areas where soil taxonomic order information was not available.
2. Erase (*Analysis Tools.tbx > Overlay > Erase*) the STATSGO2 feature class with the SSURGO feature class, creating a feature class of STATSGO2 data where SSURGO data did not exist.
3. Merge (*Data Management Tools.tbx > General > Merge*) SSURGO data with soil taxonomic order information with STATSGO2 from step 2 above,
4. Repeat steps 1, 2 and 3 for remaining states.
5. Merge (*Data Management Tools.tbx > General > Merge*) states into a single feature class.
6. Records that had been assigned 'compname' values because they lacked 'taxorder' information were assigned new, generalized taxonomic order values.

The final soils vector data were then converted *(Conversion Tools.tbx > To Raster > Polygon to Raster)* to a 270m raster; 'FACET_SOIL_ALL_ECOREG'.

Elevation Classes – Processing began with the NED 1 arc second DEM. The native product has a cell size slightly larger than 30. The native data were therefore resampled (*Data Management Tools.tbx > Raster > Raster Processing > Resample*) to 30m cells, using 'Bilinear' as the *Resampling Technique*.

Elevation and slope classes were then derived from the resampled DEM using the Python script, *0Duke_CA_Facet_Source_Layer_Prep.py*.
30m DEM data were then aggregated using the following parameters:

- *Cell factor* = 9

- *Aggregation technique* = Mean
- *Expand extent if needed* - checked
- *Ignore NoData in calculations* – checked

The output of this process was saved as 'DEM_RASTER_270M'.

'DEM_RASTER_270M' was then reclassified into 8 600m elevation zones. This output was saved to 'DEM_CLASS_RASTER_270M.'

Slope Classes – Slope (degrees) was calculated from 30m DEM data, the output saved as 'SLOPE_RASTER_030M'. This output was then aggregated to 270m cells ('SLOPE_RASTER_270M'), using the following parameters:

- *Cell factor* = 9
- *Aggregation technique* = Mean
- *Expand extent if needed* - checked
- *Ignore NoData in calculations* – checked

'SLOPE_RASTER_270M' was then reclassified into 3 slope classes: 0 – 6 º; 6 – 18 º; and GT 18º. This output was saved to 'SLOPE_CLASS_RASTER_270M'.

Land Facets

The Python script *1Duke_CA_PNW_EcoFacets_x_Condition_x_GAPSts.py* created land facets from the constituent inputs previously described. Those constituent inputs included:

- SLOPE_RASTER_270M
- DEM_RASTER_270M
- FACET_SOIL_ALL_ECOREG

In the script, a 'Combine' was performed to create a single combined raster of draft Land Facets from 'SLOPE_CLASS_RASTER_270M', 'DEM_CLASS_RASTER_270M' and 'FACET_SOIL_ALL_ECOREG.'

Fields were added to the draft Land Facets raster to hold elevation, slope and soil class description fields. Those fields were then populated by joining and calculating the field values from source lookup tables.

Once the fields were calculated, a region group was performed. This identified isolated, single-pixel examples of a facet. These were reclassified to 'NoData' to use as a nibble mask.

To remove the isolated, single-pixel examples facets. a 'Nibble' was then performed on the draft Land Facets raster using the nibble mask from above. This output was saved out as 'FACETS_ALL_ECOREGION'.

An attribute table was built (*Data Management Tools.tbx > Raster > Raster Properties > Build Raster Attribute Table)* for 'FACETS_ALL_ECOREGION.'

Description fields were added (*Data Management Tools.tbx > Fields > Add Field)* to 'FACETS_ALL_ECOREGION' for elevation, slope, soil class descriptions. Those fields were then populated by joining and calculating the field values from the combined draft Land Facets raster.

Ecofacets

Most of our analyses looked at Land Facets Stratified by ecoregion, essentially defining each combination of soil order, elevation zone and slope class as unique from that same combination in another ecoregion. This stratification makes the analyses more germane to the species assemblages that have developed under local conditions, and prevents us, for example, from comparing a facet in an arid area to that same facet in the coastal zone.

Three additional datasets are required for the full suite of Ecofacet products. Those are:

- ❖ USGS Protected Areas Database (formatted per our 'GAP_ALL_ECOREG' dataset in the PNW gdb)
- ❖ TNC Ecoregional boundaries
- ❖ USGS NLCD 2011
- ❖ Landscape Resilience (described in the next section)

The GAP protection information was used to calculate the proportion of each Facet and Ecofacet within each GAP category. This tells us which may be under protected and require more conservation attention. The NLCD data were used to calculate the proportion of each Facet and Ecofacet in a natural state, vs. converted to agriculture or development. Landscape Resilience data was used to bin each pixel into 5 quintiles of resilience, ranked from "Far above average resilience" to "Far below average resilience" for each facet, ecofacet, and ecoregion.

The remainder of the geoprocessing is executed by the python script *1Duke_CA_PNW_EcoFacets_x_Condition_x_GAPSts.py*.

Landscape Resilience

We have defined resilience as a function of both a site's diversity of topoclimates and the site's ability to support species movement, or landscape permeability. Here, we posit that topoclimates provide species localized refugia from the direct effects of a changing climate, whereas landscape permeability reflects the ability of the landscape mosaic to facilitate species movement to and between topoclimates as they shift in response to their respective climatic envelopes.

The constituent datasets for the landscape resilience surface included:

- ❖ Topoclimate diversity surface, previously described.
- ❖ Permeability surface, previously described.

Topoclimate diversity and the Permeability rasters were multiplied together using the Raster Calculator (*Spatial Analyst Tools.tbx > Map Algebra > Raster Calculator* to produce 'LR_BASE'.

‘LR_BASE’ was then standardized from 0 – 1 using the following equation in the Raster Calculator (*Spatial Analyst Tools.tbx > Map Algebra > Raster Calculator)*:

((LR_BASE – Minimum LR_BASE value) / (Maximum LR_BASE value – Minimum LR_BASE value))
This output was saved as ‘RESIL_90_ALL_ECOREG’ in the final PNW geodatabase.

A 270m version of this data was then produced to evaluate the resilience of Land Facets.

Using the aggregate tool ((*Spatial Analyst Tools.tbx > Generalization > Aggregate)*, the ‘RESIL_90_ALL_ECOREG’ surface was aggregated using the following parameters:

- Cell factor = 3
- Aggregation technique = Mean
- Expand extent if needed - checked
- Ignore NoData in calculations – checked

The output, ‘RESIL_270_ALL_ECOREG’, is also included in the final PNW geodatabase. These data were combined with Land Facets and Ecofacets to calculate resilience for each Facet and Ecofacet class.