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Northwest Forest Plan The First 20 Years (1994-2013): Watershed Condition Status and Trend

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United States Department of Agriculture

NORTHWEST
FOREST PLAN
THE FIRST 20 YEARS (1994–2013)

Watershed Condition Status and Trends

Stephanie A. Miller, Sean N. Gordon, Peter Eldred, Ronald M. Beloin,
Steve Wilcox, Mark Raggon, Heidi Andersen, and Ariel Muldoon

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Cover: a typical stream in the Cispus River watershed, Washington. Photo by Alanna Wong.

Abstract

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The Aquatic and Riparian Effectiveness Monitoring Program focuses on assessing the degree to which federal land management under the aquatic conservation strategy (ACS) of the Northwest Forest Plan (NWFP) has been effective in maintaining and improving watershed conditions. We used stream sampling data and upslope/riparian geographic information system (GIS) and remote-sensing data to evaluate condition for sixth-field watersheds in each aquatic province within the NWFP area.

Stream conditions were evaluated based on sampling data collected from 2002 to 2013 (214 watersheds) as part of an 8-year repeating (rotating) sample design. For both rotations, approximately 60 percent of the stream scores fell between 40 and 60 and relatively few (2 percent) were less than 20; no watersheds scored above 80 during either rotation. We detected small but improving status trends in physical habitat, aquatic macroinvertebrates scores, and water temperature.

Upslope/riparian condition scores were calculated for 1993 and 2012, and the difference between these two distributions of scores was used to represent trend. In 2012, a total of 26 percent of the overall watershed area received scores above 80, 68 percent scored between 40 and 80, and only 6 percent scored below 40. Since 1993, scores in 16 percent of the NWFP area increased by more than 5 percent, while only 7 percent declined by a similar magnitude. Although at the plan level the mean score changed little (+1), there were broad-scale moderate gains resulting from vegetation growth and larger but more concentrated gains resulting from road decommissioning. These gains, which occurred predominantly in areas most heavily managed prior to the NWFP, were largely offset by high declines in scores stemming from large fires, particularly in reserve areas.

Keywords: Effectiveness monitoring, status and trend monitoring, aquatic ecosystems, riparian ecosystems, watersheds, decision-support models, Northwest Forest Plan, Aquatic Conservation Strategy, Pacific Northwest.

Preface

The effectiveness monitoring program plan for the Northwest Forest Plan (NWFP) was approved by an intergovernmental advisory committee in 1995 to meet the requirements for tracking status and trend of watershed condition, late-successional old growth, population and habitats of northern spotted owls (*Strix occidentalis caurina*) and marbled murrelets (*Brachyramphus marmoratus*), social and economic conditions, and tribal relationships. Monitoring is conducted in 1- to 5-year or 1- to 8-year intervals depending on the program. Monitoring results for the first 10 (Gallo et al. 2005) and 15 (Lanigan et al. 2012) years were documented in a series of general technical reports available online at https://www.fs.fed.us/pnw/publications/gtrs.shtml. This report covers the first 20 years of the NWFP.

Summary

The watershed monitoring module of the Northwest Forest Plan (NWFP, or Plan), also known as the Aquatic and Riparian Effectiveness Monitoring Program (AREMP), determines if the Plan's Aquatic Conservation Strategy (ACS) is achieving the goals of maintaining and restoring the condition of watersheds in the area being evaluated. This area includes lands administered by the U.S. Department of Agriculture Forest Service (FS) and the U.S. Department of the Interior's Bureau of Land Management (BLM) and National Park Service (NPS). Only the federal portion of sixth-field watersheds was included when determining watershed condition status and trend because federal land managers have no jurisdiction over nonfederal lands. Overall results are also broken down by the NWFP land use management allocations and by key versus non-key watershed designations.

We evaluated stream and upslope/riparian condition for each aquatic province within the NWFP. Scores for both the stream and upslope/riparian assessments were normalized to fall between 0 and 100. The stream evaluation was based on stream data (e.g., substrate, pieces of large wood, percentage of pool tail fines, water temperature, and macroinvertebrates) sampled from 2002 to 2013 (in 214 watersheds) as part of a repeating (i.e., rotation) sample design. We are currently halfway through our second rotation of stream sampling and have repeated 110 watersheds since the second rotation began in 2009. This analysis uses roughly half the number of watersheds as was originally intended by the sample design because revisitation will not be completed until 2017. This report compares the first rotation of visits (2002–2009) to the first 4 years of the second rotation (2010–2013); it also estimates the yearly trend in status scores to give a general idea of current patterns. We used a reference network nearest-neighbor statistical approach to calculate the physical habitat scores for each watershed. The analysis focuses on the current state of the landscape and does not try to identify what the range of natural variation was under the disturbance regime present before Euro-American settlement or to identify areas free from all human disturbance. The reference network used here was built from a set of least-human-disturbed sites, which excludes sites with large amounts of human impacts but includes sites with natural disturbances. Aquatic macroinvertebrates and 7-day average maximum water temperature were analyzed separately from physical habitat to provide an additional assessment of overall watershed condition.

For both rotations, approximately 60 percent of the stream scores fell between 40 and 60, and relatively few (2 percent) were less than 20; no watershed scores were above 80 during either rotation. For watersheds with scores under 40, the substrate and pool tail fines score components of the physical habitat were the most influential factors.

We detected improving trends in the yearly status scores for physical habitat, aquatic macroinvertebrates, and 7-day average maximum water temperatures. Future sampling will reveal whether this increase in aquatic macroinvertebrate assemblages and reduction in mean watershed temperatures persists. Completing the current and future rotations based on our current sampling design will inform our understanding of these trends. Because the second rotation is not scheduled to be completed until 2017, any rotational trend results should be considered preliminary because we have not achieved design sample size.

Upslope/riparian conditions were evaluated for federal lands in all 1,974 sixth-field watersheds in the NWFP area with at least 5 percent in federal ownership. The assessment was based on factors affecting five major aquatic processes: sediment production and delivery (mass wasting), wood production and delivery, riparian habitat, hydrologic processes (specifically peak flows), and fish passage. The status of each process was estimated based on impacts of road densities and vegetation conditions derived from mapped data, including road metrics from U.S. Forest Service and Bureau of Land Management geographic information system (GIS) road layers and vegetation metrics derived from satellite imagery.

In 2012, a total of 26 percent of watersheds scored above 80; 68 percent scored between 40 and 80; and only 6 percent scored below 40. Less than 1 percent of the area scored below 20 in 1993 and 2012 status assessments. Since 1993, scores in 16 percent of the NWFP area increased by more than 5 percent, while only 7 percent declined by a similar magnitude. Although at the plan level the mean score changed little (+1), an increase in scores was especially noticeable as a shift from scores in the low to mid-range (15 to 50) to the higher range (60 to 90). There were broad-scale moderate gains resulting from vegetation growth and larger but more concentrated gains resulting from road decommissioning. These gains, which occurred predominantly in the areas most heavily managed prior to the NWFP, were largely offset by high declines in scores stemming from large fires, particularly in reserve areas.

In terms of the land use allocations set by the NWFP, upslope/riparian condition scores were highest for congressionally reserved (CR) areas (mean ± standard deviation for 1993, 2012) (75 ± 18, 74 ± 18), followed by late-successional reserves (LSR) (66 ± 20, 68 ± 19) and matrix lands (62 ± 19, 65 ± 19). Changes in mean scores over the 20-year period were slight, with CR areas indicating a potential slight decline (-1 ± 7), while LSR and matrix lands indicating potentially small increases (+2 ± 8, +3 ± 6). Scores for key watersheds, designated for their current or potential capacity to provide high-quality habitat or refuge for aquatic- and riparian-dependent species, differed little from non-key watersheds (68 ± 20, 68 ± 19 versus 67 ± 20, 69 ± 19).

The spatial distribution of watershed scores showed some noticeable patterns. The highest scores (>80) were found in the central Olympic Peninsula (Olympic National Park), in the north-central Cascade Range, and scattered along the Cascades in Oregon and Washington, often corresponding to designated wilderness areas. Other high-scoring areas occurred in the Siuslaw National Forest, in the northeast and southwest areas of the Rogue River-Siskiyou National Forest, and in scattered wilderness areas in the Klamath Mountains in northern California. Low scores (<40) were seen in the southern Olympic Peninsula region and along the eastern flank of the Oregon Coast Range and western flanks of the Cascade Range in Oregon and Washington. However, these lower scoring areas also showed the most consistent, moderate upward trend in scores over the Plan area. Growth in vegetation and decommissioning of roads made considerable positive impact on the upslope/riparian condition scores in these areas. These gains, which occurred predominantly in areas most heavily managed prior to the NWFP, were largely offset by high declines in scores stemming from large fires, particularly in reserve areas.

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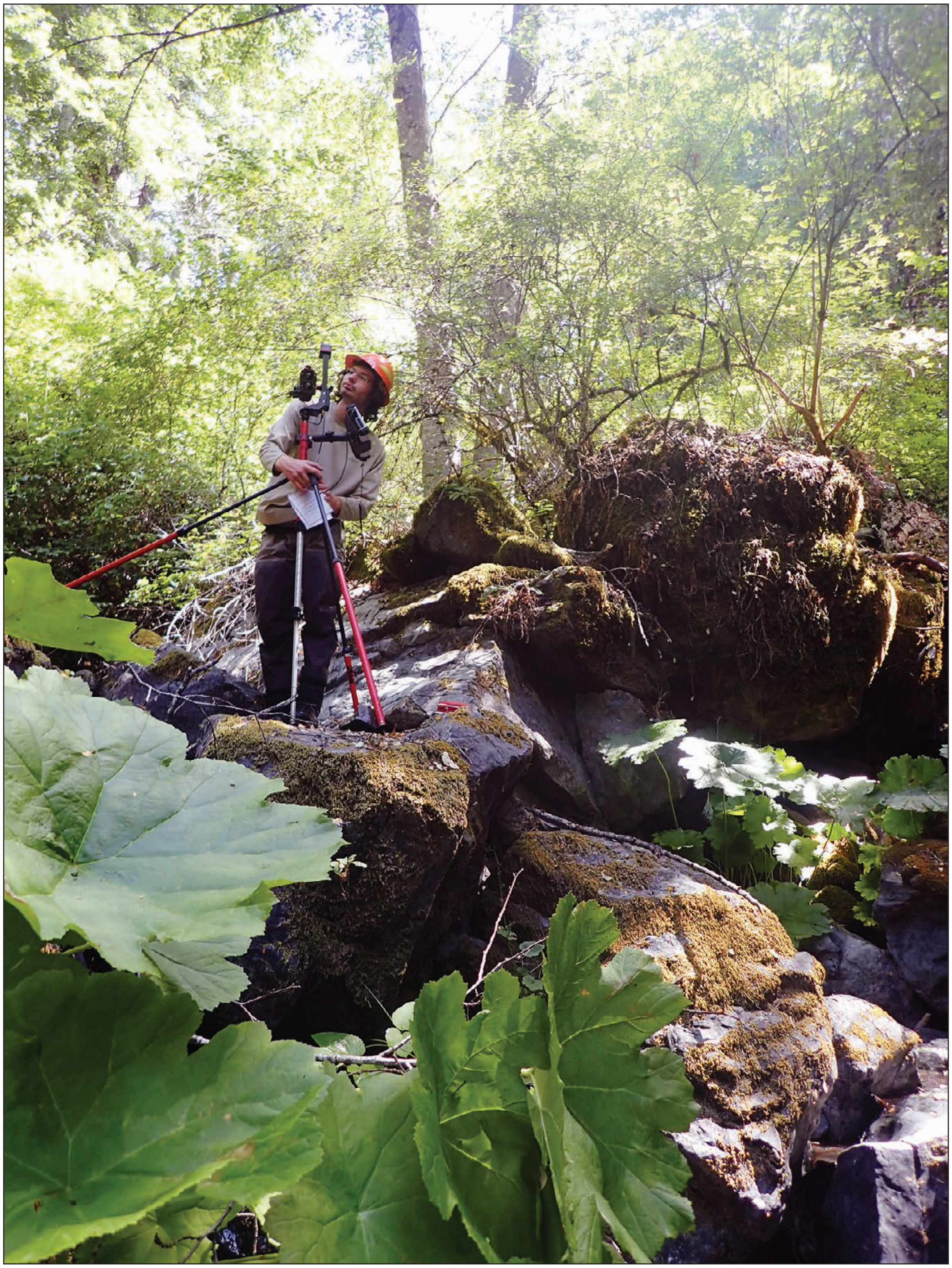


Morganne Price

Field crew sets up equipment to measure stream channel morphology.

Chapter 1: Introduction

In 1994, the Northwest Forest Plan (NWFP, or Plan) Record of Decision amended 19 national forest and seven Bureau of Land Management (BLM) resource plans within the range of the northern spotted owl (*Strix occidentalis caurina*) (USDA and USDI 1994). The NWFP put in place a new approach to federal land management. Key components of the Plan included a new set of land use allocations—late-successional reserves, matrix lands, riparian reserves, adaptive management areas, and key watersheds. The NWFP standards and guidelines provided direction regarding how these land use allocations were to be managed. In addition, the NWFP put in place a variety of strategies and processes to be implemented. These included adaptive management, an aquatic conservation strategy (ACS), late-successional reserve and watershed assessments, a survey-and-manage program, an interagency executive organization, social and economic mitigation initiatives, and monitoring.

The monitoring component of the Plan provided a means to address the effectiveness of these strategies and compliance with forest management laws and policy. Monitoring is essential and required:

> Monitoring is an essential component of the selected alternative. It ensures that management actions meet the prescribed standards and guidelines and that they comply with applicable laws and policies. Monitoring will provide information to determine if the standards and guidelines are being followed, verify if they are achieving the desired results, and determine if underlying assumptions are sound [USDA and USDI 1994].

U.S. District Court Judge William Dwyer reinforced the importance of monitoring in his 1994 decision declaring the NWFP legally acceptable: “Monitoring is central to the [NWFP’s] validity. If it is not funded, or not done for any reason, the plan will have to be reconsidered” (Dwyer 1994).

An interagency effectiveness monitoring framework was implemented to meet requirements for tracking status and trend for watershed condition, late-successional and old-growth forests, social and economic conditions, tribal relationships, and population and habitat for marbled murrelets (*Brachyramphus marmoratus*) and northern spotted owls. The Aquatic and Riparian Effectiveness Monitoring Program (AREMP) was developed to implement the effectiveness monitoring component of the ACS. Periodic analysis and interpretation of monitoring data is essential to completing the adaptive management cycle. This important step was described in the overall monitoring strategy (Mulder et al. 1999) and was approved by the Regional Interagency Executive Committee. Beginning in 2005, monitoring reports have been published at 5-year intervals and made available at https://reo.gov/monitoring/.

AREMP assesses the status and trend of watersheds at the sixth-field hydrological unit (HU) scale. The program employs two different methodologies to evaluate condition. The upslope/riparian condition program component uses geographic information system (GIS) data to evaluate all watersheds with at least 5 percent of their area on federal land within the NWFP area. The stream-condition component is based on monitoring stream attributes within randomly selected watersheds with a minimum of 25-percent federal ownership along the 1:100,000 stream layer.

This 20-year report evaluates status and changes in condition under the ACS during the years 1993–2013. Although this report is intended to evaluate 20 years of data, we were able to achieve a full 20-year analysis for only the upslope/riparian portion of the program, for which data have been available since the NWFP’s inception. The stream-condition monitoring program began in 2002 and is currently on an 8-year rotation to visit approximately 250 randomly selected watersheds. The first rotation was completed in 2009; we are currently in the second rotation and are about halfway through repeating data collection on these watersheds.

Overview of the Aquatic Conservation Strategy

The ACS is a comprehensive, regionwide strategy designed to maintain, restore, and protect those processes and landforms that create good ecological conditions in watersheds, such as high-quality habitat for aquatic and riparian organisms and good water quality (FEMAT 1993, USDA and USDI 1994). The strategy contains nine objectives that describe general characteristics of functional aquatic and riparian ecosystems that are intended to maintain and restore good habitat (see Reeves et al. 2004). This approach is intended to prevent further degradation of aquatic ecosystems and to restore habitat over broad landscapes, as opposed to focusing on individual projects or species. Because aquatic and riparian organisms evolved in dynamic environments influenced by natural disturbance, the authors of the strategy believe that stewardship of aquatic resources will most likely protect biological diversity and productivity when land use activities do not substantially alter the natural disturbance regime to which organisms are adapted. Therefore, the strategy uses several tactics to try to maintain the natural disturbance regime in watersheds. The strategy also includes standards and guidelines that apply to management activities in riparian reserves and key watersheds. The four components of the strategy are intended to work in concert to maintain and restore the health of aquatic and riparian ecosystems:

- Watershed analysis—characterize watersheds and provide a basis (context) for making management decisions.
- Riparian reserves—enhance habitat for riparian-dependent organisms, provide dispersal corridors for terrestrial species, and protect water quality.
- Key watersheds—provide high-quality habitat or refuge for aquatic- and riparian-dependent species after restoration.
- Watershed restoration—recover degraded habitat and maintain existing good conditions.

Although late-successional reserves are not listed among the components of the strategy, they provide increased protection for aquatic and riparian ecosystems. Late-successional reserves contain areas of high-quality stream habitat that serve as refuge for aquatic and riparian organisms and as source areas from which organisms can move to recolonize formerly degraded areas (USDA and USDI 1994).

Monitoring was included in the strategy to achieve three goals (USDA and USDI 1994: section B-32):

- Ensure that management actions follow the standards and guidelines and comply with applicable laws and policies (implementation monitoring).
- Determine the effectiveness of management practices at multiple spatial scales ranging from individual watersheds to the entire NWFP area (effectiveness monitoring).
- Determine whether the assumptions underlying the strategy are sound (validation monitoring).

The first goal was accomplished through the implementation monitoring program (Baker et al. 2005). AREMP was developed to reach the second goal of effectiveness monitoring.

Effectiveness Monitoring Questions

AREMP is charged with answering questions about the effectiveness of the ACS in achieving its goal of maintaining and improving the condition of watersheds in the NWFP area (Reeves et al. 2004). This report focuses on responding to two questions that provide insight for evaluating the success of the aquatic conservation strategy:

1. What is the status and trend of stream conditions?
2. What is the status and trend of upslope/riparian watershed conditions?

Stream conditions and upslope riparian conditions are defined, methods and analytical approaches are described, and results are reported separately in the following sections of this report.

Erik DeSilva

Crew members lay out a stream survey site.

Chapter 2: Methods

To answer the two principal monitoring questions outlined in chapter 1 (see "Effectiveness Monitoring Questions" section), different data sources and methods were used. Owing to updates in information and data sources and to improvements in analytical techniques, results in this report are not directly comparable to previous reports. In this report, comparisons to earlier years use consistent and updated methodology throughout all time periods and represent the most current information available as of 2013. We first describe the common elements of the program, study area, and conceptual models, then provide more details on study designs, data sources, and analytical procedures for the two principal monitoring questions.

Overview of the Aquatic and Riparian Effectiveness Monitoring Program

The Aquatic and Riparian Effectiveness Monitoring Program (AREMP) is responsible for the effectiveness monitoring component of the Aquatic Conservation Strategy (ACS). Its purpose is to assess the effectiveness of the Northwest Forest Plan (NWFP, or the Plan) by periodically determining the status of watershed condition and using this information to track trends in the condition of watersheds through time. Watershed condition refers to a combination of aquatic, riparian, and upslope characteristics within sixth-field hydrological units (HU). Hydrological units are based on the U.S. Geological Survey classification of river systems defined by topography and classified into smaller, relatively uniformly sized subunits using a combination of drainage basins or distinct hydrological features (Seaber et al. 1987). Sixth-field HUs are small units (10,000 to 40,000 ac) that are thought to have less internal variation, thus allowing us to more easily detect changes compared to larger fifth-field units (Reeves et al. 2004). Hydrological units are commonly used as a framework for water-resource and related planning and are the basis for defining watersheds in the ACS (Reeves et al. 2004). True watersheds are defined as topographic surfaces where water drains to a specific point, and they differ extensively in scale (Omernik et al. 2011). We acknowledge that hydrological units and true watersheds are not always synonymous. The sixth-field HU provides a discrete unit that is used as the basis for AREMP monitoring design. Although they were the smallest consistently delineated units available at the time, they have undergone minor boundary modifications since the NWFP record of decision was signed. These sixth-field HUs, henceforth called watersheds, serve as discrete units that can be aggregated at multiple spatial scales to make assessments of condition.

The original intent of AREMP was to combine all characteristics into a single watershed evaluation (Reeves et al. 2004). However, the evaluation process evolved, leading to stream condition and upslope/riparian condition being considered separately because different data sources and sampling designs were used. Many geographic information system (GIS) data sources are not updated yearly, making yearly upslope condition assessments difficult because they often are temporally not in sync and also are computationally intensive. Further, the upslope assessments are considered a census, whereas the stream program relies on a statistical sample to extrapolate to the region. Stream condition is based on physical stream data (e.g., substrate, pieces of large wood, pool tail fines), macroinvertebrates, and water temperature. Upslope/riparian condition is based on mapped data (e.g., road density and vegetation data).

Stream condition and upslope/riparian condition are determined by integrating multiple sources of information (Reeves et al. 2004). The results are assessed as a distribution of condition scores across the NWFP area. If the NWFP is effective, the distribution of conditions should either stay the same or improve over time (Reeves et al. 2004). Note that the authors of the ACS did not intend for each of the objectives to be monitored individually, nor did they expect that the objectives would be met in each watershed at all times (USDA and USDI 2003).

Evaluating the effectiveness of the ACS is based on measuring changes in the distribution of stream and upslope/riparian condition scores through time. The ACS does not describe the baseline condition of streams and watersheds, nor does it define a desired distribution. We infer that if the strategy has been effective in maintaining and improving the condition of watersheds, then the distribution of stream and upslope/riparian condition scores should shift in a direction that indicates improvement (Reeves et al. 2004).

Definition of Watershed Condition

The definition of watershed condition developed by the monitoring program is based on the goals of the ACS and on guidance provided by the aquatic monitoring plan (Reeves et al. 2004). The NWFP was designed to account for the complex and dynamic nature of aquatic ecosystems resulting from the wide range of physical characteristics, natural disturbance events, and climatic features of the region (Benda et al. 1998, Naiman et al. 1992). Monitoring these dynamic watershed processes was accomplished by linking them to measurable physical attributes (e.g., vegetation structure, road density, water temperature). Reeves et al. (2004) initially identified 90 potential attributes that represent key functions and processes in watersheds. This number of attributes was reduced based on criteria established by Noon et al. (1999). The monitoring program further removed some attributes that were found not to produce useful or consistent information (Lanigan et al. 2007). The remaining attributes represent upslope, riparian, and stream processes.

Many of the physical indicators and associated thresholds were originally chosen for their relevance to native or desired fish species because of these species' roles in driving management policies (including the NWFP itself) and the availability of research related to their habitat needs. However, this report represents a shift toward the broader intent of the ACS and assessment of the entire sample frame, which extends outside the distribution of salmonids. The ACS objectives clearly aimed to protect salmon and steelhead habitat on federal lands and they also strived to protect other fish and riparian-dependent organisms. The ACS notes that defining explicit standards for habitat elements would be "insufficient for protecting even target species." AREMP was designed to assess the broader extent of the ACS and includes approximately 75 percent of sample sites outside anadromous fish-bearing streams (Miller et al. n.d.a.). However, indicators and thresholds used in previous assessments were associated with the habitat requirements for organisms that are not present within the majority of the areas the program samples. This report represents a shift toward the broader intent of the ACS and assessment of the entire sample frame.

AREMP was developed to assess the effectiveness of cumulative federal management actions, as defined by the ACS, on aquatic and riparian ecosystems (USDA and USDI 1994). In the design phase, it was noted that one of challenges to implement AREMP was the poor state of knowledge about aquatic/riparian science. For example, the frequency distribution of expected watershed condition scores and information regarding reference conditions needed to be developed as watersheds were monitored (Reeves et al. 2004: 5). Empirical analysis procedures were expected to be developed as new science became available and as data were collected as part of the monitoring program (Reeves et al. 2004).

In this assessment, we use a defined reference network of least-human-disturbed sites across the NWFP to estimate comparison indicator values for managed sites. We define the least-human-disturbed reference network as those areas currently observed to be under minimal human impact (but including fires and other natural disturbances) since AREMP began monitoring (Agee 1993, Parks et al. 2015, Stephens and Ruth 2005). However, several issues with using least-human-disturbed forests warrant recognition. First, the subset of these forests in the NWFP area is unlikely to fully represent the historical range of variation of native forests in the region. It is estimated that "older forests of today cover about half the area they did a century ago" (Davis et al. 2017). It is unknown how native forest heterogeneity has been altered as a consequence. Note that many forests in the "least-human-disturbed" watersheds of the region have been altered by fire suppression, which has increased stand density and shade-tolerant tree species, and which has reduced the occurrence of early-seral vegetation. In moister forests of the region, fire suppression has reduced the occurrence of stand-replacement disturbances. In drier forests, increased fuel loads may have led to larger patches of high-severity fire than those that would have occurred historically. As it would be very challenging to define a true reference condition across a landscape in which all sites have been subject to at least some human impacts, including climate change, the use of least-human-disturbed areas to isolate effects of human management is a useful innovation, despite the limitations noted above. Deviation from this range of expectations is used as evidence for degradation resulting from management activities. In using this common least-human-disturbed reference condition approach, the practitioner is asking whether management activities are altering the biological, physical, or chemical properties of an ecosystem beyond a level observed within a reference network.

Individual watersheds will cycle through conditions of high and low habitat quality, and not all watersheds can be expected to have high condition scores at any one time (Naiman et al. 1992, Reeves et al. 1995, Roper et al. 1997). Therefore, the most important product of the monitoring program is the overall distribution of individual watershed scores in the NWFP area. Implementing the ACS should result in an overall distribution of watershed condition scores that is maintained or improves over time because some watersheds are currently assumed to be degraded (FEMAT 1993).

Study Area

The NWFP encompasses approximately 9.7 million ha (24 million ac) of federal lands in western Washington, western Oregon, and northwestern California and includes the entire geographic range of the northern spotted owl (*Strix occidentalis caurina*) (fig. 1). Stream and riparian habitat conditions differ greatly across the NWFP area because of natural and management-related factors. Geologic and climatic history influence topographic relief, landforms, channel patterns, and dominant erosion processes. Precipitation ranges from more than 508 cm (200 inches) per year in some areas near the coast to less than 51 cm (20 inches) on the east side of the Cascade Range. Riparian vegetation communities are structured by climate and the disturbance regimes of the area, including hydrologic processes and disturbances such as forest fires (Benda et al. 1998, Naiman et al. 1992). Many of these critical components of landscape form and function create distinctive combinations that are characteristic of each physiographic province in the region. Physiographic provinces incorporate physical, biological, and environmental factors that shape broad-scale landscapes and therefore reflect differences in responses such as soil development and plant community structure.

Physiographic provinces are useful in describing both terrestrial and aquatic ecosystems, and different processes dominate the functioning of these ecosystems. Consequently, the Forest Ecosystem Management Assessment Team (FEMAT 1993) used different physiographic province boundaries for aquatic and terrestrial ecosystems. The physiographic boundaries used in this analysis were developed from those used in the aquatic ecosystem assessment (FEMAT 1993) and were based on broadly drawn precipitation and geologic zones, as well as political boundaries (state lines). These province boundaries differ from those used by the other effectiveness monitoring components (e.g., the late-successional old-growth and northern spotted owl assessments), which were delineated primarily by vegetation type and political boundaries. The aquatic province boundaries used by FEMAT (1993) were not available in a digital format, so their province boundary lines were refined by using level-four lines described by Omernik in Oregon and Washington (Bryce et al. 1999), Bailey ecological subsections lines in California (Bailey et al. 1994), and the Cascade Range crest derived from the Forest Service Pacific Northwest Region sixth-field HU watershed layer.

The NWFP area contains eight aquatic physiographic provinces, including the Olympic Peninsula, North Cascades, Puget-Willamette Trough, West Cascades, Washington-Oregon Coast, High Cascades, Klamath-Siskiyou, and Franciscan (fig 1). Land ownership in the Puget-Willamette Trough is predominantly private, and none of the watersheds in this province met the monitoring program minimum criterion of federal land ownership. Consequently, this province was not included in the analysis. Descriptions of the provinces, based largely on those presented by FEMAT (1993), are available in Gallo et al. (2005).

Because the NWFP applies only to federally managed lands, watersheds must contain a minimum of 25 percent of the total length of the stream (1:100,000 National Hydrography Dataset stream layer) within federal ownership (USDA Forest Service [FS], USDI Bureau of Land Management [BLM], or USDI National Park Service [NPS]) to be considered for sampling and analysis in the stream monitoring program. The ownership criterion was recommended by Reeves et al. (2004) to gauge the influence of

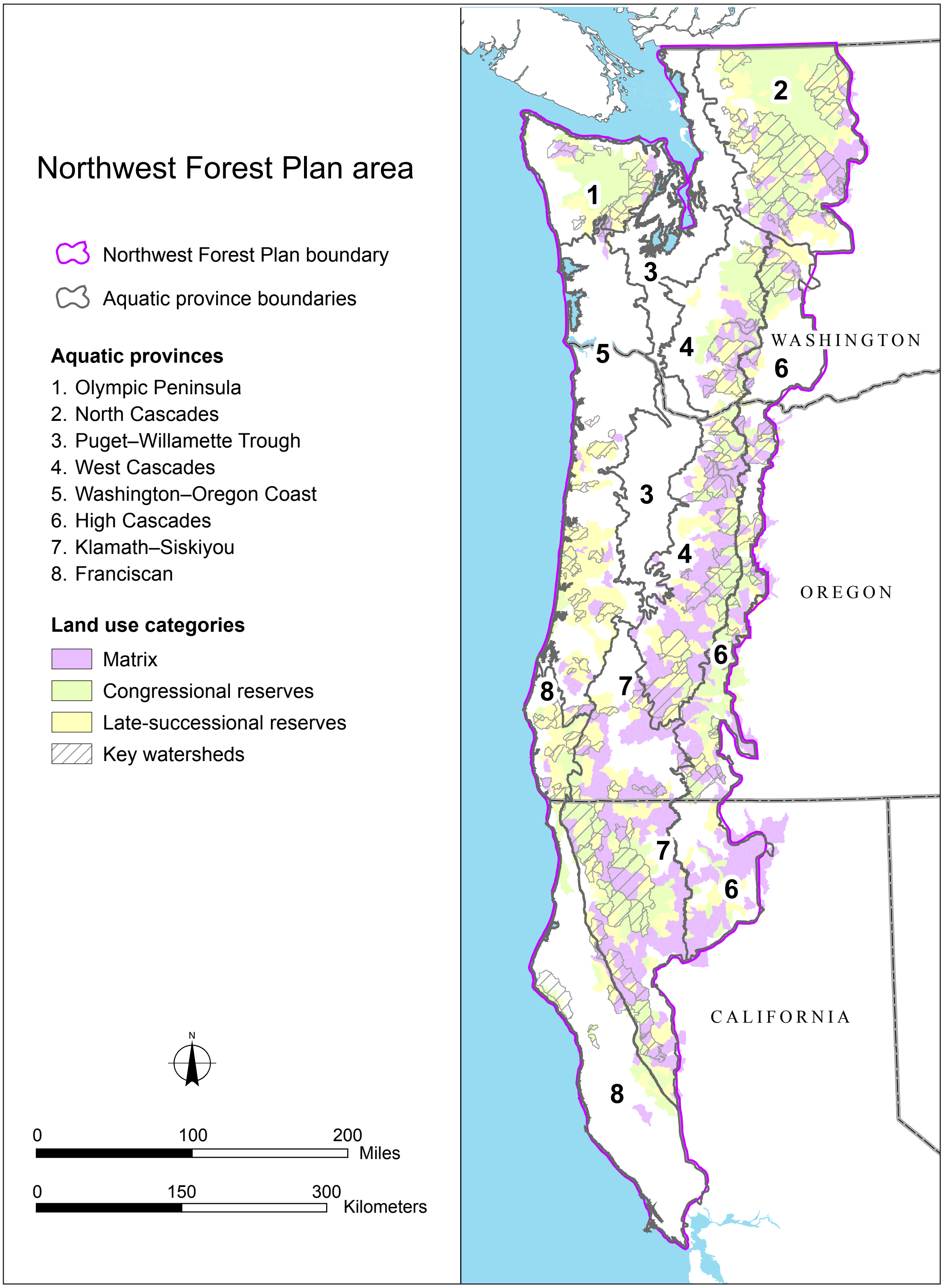


Figure 1—Map of the Northwest Forest Plan (NWFP) area, which encompasses the range of the northern spotted owl, showing seven aquatic provinces used to assess watershed condition. Lands being evaluated include those administered by the USDA Forest Service and the USDI Bureau of Land Management and National Park Service. Land use categories assign different management guidelines and priorities to zones within the NWFP area.

the strategy while avoiding sampling watersheds in which the contribution of federal lands to the condition of the watershed was less significant. To be more consistent with the Forest Service national watershed condition framework (USDA FS 2011a, 2011b) and to include a greater percentage of BLM land, for this upslope/riparian condition analysis we increased the amount of land area analyzed to include watersheds with as little as 5 percent federal lands by area. Feedback from local managers suggested that it would be more useful to local units to have more watersheds included in the upslope analysis. The NWFP area contains 2,810 watersheds, of which 2,039 contain some land that is federally owned, and 1,974 have at least 5 percent federal ownership by area. The ownership criterion excludes about 1 percent of the federal lands in the NWFP area from this analysis. Only the federal portion of watersheds was included when determining watershed condition status and trend because federal agency land managers have no jurisdiction over management of nonfederal lands.

Land Use Categories

Land use categories provide a key spatial component of the NWFP by assigning different management guidelines and priorities to zones within the NWFP area. We reviewed our two monitoring questions in the context of two types of land classification: the general NWFP land use allocations (Congressionally reserved, late-successional reserve, and matrix) and the ACS designations of key versus non-key watersheds. The land use allocation categories presented here are the same as those described by Tuchmann et al. (1996). Boundaries for land use categories did not follow watershed boundaries; consequently, multiple land use categories may be present in individual watersheds. Upslope/riparian analysis used actual boundaries for each land use category. For the stream assessment, each watershed was classified into a single land use category based on the category that covered the largest amount of its area. The following paragraphs briefly describe each category.

Congressional reserves (CR)—
Lands reserved by the U.S. Congress such as wilderness, wild and scenic rivers, and national parks and monuments.

Late-successional reserves (LSR)—
Lands reserved for the protection and restoration of late-successional and old-growth forest ecosystems and habitat for associated species, including marbled murrelet reserves and northern spotted owl activity core reserves. Adaptive management areas managed under LSR guidelines were included in LSR (see below).

Matrix—
Lands not included in one of the other allocations. Scheduled timber harvest activities may take place in matrix lands. For analysis and reporting purposes, some adaptive management areas were grouped with matrix (see below).

Riparian reserves—
Lands along streams and potentially connected unstable areas in which special standards and guidelines direct land use in order to protect riparian and aquatic habitats. These reserves were not totaled as a separate land allocation because they have not been formally mapped for much of the NWFP area; instead they are included as part of the above land allocations in which they fall. However, the upslope/riparian assessment does incorporate approximate riparian reserve areas in a number of its indicators.

Adaptive management areas—
Areas identified to develop and test innovative management approaches for integrating and achieving ecological, economic, and other social and community objectives (USDA and USDI 1994). These include a mix of lands where timber production can occur and where timber production must follow LSR guidelines. For analysis and reporting purposes, watersheds in adaptive management areas were grouped with either matrix lands or LSR, depending on which allocation covered the largest amount of its area.

Key watersheds—
Areas intended to "serve as refuge for aquatic organisms, particularly in the short term for at-risk fish populations, to have the greatest potential for restoration, or to provide

sources of high-quality water" (Haynes et al. 2006). Key watersheds were identified as part of the ACS and were independent of the land use allocations in the NWFP, thus key and non-key watershed designations overlay the other land use allocations. Key watershed delineation began prior to the development of the interagency standard fifth-field and sixth-field watershed boundaries, so their boundaries are not always coincident. For this analysis, 520 of our 1,974 watersheds are considered key because they have more than 50 percent of the area designated as key watershed. The remaining 1,454 watersheds are considered as non-key in this assessment.

Study Design

Assessment of Watershed Condition

For this assessment, models were developed separately for stream and upslope/riparian condition following the processes defined by the monitoring plan and the datasets. Upslope/riparian evaluations were combined in one model because they were based on the same data sources: watershed-wide mapped data (e.g., road density, canopy cover) derived from satellite imagery and other corporate datasets. The stream status evaluation was based on sampling stream data (e.g., 7-day maximum average water temperature, physical habitat, macroinvertebrates) collected in watersheds by AREMP field crews from 2002 to 2013. Each model comprises three basic elements: a list of measurable watershed attributes to evaluate; evaluation criteria for rating each attribute; and a model structure, which defines how the attribute scores were aggregated into an overall score. Data from each watershed were analyzed through the appropriate models to produce composite scores on a scale from 0 to 100. Given the presence of natural disturbance, the expectation is not to have all of the watersheds with a score of 100 but to maintain a range across the landscape similar to what might be expected based on the reference network scores. The ACS goal is to ensure that the initial distribution of conditions are maintained or are improved over time.

Monitoring Questions

1. What Is the Status and Trend of Stream Conditions?

Study design—
At the inception of the NWFP, 1,373 watersheds in the sixth-field watershed coverage (version 1.1, dated 2002) with greater than 25 percent of their area in federal ownership were identified, and 250 were randomly selected using a spatially balanced sampling method (Stevens and Olsen 2003, 2004). The original study design called for sampling 50 watersheds per year, with repeat visits to watersheds beginning on the sixth sampling year. Because of funding limitations, this goal was not realized. The study design was altered to complete about 28 watersheds per year, with repeat visits beginning in the ninth year of sampling. An 8-year cycle of visits is referred to as a rotation. As of 2013, we have visited a total of 214 watersheds and are halfway through the second rotation; 189 watersheds were visited during the first rotation, and, so far, 25 new watersheds have been visited during the second rotation; 110 watersheds have been repeated.

Within each watershed, stream data were collected at multiple (4 to 11) sites. These sites were also selected using a spatially balanced procedure subject to logistical constraints (e.g., unable to sample four sites minimum, fire, or illegal activity). Sample points were drawn from the 1:100,000 National Hydrological Data Layer (dated 2000), where points represent the downstream starting location for stream surveys. The survey length at each site was determined as 20 times the average bankfull width, with a minimum and maximum of 160 m and 460 m, respectively. Eleven equally spaced transects over the stream length were surveyed at each site.

Attributes—
Stream attributes were collected at each site; details on data collection methods can be found in the AREMP field protocol (AREMP 2013). Data for each transect attribute were summarized together at the site scale. Each site level attribute was classified into one of four metrics: pool tail fines, wood, substrate, or macroinvertebrates. Water temperature, collected at the lowest point on federal lands

within each watershed, was analyzed separately from the physical habitat and macroinvertebrates. Three metrics, pools (pool tail fines), wood (medium and large frequency), and substrate (percent fines under 6 mm), were used as the basis for calculating physical habitat stream condition scores from the site level individual attributes (fig. 2). Using these metrics allows for increased comparability of scores across aquatic physiographic provinces and retains much of the framework for watershed condition defined through provincial expert workshops. Ultimately, the attributes selected for inclusion in each model element (fig. 2) were those that were able to detect a management signal (Al-Chokhachy et al. 2010, Anlauf et al. 2011, Stoddard et al. 2007).

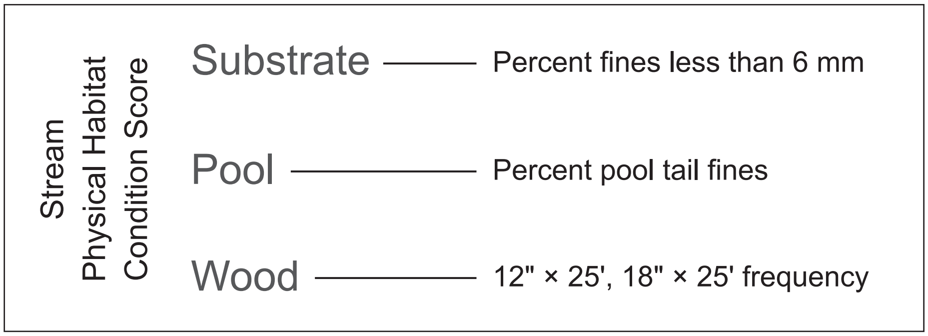


Figure 2—Stream physical habitat condition model evaluation structure included three metrics: pool tail fines, wood, and substrate. Each metric contains individual site-level attributes used as the basis for calculating the metric. Site-level stream physical habitat condition values were aggregated and analyzed hierarchically at the watershed level. Nearest-neighbor characteristics used to describe individual attributes can be referenced in table 8.

A change from previous models was to evaluate macroinvertebrates separately from physical habitat. Previously, both macroinvertebrates and amphibians data were collected and summarized together into a biological condition score. As of 2012, we no longer sample for amphibians because of the unreliability of presence/absence data. Macroinvertebrates are a useful indicator of degradation in a system (Hawkins et al. 2000). Similarly to temperature, we have chosen to analyze macroinvertebrates separately and not integrate this score into an overall stream condition score. For the macroinvertebrate metric, we are using an observed-to-expected (O/E) index developed specifically for the AREMP sample frame (Miller et al., n.d.). These separate macroinvertebrate and temperature scores will be used in concert with the physical habitat index as multiple lines of evidence for the condition of the system; recognizing that each metric alone may be misleading as to watershed condition trend over time, results from all three metrics should be used in concert to interpret overall condition.

Data analysis—
Although the field-sampled attributes were expected to remain constant over time, analytical procedures were anticipated to change as new science became available (Reeves et al. 2004). For this report, each stream physical habitat attribute was evaluated and scored using an updated approach from previous reports. Past evaluations relied on a decision-support model, with scoring thresholds taken directly from the literature, expert opinion, or data from other studies (some of which had sampling protocols that were not comparable to those used by AREMP). In addition, many threshold values did not encompass the range of values collected in AREMP data, and often the threshold range was smaller than AREMP measurement error of a given attribute. Thresholds used in previous assessments were associated with the habitat requirements for salmonids, which are not present within the majority of the areas that the program samples. Rather than define new thresholds for individual organisms, which would take information we did not currently have, we chose to use a reference condition approach as a basis for scoring. Here, to understand whether cumulative management was effective under the ACS, we ask whether the distribution of stream conditions was maintained or shifted toward conditions observed in the least-human-disturbed reference network.

Reference conditions are frequently used by bioassessment programs that monitor ecological condition throughout the world (Herlihy et. al. 2009; Pollock et al. 2012; Pont et al. 2006, 2007, 2009; Whittier et al. 2007). We defined a reference network distribution from existing sampled sites that experienced minimal human impacts and which represent the state of the landscape since AREMP began sampling in 2002 (Miller et al. 2016). Here we compare conditions in managed sites to conditions found in these sites with minimal human impacts; these areas provide our best estimate not of pristine conditions but of conditions that might have been expected with minimal forest management since the inception of the NWFP. We used GIS and remote-sensing data summarized at two spatial extents: true watershed (broad level human disturbance) and a smaller 2-km polygon watershed above a site (localized human disturbance), to quantify stressor and natural (environmental) variables. More than 5,500 candidate sites compiled from five agencies were used to define least-disturbed reference conditions. Each watershed was characterized using a suite of land use and land-cover variables that quantified both anthropogenic stressors and natural characteristics. Reference sites were defined as sites that fell below the 25th percentile for all human disturbance variables (table 1), then subsequently passed inspection based on visual assessment of the lack of frequent or intense human disturbance in aerial photographs. Visual inspection of multiple years of Google Earth™ images identified 200 sites that had little to no evidence of any harvest within the last 20 years at either the true watershed or localized scales. Another 60 sites were also included as least disturbed but had some evidence of forest harvest in a small percentage (less than 10 percent) of the overall catchment at a distance greater than 2 km upstream from the data collection site. The visual screening tool eliminated about 30 sites from consideration as least disturbed by human activity, such as logging in the catchment. Visual inspection found that sites designated as least disturbed did have evidence of natural disturbances—both landslides and fires. Natural disturbance was not used as a method to select the least disturbed, but was recorded to ensure that we included a range of natural disturbances and seral stages across the landscape within the least-human-disturbed reference network. To ensure the consistency of metrics, the final reference network for this analysis was restricted to AREMP sites (n = 257). Overall, these sites were well distributed across observed gradients of climate and geology within the AREMP study area. Least-human-disturbed sites were found at slightly higher elevations than managed sites, likely due to easier human access to lower elevation forests for harvest or conversion to other uses, and least-human-disturbed sites were therefore slightly less erosive and slightly cooler than managed sites.

Scoring for each attribute is based on calculating the deviation of an attribute at an individual site from the expected value estimated from a network of least-human-disturbed reference sites with similar environmental characteristics. Environmental characteristics are variables such as geology that do not change with management activities. Expected values of stream attributes will vary with these characteristics. For example, characteristics such as stream gradient or elevation can strongly influence what we would expect the values of attributes to be in least-human-disturbed systems; as such, these types of characteristics must be accounted for when using a reference network (Stoddard et al. 2007). In previous assessments, characteristics such as gradient above 4 percent eliminated use of individual attributes, despite the fact that sites were commonly above this threshold.

Table 1—Reference percentile thresholds

			Percentile	
Disturbance variables		**Unit**	**25th**	**90th**
Road density	Custom data[a]	km/km^2	1.35	3.87
Stream crossing	Custom data[a]	Count/km^2	0.24	1.01
Agriculture	Jin et al. 2013	Percent	0.05	2.74
Developed open space	Jin et al. 2013	Percent	2.00	7.82
Mines	Mine data[b]	Percent	0.21	26.64
Gravel mines	Mine data[b]	Mines/km^2	0.01	0.06
Canals	NHD[c]	Percent	1.70	29.27
Distance to dam	NHD[c]	Kilometers	20.56*	3.56

[a] Custom dataset completed from Forest Service, Bureau of Land Management, and Chico State University data.

[b] Mine data (http://minerals.usgs.gov).

[c] National hydrology dataset (http://nhd.usgs.gov).

Note: Candidate reference sites were defined as sites that fell below the 25th percentile for all human disturbance variables with the exception of distance to dam, where the 75th percentile* was used. Candidate least human-disturbed reference sites were visually inspected using aerial photos before passing into the reference network used for nearest-neighbor analysis. The 90th percentile was used to define sites with the most human disturbances.

Consequently, sites were eliminated from analysis, which resulted in overweighting of individual attributes included in the watershed condition scores both at the site and watershed level, as well as in reduced site sample sizes within many watersheds. We evaluated three approaches to selecting reference sites (Miller et al. n.d.) and settled on a nearest-neighbor approach (described by Bates Prins and Smith 2007) to account for environmental characteristics, in which the "distance" between a site and its network of least-human-disturbed reference sites was calculated based on these environmental characteristics (app. 1) (Yates and Bailey 2010). Expected values of an attribute at an individual site were estimated from its reference network of least-human-disturbed sites "nearest" to that site with respect to environmental characteristics. The neighbors for a site were not necessarily close in space, but rather were similar based on these environmental characteristics.

The nearest-neighbor approach requires that we select both the number of neighbors that match a site and the environmental characteristics to match. These were selected for each attribute by finding the combination of the number of neighboring sites and a subset of environmental characteristics that minimized the mean squared error (MSE) of the reference network chosen as previously outlined (Bates Prins and Smith 2007). This procedure was performed separately for each attribute, so that the number of neighbors, environmental characteristics, and size of the reference network used differed among attributes (app. 2). Scores were calculated on a continuous scale from 0 to 10 based on the 90-percent prediction intervals around the expected value of an attribute for each site (see Al-Chokhachy et al. 2010, Stoddard et al. 2007).

For physical habitat assessment, individual attribute scores (e.g., pool tail fines, substrate, wood) were averaged within each site to create an overall physical habitat score. If one attribute was missing for a site, only the non-missing attributes were used to calculate the metric score. If two or more attributes were missing for a site, no physical habitat score was calculated, and the site was not used in any subsequent analyses. This approach improved the number of sites included in the analysis and remedied the unintended consequence of the overweighting of individual attributes, which occurred in previous assessments. Site scores were scaled from 0 to 100. Watershed-level stream physical habitat condition scores were calculated as the average site-level condition scores within each respective watershed that contained three or more sites using the spsurvey package in R (Kincaid and Olsen 2013, R Core Team 2013). Watersheds with fewer than three sites were not used in any analysis.

Macroinvertebrates were assessed at the site level by using an observed-to-expected (O/E) index developed by the Center for Monitoring and Assessment of Freshwater Ecosystems in Logan, Utah. The O/E model compares the taxa at an observed site to similar reference sites (see Hawkins et al. 2000 for details). Sites were grouped into classes based on macroinvertebrate assemblage composition similarity. The expected class membership was predicted by using a number of predictor attributes (similar to environmental characteristics used in the nearest-neighbor analysis). All data were standardized to their appropriate operational taxonomic unit prior to analysis and resampled to a 300 fixed count. An O/E score value of 1 indicates that all expected species were found at a site, while a value of 0 indicates that no expected species were found. Watershed-level macroinvertebrate O/E scores were calculated based on aggregated site-level O/E scores using the spsurvey package in R (Kincaid and Olsen 2013, R Core Team 2013). We again

ask whether the aquatic macroinvertebrate communities were maintained or if the distribution shifted toward least-human-disturbed reference conditions.

Water temperature loggers were deployed in early spring at the lowest point on federal lands within each watershed, and data were typically collected into late fall. Data collected hourly were summarized as the 7-day rolling average of the daily maximum temperatures ("7-DADMax"). We defined the season as June 1 to September 15, then calculated the maximum 7-DADMax from this period. Temperature data were summarized across watersheds using the spsurvey package in R (Kincaid and Olsen 2013, R Core Team 2013). This analysis evaluates whether the distribution of 7-day average maximum water temperatures across watersheds has been maintained or shifted toward lower temperatures.

We used descriptive statistics and graphical displays to present stream physical habitat and macroinvertebrate scores and water temperature data for the entire NWFP area, grouped by physiographic aquatic province, land use allocations, and key and non-key watersheds. Mean overall condition was estimated with 95-percent confidence intervals for each group within each rotation. We tested for differences in the cumulative frequency distributions (cdf) among the groups by using the contcdf.test in the spsurvey package within the program R (Kincaid and Olsen 2013, R Core Team 2013). This was done only within the first rotation and for the NWFP overall. No tests have yet been performed within the second rotation because the rotation will not be completed until 2017, and we have limited power to detect true biological differences because we have not yet reached a sufficient sample size. To assess whether the mean of the cumulative frequency distribution shifted toward better condition, we used a two-sample t-test (Sokal and Rohlf 1995). The ACS is considered effective if the distribution of watershed condition scores is maintained or improves over time. We used a linear mixed-model fit with package lme4 (Bates et al. 2014) to test for a linear relationship between the stream metric status scores and time, after accounting for province. Individual year and watershed, as well as province, were used as random effects in this model to account for year, watershed, and province variability. An F-test with a Kenward-Roger approximation was used to test significance of linear trend for each indicator.

2. What Is the Status and Trend of Upslope/Riparian Conditions?

Study design—

In past assessments, the upslope/riparian analysis used the same criteria as the stream evaluation (at least 25 percent of stream channels along the 1:100,000 stream layer in federal ownership) to define the scope of watersheds to include. For this report, we broadened the scope to any watershed with 5 percent or greater federal ownership in order to be more compatible with recent U.S. Forest Service national watershed assessment guidelines (USDA FS 2011a, b) and to include more BLM lands. Only the federal portion of watersheds was included when determining watershed condition because federal agency land managers have no jurisdiction over management of nonfederal lands. The NWFP area contained 1,974 watersheds that met this sampling threshold. For reporting purposes, we further subdivided these watersheds by the NWFP land use allocations and key/non-key watersheds as previously described. We are interested in understanding whether the distribution of upslope/riparian conditions across watersheds has been maintained or has shifted toward higher conditions.

Riparian reserves were defined in the NWFP to have widths varying from 30 to 90 m (100 to 300 feet) based on a combination of 100-year flood plains, breaks in slope, riparian vegetation, and site-potential trees (USDA and USDI 1994), but these boundaries have yet to be delineated. For this report, we have delineated riparian areas using a uniform 90-m buffer (about 300 feet) on either side of the 1:100,000 stream layer. This wide buffer was chosen given the coarse resolution of the satellite vegetation data (30 m) and the uncertain positional accuracy of the stream layer. Higher resolution stream lines (1:24,000) were not used because of uneven density over the Plan area that would make comparability among areas inconsistent.

Upslope attributes were calculated for the entire federal portion of the watershed, including the riparian area. Although this approach may count riparian areas twice, the upslope/riparian attributes are assessed as proxies for different processes, and multicollinearity is not an issue because we are not statistically estimating the influence of explanatory factors. Watershed-wide metrics also avoid the problem of wide variation in the amount of nonriparian areas in watersheds and tend to be consistent with available studies on watershed impacts (e.g., road density was typically measured as total watershed density).

Attributes—

In past reports, an assessment model and associated metrics were developed for each aquatic province through regional expert workshops (Gordon and Gallo 2011). This flexibility was intended to account for broad biophysical differences (vegetation, geology, precipitation, etc.), but it also decreased the consistency between provinces. For this report, we combined the different models into a single unified model structure based on an analysis of commonalities and differences. Biophysical differences are now handled by setting vegetation evaluation criteria relative to appropriate vegetation zones, as developed by Davis et al. (2015), along with the integration of geology, landform, and precipitation layers in the sedimentation metric. Additionally, the attributes are now organized explicitly to represent key watershed processes (Beechie and Bolton 1999, Beechie et al. 2010, Reeves et al. 2004) (fig. 3). The following sections describe indicators used for each of these key watershed processes. Some indicators were repeated under different processes and so were effectively double-counted. This was an intentional choice to reflect the importance of the attribute to multiple processes.

Sediment production and delivery (mass wasting)—High rates of sediment delivery to streams from episodic mass-wasting events such as landslides and erosion have been shown to have detrimental effects on salmonids and other aquatic biota (Cover et al. 2008, Jensen et al. 2009). Natural rates for these processes are determined by a variety of factors, including slope, concavity, soils, geology, geomorphology, and precipitation (Miller and Burnett 2008, Montgomery and Dietrich 1994, Montgomery et al. 2000, Turner et al. 2010). Within the range of the northern spotted owl, federal forest management affects these rates primarily through road and vegetation disturbances. To evaluate the process of sedimentation production and transport, the AREMP model used the difference between an estimated background rate of sediment delivery and an estimated rate based on the status of road and vegetation disturbances.

Factors considered in the background risk of sediment delivery were estimated differently in California (U.S. Forest Service Region 5) and Oregon/Washington (Region 6) owing to the availability of differing datasets. On Region 5 lands, background risk was estimated using a simplified version of a Forest Service geomorphic terranes model (Elder 2008). Forest Service geologists assigned sediment delivery multipliers to bedrock geology types, combined with three slope classes. For areas outside the Forest Service geologic mapping, geologists cross-walked these slope-geology multipliers to the 10 classes in a statewide deep-seated landslide risk map produced by the California Geological Survey (Wills et al. 2011) (table 2).

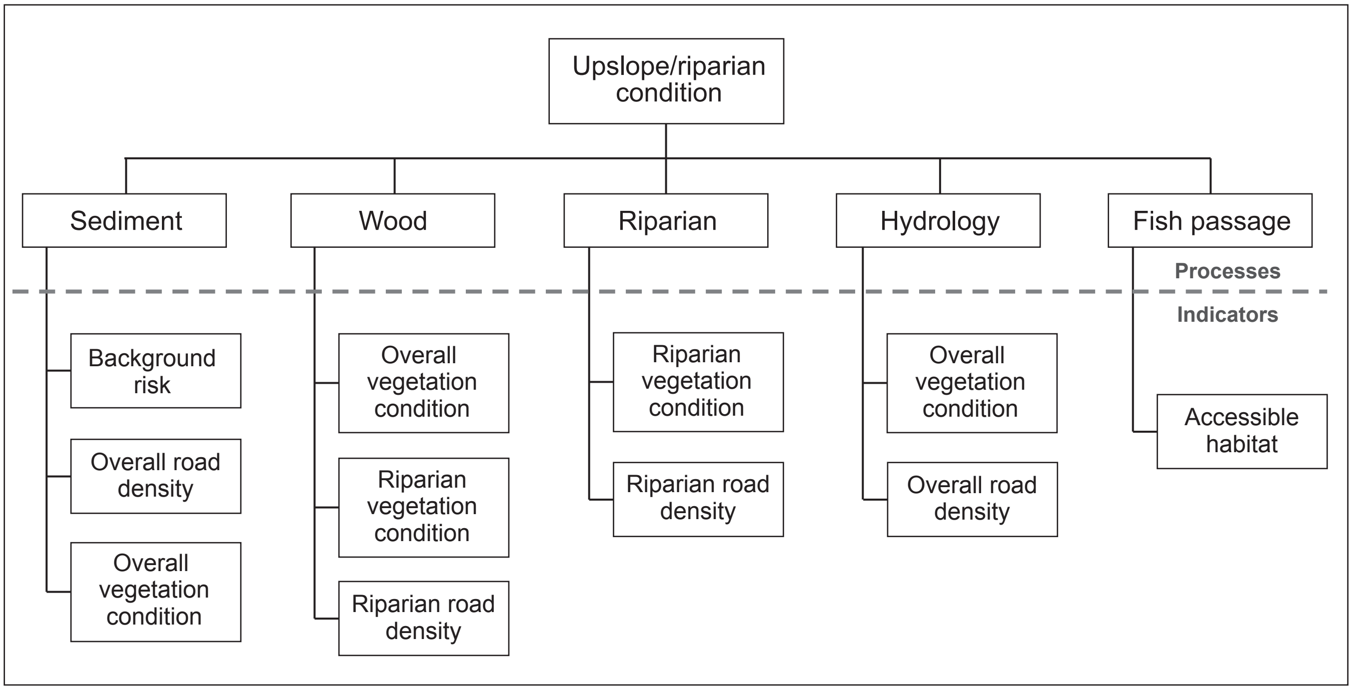


Figure 3—Overall upslope/riparian condition was based on the combination of five process indicators, which were in turn derived from a number of finer grained metrics.

Table 2—Sediment assessment model inputs for California

		Slope class (percent)		
Modeling regions and geology types	**Susceptibility class**	**≤ 15**	**15–55**	**≥ 55**
		Cubic yards/acre/year		
U.S. Forest Service lands:				
About 1,700 types of bedrock geology	See note	0.0005–0.2	0.005–0.5	0.01–5.5
Non-U.S. Forest Service lands:				
Cascade volcanic, metavolcanic, plutons, sandstones	0	0.0005	0.005	0.01
	3	0.005	0.015	0.25
	6	0.005	0.02	0.1
Schistose rocks, metasediments, argillite, serpentine	5	0.005	1.5	4
	7	0.05	0.3	1
	8	0.05	1	2.5
Unconsolidated Q deposits, galice, quartz-mica schist	9	0.1	0.5	2
	10	0.1	2	4.5

Note: Contact authors for details on quantitative ratings for about 1,700 types of bedrock geology by three slope classes.

In Oregon and Washington, background risk was based on slope steepness and convergence, as calculated in the Netmap model (LSDEL parameter) (Benda et al. 2007), and was adjusted using multipliers for geology, landform associations, and three precipitation factors (winter rainfall, storm maxima, and rain-on-snow areas), all based on expert judgment of agency soil scientists and geologists (table 3).

The impacts of road and vegetation conditions on landslide risk were modeled similarly across the two regions using multipliers adapted from Region 5 geomorphic terranes model (table 4). Road and vegetation multipliers were applied to the background risk layer, and the average risk over the unit was recalculated. The indicator of sediment production was then calculated as the risk with roads and vegetation minus the background risk. No explicit thresholds for sediment-level impacts on aquatic habitat were found in the literature, so the model uses a range based on the standard deviations of the background risk (table 5). Note that the Oregon-Washington and California models are based on different units, so the thresholds used also differ.

Table 3—Sediment assessment model inputs for Oregon/Washington

Model inputs	**Susceptibility rating**	
	Qualitative rating	*Quantitative score*
Bedrock geology:		
Unconsolidated	High	100
Volcanic (tuffs, pumice, ash, lahars)		80
Sedimentary		50
Metamorphic/peridotite		25
Extrusive (andesite/basalt)		0
Intrusive	Low	0
Landform associations:		
Categorical ratings on 150 types	[a]	[a]
	Susceptibility thresholds	
	0	100
Precipitation:		
Winter (December–March) (millimeters)	≤ 700	≥ 1200
Storm maxima:		
West-side (24 hour–25 year) (inches)	≤5	≥10
East-side (6 hour–100 year) (inches)	≤1.7	≥2.1
Rain-on-snow zones	False	True

[a] Contact authors for details.

Table 4—Sediment impact multipliers for roads and vegetation conditions

Impact type	Indicator score	Sediment multiplier
Roads	(any road)	20
Vegetation score	0–25	5
	26–40	2
	41–55	1.5
	55–70	1.1
	71–100	1

Table 5—Scoring thresholds for sediment impact (based on standard deviations of the background risk)

Modeling regions	Standard deviation of background risk	Scoring thresholds 0	Scoring thresholds 100
Oregon/Washington (landslides/km^2)	0.45	≥ 0.9	≤ 0.2
California (yd^3/ac)	1.5	≥ 3.0	≤ 0.75

Wood production and delivery—

Large wood plays a major role in structuring aquatic habitat in the Pacific Northwest (Andrus et al. 1988). Reeves et al. (2004) recommended assessing the wood production and delivery process by measuring forest composition and structure class. Previous reports used expert-derived thresholds for average tree size and canopy cover set by province (and, in a few cases, subprovinces). In this assessment, we transitioned to a more empirical approach. For each NWFP vegetation zone as defined by Davis et al. (2015), we calculated a reference distribution for mean tree diameter and canopy cover from areas with less than 10-percent disturbance based on historical data (Landsat 1985–2012) (Cohen et al. 2010, Kennedy et al. 2010). Each attribute score was then based on the departure from the mean of this reference distribution, with a less than -5 percent departure receiving a less-disturbed score of 100, and a greater than -45 percent departure receiving a score of 0. The minimum of the size and cover scores was taken as the watershed-wide vegetation indicator score because reference condition departures can be indicated by either metric alone (e.g., early and late seral may share the same cover metric but will differ by size). Because a large proportion of stream wood comes from the riparian area, a separate indicator was calculated explicitly for riparian vegetation condition, effectively giving it equal weight to the overall vegetation condition indicator.

Riparian shading and habitat—

Riparian conditions play a key role in a number of aquatic processes, including the effect of shading on stream temperatures, the effects of roots on bank stability, and the provision of habitat for a number of species (Naiman and Decamps 1997). The AREMP model rates the condition of these processes by using the average of two indicators: riparian vegetation condition and riparian road density. Riparian vegetation condition was measured as the departure of riparian vegetation from less than 10-percent disturbed vegetation conditions, as described above in “Wood Production and Delivery.” Riparian road density was measured as road miles in the riparian area per stream mile, and evaluation thresholds were derived as an average of values used by different provinces in the 15-year assessment: ≥ 0.4 road miles/stream mile receives a score of 0; ≤ 0.1 road miles/stream mile receives a score of 100.

Hydrology—

Upslope/riparian conditions affect the quantity and timing of water reaching the stream system, and consequently, the habitat of aquatic and riparian biota (Poff et al. 1997). No consistent regional data were available on dams and diversions, so this analysis was limited to the influences of road and vegetation changes on peak flows. Grant et al. (2008) attempted to synthesize a diverse set of studies on the effects of forest practices on peak flows. Results showed considerable variability among watersheds in the hydrologic response of streams to the same changes in forest cover or road densities. However, because most drivers of these differences are not yet well understood or well quantified, we based this indicator on average response values. One driver addressed in Grant’s synthesis is mid-elevation “rain-on-snow” zones, which have been found to be particularly sensitive because of the potential fast release of water from accumulated snowpack. Results were divided into two zones, rain-on-snow and rain-dominated, and it was additionally reasoned that snow-dominated zones would behave similarly to rain-dominated areas. In the rain-on-snow zone, their linear estimate shows a +10-percent change in peak flow at 15 percent area harvested; it reaches +15 percent change in peak flow at a 50-percent harvest level, and culminates at a 25-percent flow change at 100-percent harvested. These effects were expected to double in watersheds with a high percentage of road area (greater than 2 percent or 5.4 mi/mi^2) (Grant et al. 2008). For rain-dominated zones, their linear estimate showed a possible effect on peak flow at 15-percent area harvested; it reaches +10-percent change in peak flow at a 50-percent harvest level, and culminates at a 30-percent flow change at 100 percent harvested. All studies in the rain zones contain roads. Additionally, Grant et al. (2008) noted that only low-gradient streams are likely to be susceptible to peak flow effects.

Using a linear approximation based on the thresholds above and assuming that roads contributed half the total increase, we estimated the percentage of peak flow increase from vegetation in a rain-dominant zone as 0.14 × [percent of vegetation disturbance]. Increases in the rain-on-snow zone were approximately 50 percent higher, so the multiplier was 0.21. Flow with greater than 2-percent roading approximately doubled, so we estimated a separate roads effect using a linear interpolation between the origin (0,0) and a point equivalent to the 100-percent vegetation loss at 2-percent road density (5.4 mi/mi^2), resulting in a multiplier of 2.5 in rain-dominated zones and 3.8 in rain-on-snow zones. The percentage increases from roads and vegetation were then summed to estimate the overall indicator for peak flow change.

We found little information in the literature on which to base scoring thresholds; only one indirect estimate of an acceptable or unacceptable level of peak flow was identified. Beamer et al. (2003) rated subbasins with more than 50 percent watershed area in hydrological immature vegetation resulting from land use and more than 2 km of road length per km^2 of watershed area as "very likely impaired." Based on our multipliers above, this level of impact would result in a 36-percent increase in peak flow. Therefore, the AREMP model used 36-percent increase as the lower threshold (score 0) and a minor increase of 5 percent was used as the upper threshold (score 100). To adjust the impacts by stream susceptibility, we weighted the overall score against the other processes using the proportion of low-gradient stream (less than 4 percent, based on Grant et al. (2008) and input from specialists). A unit with no low-gradient stream was not counted with this indicator, while a unit with 50-percent low-gradient stream was weighted 50 percent compared to the other indicators.

Fish passage—

Much of the connectivity of habitat used by anadromous salmonids has been reduced by man-made barriers in streams, particularly dams and culverts used at road-stream crossings (Chelgren and Dunham 2015, Kemp and O'Hanley 2010, Sheer and Steel 2006, Steel et al. 2004). The AREMP model indicator for this process was the percentage of potential salmonid habitat estimated to be accessible (i.e., not blocked by a man-made barrier). Streams with gradients less the 20 percent were assumed to be potential fish habitat based on previous studies and state assessment guidelines (Sheer and Steel 2006). While a regional Forest Service fish passage database is in preparation, no comprehensive assessment of barriers was available at the time of this report. As such, our assessment used road-stream crossings generated with GIS layers as an estimate of barriers. Regional databases were used to determine crossings that were bridges, and therefore not a fish passage issue. Because the bridge databases were incomplete, the average catchment size above the bridge crossings was calculated, and other crossing catchments that were equal or larger in size were also assumed to be bridges. All miles of fish habitat above a non-bridge crossing were assumed to be blocked. Because no consistent database of barrier removals was available, only the removal of crossings from road decommissioning was counted. The percentage of habitat available was used directly as the score; no further evaluation criteria were applied.

Data analysis—

The AREMP upslope/riparian assessment used a multicriteria evaluation approach similar to previous reports, where attributes representing each process were scored to a common 0 to 100 scale, then these scores were combined using a weighted average approach (Gordon 2014, Keeney and Raiffa 1976). Each process was given an equal weight of 1. For analysis units in which a particular attribute was missing (e.g., some small land use allocation areas lacked a stream segment and riparian area), only the remaining attribute scores were used. The normalized upslope/riparian condition scores ranged from 0 to 100.

Using historical datasets, scores for each of the attributes were determined for two time periods: 1993 (before the NWFP) and 2012 (using the latest data available). Trend in condition scores for attributes and the overall watershed condition score were calculated by simply subtracting 1993 scores from 2012 scores. Positive trend scores indicate an improvement in condition and negative scores a decline.

Because data on every watershed in the target population were analyzed, inferential statistics were not needed to test the reliability of generalizing results from a sample to a larger population. All differences were effectively statistically significant, so what remains for judgment was whether differences were meaningful in terms of biology or management. Nevertheless, there was measurement error in the underlying data attributes and model uncertainty in terms of how the composite index was composed. Error estimates for the vegetation data can be found in (Davis et al. 2015) and error estimates for the roads indicators remain the same as detailed in the 15-year assessment (Lanigan et al. 2012).

Steve Wilcox

An example of stream bank erosion.

Chapter 3: Results

Results presented for each of the key monitoring questions provide insight for evaluating the success of the aquatic conservation strategy for the entire Northwest Forest Plan (NWFP) area and by land use allocation. As described in chapter 2, normalized condition model scores range from 0 to 100.

Monitoring Questions

1. What Is the Status and Trend of Stream Conditions?

Northwest Forest Plan area and provinces—
Within the NWFP area, stream physical habitat condition status scores varied from year to year (fig. 4). Here we report the status for rotation 1 (2002–2009) and rotation 2 (2010–2013), as well as an estimate of a linear trend through time.

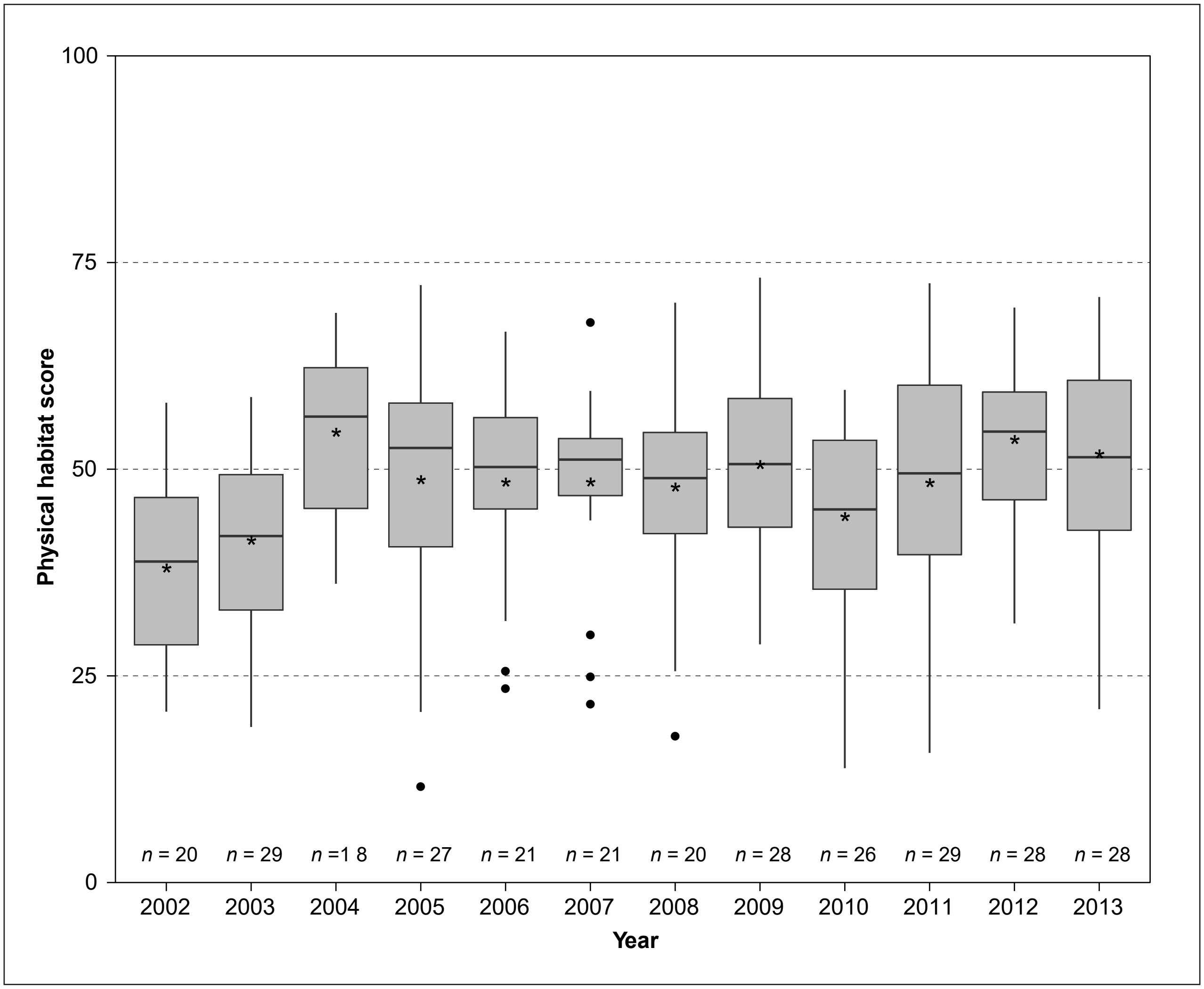


Figure 4—Distribution of stream physical habitat condition status scores by year. Median stream physical habitat scores are represented by the solid line; asterisks represent mean values. The number of watersheds visited each year is denoted by *n* along the bottom of the graph.

Stream physical habitat scores ranged from 12 to 73 with a mean score of 46.9 and a 95-percent confidence interval (CI) ranging from 45.7 to 48.1 during the first rotation and a mean score of 49.4 (CI = 47.9 to 51.0) during the second rotation. Only 2 percent of the scores fell below 20 during either rotation. The majority of stream attribute scores for both rotations fell between 40 and 60 (59 and 61 percent, respectively), and no watershed was above 80 during either rotation (figs. 4 and 5). There was evidence of a slight positive overall linear trend in physical habitat status over time (table 6). Figure 6 displays the spatial distribution of stream physical habitat scores across the Plan area for both rotations. Low scores were primarily found in Washington-Oregon Coast province (fig. 7).

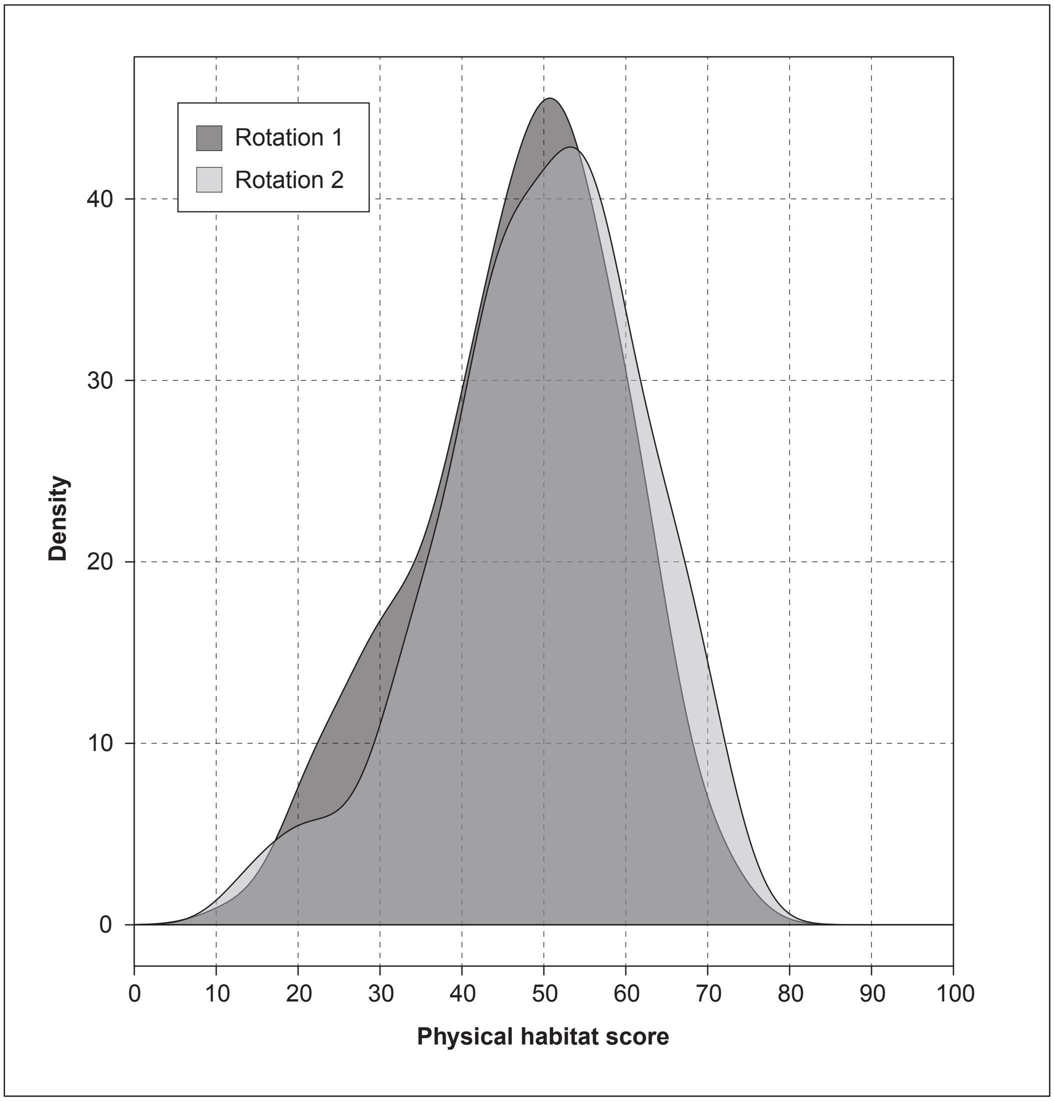


Figure 5—Distribution of estimated physical habitat scores by rotation using weighted density plot. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013. Density represents a continuous probability distribution based on the percentage of watersheds.

Table 6—Northwest Forest Plan 20-year results from the trend analysis testing for a linear relationship between stream metric scores and time after accounting for year, watershed and province, 2002–2013

Indicator	Trend estimate	95% LCL	95% UCL	-F-test	df	P-value
Physical habitat	+0.81	0.31	1.32	10.90	7.85	**0.01**
Pool tail fines	+0.05	0	0.10	4.31	5.32	0.09
Wood	+0.09	-0.01	0.18	3.14	7.89	0.11
Substrate	+0.10	0.03	0.16	9.90	5.76	**0.02**
Macroinvertebrates	+0.01	0.00	0.01	10.84	5.67	**0.02**
Temperature	-0.09	-0.24	0.08	1.19	6.86	0.31

df = degrees of freedom.

The upper (UCL) and lower (LCL) 95-percent confidence limits were included for each trend estimate.

An F-test with a Kenward-Roger approximation was used to test the significance of linear trend for each indicator.

The denominator degrees of freedom (df) are listed (numerator df was two for all tests).

Boldfaced p-values denote a significant trend in annual status estimates ($\alpha = 0.05$). The sign for each trend estimate denotes the trend direction.

For the low-scoring watersheds (scores less than 40), substrate and pool tail fine scores were usually the most influential in both rotations. Scores for these individual attributes are reported on a scale of 0 to 10. Only the Washington-Oregon Coast Range province had mean and median pool tail fine scores well below 5 during the first and second rotations (fig. 8). Both wood and substrate scores were centered around 5 with the exception of the Washington-Oregon Coast Range, where the mean and median substrate scores were below 2.5 (figs. 9 and 10). Mean estimated substrate scores increased between rotations; however, no differences were detected in pool tail fines or wood scores (table 7). Evidence of a positive yearly trend was detected in substrate scores for the NWFP area, but no yearly trend was detected in pool tail fines or wood scores (table 6).

For aquatic macroinvertebrates, we found that at least 25 percent of the watersheds had more stream invertebrate assemblages than expected, as denoted by scores above 1. At the same time, about 25 percent of the watersheds had scores below 0.6; scores of 0.6 signify 40-percent fewer stream invertebrate assemblages than expected from reference condition. Mean and median OE scores from each province did not fall below 0.7 in either rotation (fig. 11). We found a mean difference in rotations (table 7) and a positive trend over time (table 6).

The National Marine Fisheries Service water temperature standards for a properly functioning system for anadromous fish is accepted as 15 °C, while the state of Oregon standard for core temperatures in salmonid habitat is 16 °C (based on the 7-day average daily maximum temperature, 7DADMax). Mean and median 7DADMax values ranged from 16 to 19 °C over the 13 survey years, indicating that federal lands located in lower reaches within these watersheds do not meet desired criteria based on both National Marine Fisheries and state of Oregon standards (fig. 12). Temperature was the only metric estimate with a significantly negative sloping trend, indicating an improving trend with a decrease in observed mean 7DADMax temperatures over time (table 7). The mean estimated distribution scores were significantly different between rotations (table 7).

Land use category—

Congressionally reserved land estimated physical habitat condition score was 50.4 (CI 48.5 to 52.4) in the first rotation and 55.1 (CI 52.4 to 57.7) during the second rotation (table 7). Late-successional reserve (LSR) land estimated mean score was 44.2 (CI 41.8 to 46.5) in the first rotation and 46.1 (CI 43.5 to 48.8) during the second rotation. Matrix land status score was 47.4 (CI 45.1 to 49.7) in the first rotation and 49.1 (CI 45.5 to 52.6) in the second. The

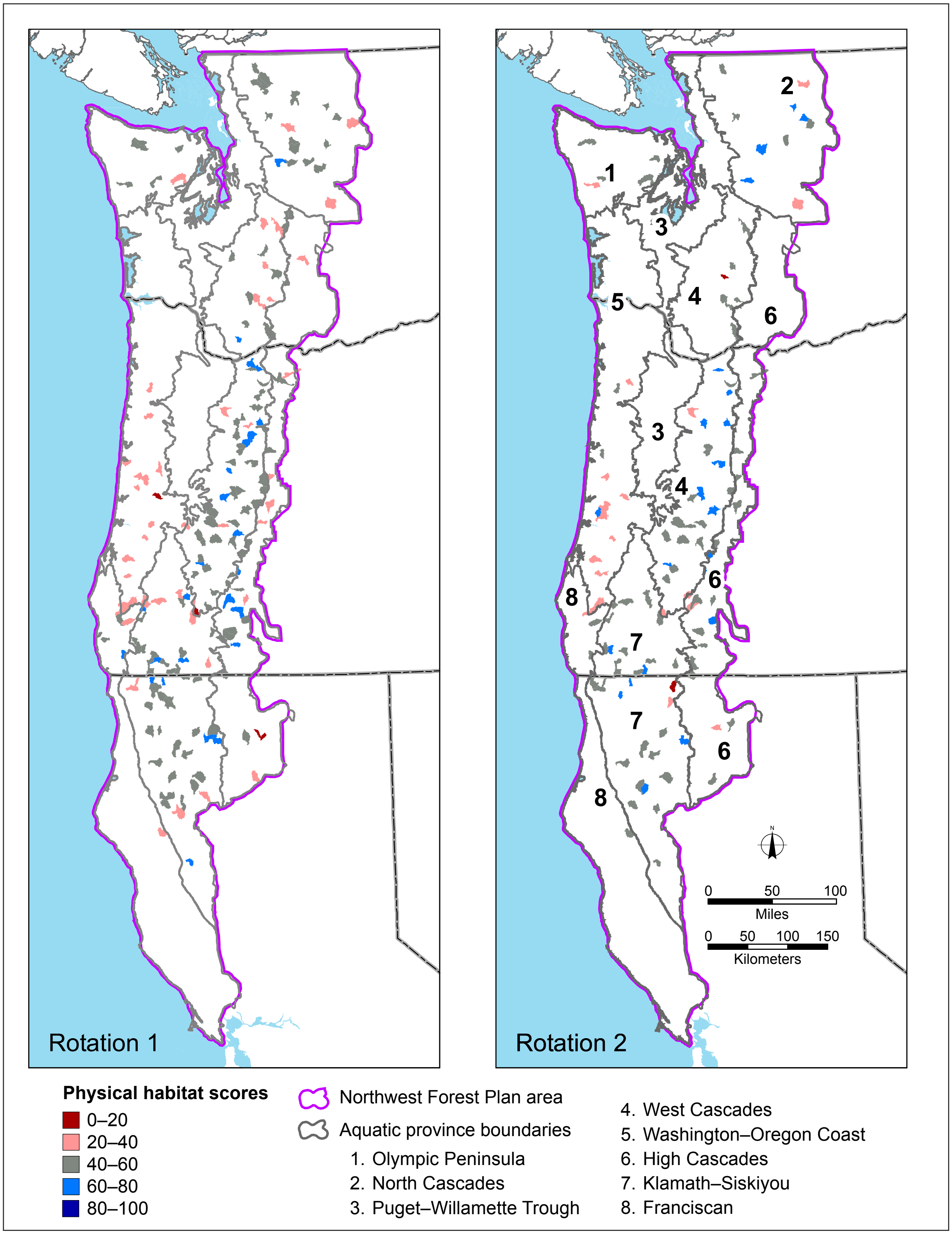


Figure 6—Spatial distribution of stream physical habitat scores for the Northwest Forest Plan (NWFP) area for each rotation. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

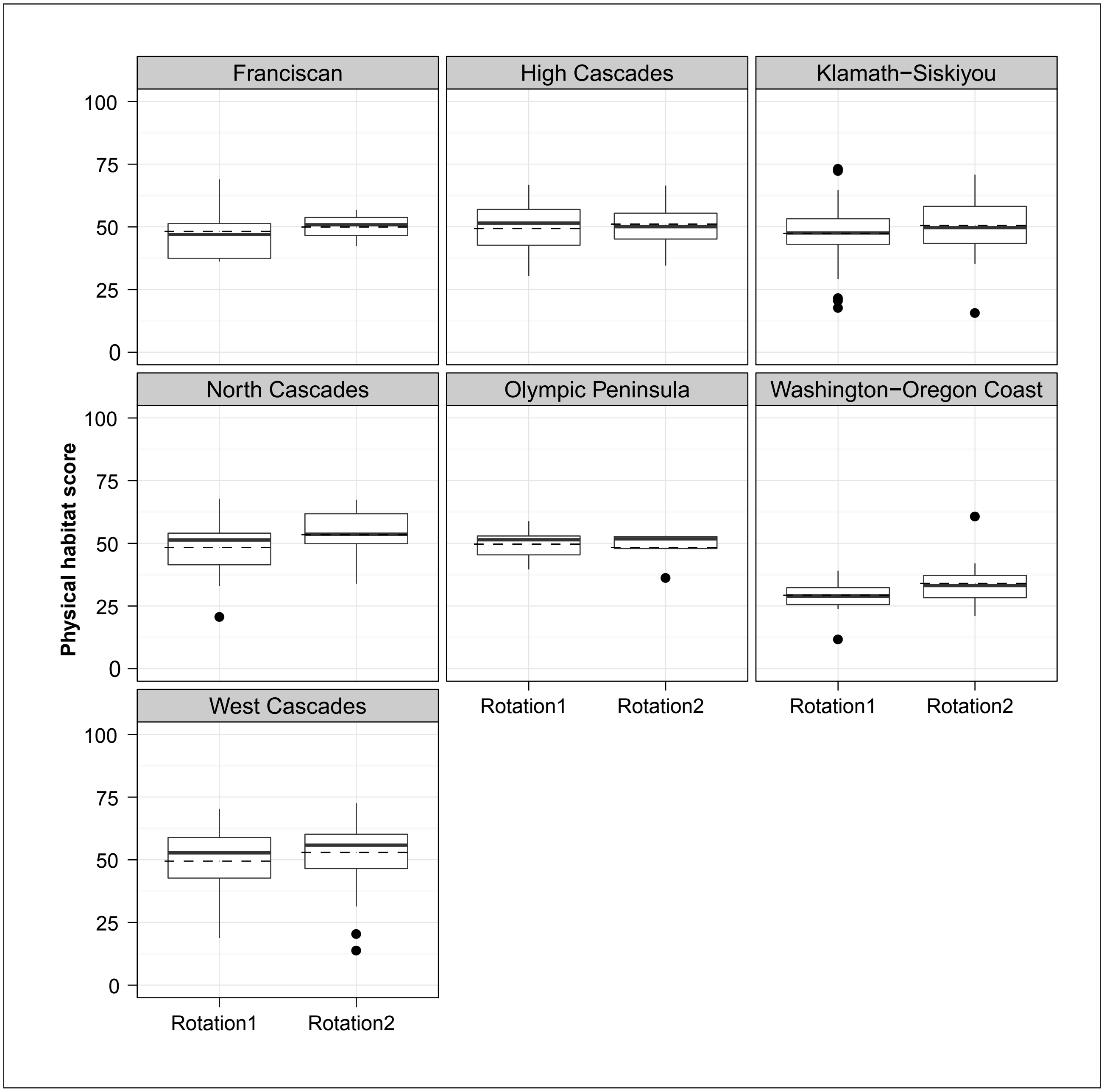


Figure 7—Distribution of stream physical habitat condition scores for each rotation separately for each aquatic province. Median stream physical habitat scores are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

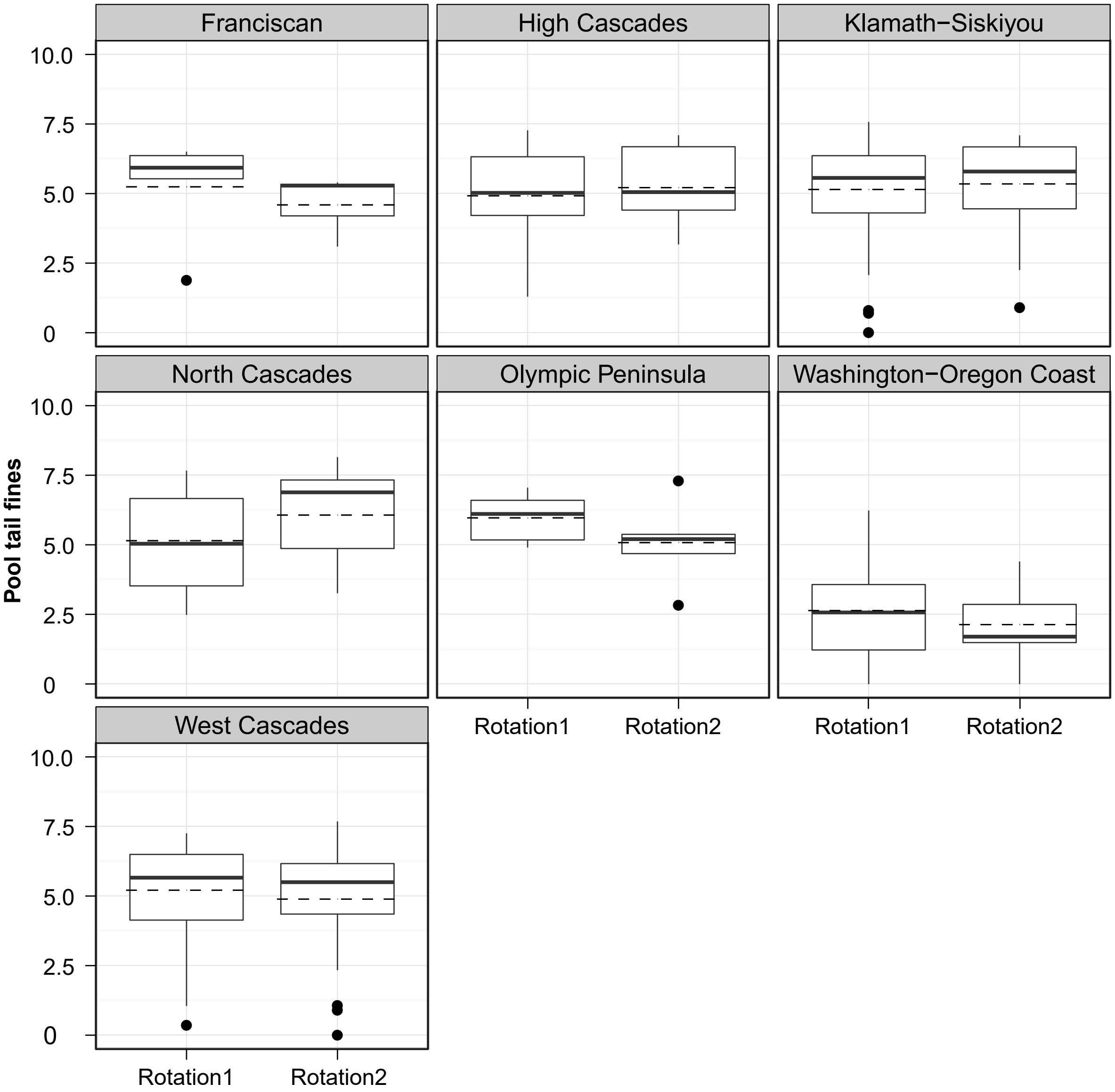


Figure 8—Distribution of stream pool tail fines scores (y-axis) for each rotation (x-axis) separately for each aquatic province. Median stream pool scores are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

Table 7—Estimates for stream metric scores and mean estimates between rotations for Northwest Forest Plan (NWFP) land use allocations, 2002–2013

Indicator	Land use category	Number	Rotation 1 estimate	Standard error	95% LCL	95% UCL	Number	Rotation 2 estimate	Standard error	95% LCL	95% UCL	t
Physical habitat	NWFP	184	46.9	0.6	45.7	48.1	111	49.4	0.8	47.9	51.0	**2.5**
	LSR	67	44.2	1.2	41.8	46.5	45	46.1	1.4	43.4	48.8	
	Matrix	73	47.4	1.2	45.1	49.7	37	49.1	1.8	45.5	52.6	
	Reserved	44	50.4	1.0	48.5	52.4	29	55.1	1.3	52.4	57.7	
	Non-key	116	46.6	0.8	45.0	48.2	70	48.4	1.1	46.3	50.6	
	Key	68	47.5	1.1	45.4	49.7	41	51.2	1.2	48.8	53.6	
Pool tail fines	NWFP	184	4.9	0.1	4.8	5.1	111	4.9	0.1	4.6	5.1	-0.6
	LSR	67	4.5	0.2	4.2	4.9	45	4.1	0.2	3.8	4.5	
	Matrix	73	5.1	0.2	4.8	5.4	37	4.9	0.2	4.5	5.4	
	Reserved	44	5.4	0.2	5.0	5.7	29	5.9	0.2	5.5	6.2	
	Non-key	116	4.9	0.1	4.7	5.2	70	5.0	0.2	4.7	5.3	
	Key	68	5.0	0.2	4.7	5.3	41	4.7	0.2	4.3	5.0	
Wood	NWFP	184	5.0	0.1	4.8	5.2	111	5.2	0.1	5.0	5.4	+1.2
	LSR	67	4.9	0.2	4.6	5.2	45	5.3	0.2	5.0	5.7	
	Matrix	73	5.1	0.2	4.7	5.5	37	5.0	0.2	4.6	5.4	
	Reserved	44	5.0	0.2	4.7	5.4	29	5.3	0.2	4.9	5.6	
	Non-key	116	4.9	0.1	4.7	5.2	70	4.9	0.1	4.7	5.2	
	Key	68	5.2	0.2	4.9	5.5	41	5.6	0.2	5.3	6.0	
Substrate	NWFP	184	4.4	0.1	4.2	4.6	111	5.0	0.1	4.7	5.3	**+3.6**
	LSR	67	4.1	0.2	3.7	4.4	45	4.5	0.2	4.0	4.9	
	Matrix	73	4.4	0.2	4.0	4.7	37	5.1	0.3	4.6	5.7	
	Reserved	44	5.0	0.2	4.7	5.4	29	5.6	0.2	5.3	6.0	
	Non-key	116	4.4	0.1	4.2	4.7	70	4.9	0.2	4.6	5.2	
	Key	68	4.4	0.2	4.0	4.7	41	5.1	0.2	4.7	5.6	
Macroinvertebrates	NWFP	183	0.85	0.01	0.83	0.86	108	0.88	0.01	0.86	0.90	**+2.9**
	LSR	71	0.83	0.01	0.81	0.86	43	0.90	0.02	0.86	0.93	
	Matrix	67	0.86	0.01	0.83	0.89	36	0.91	0.01	0.89	0.94	
	Reserved	45	0.85	0.02	0.81	0.89	29	0.82	0.03	0.77	0.87	
	Non-key	116	0.84	0.01	0.82	0.86	68	0.89	0.01	0.86	0.91	
	Key	67	0.86	0.01	0.83	0.88	40	0.88	0.01	0.85	0.91	
Temperature	NWFP	165	17.9	0.2	17.5	18.4	130	16.6	0.2	16.1	17.1	**-4.1**
	LSR	58	18.6	0.3	18.1	19.2	52	17.0	0.4	16.3	17.7	
	Matrix	70	18.6	0.4	17.8	19.5	47	17.2	0.6	16.1	18.3	
	Reserved	37	15.6	0.4	14.8	16.3	31	14.9	0.4	14.1	15.7	
	Non-key	106	18.1	0.3	17.5	18.7	83	16.7	0.3	16.0	17.3	
	Key	59	17.6	0.3	17.0	18.2	47	16.4	0.5	15.5	17.3	

LCL = lower confidence limit; UCL = upper confidence limit; LSR = late-successional reserve.

The number of watersheds used in the analysis (n), standard error (SE), along with the lower and upper 95-percent confidence limit, by rotation. Boldfaced t values represent a significant difference (two-sample t-test, α = 0.05)

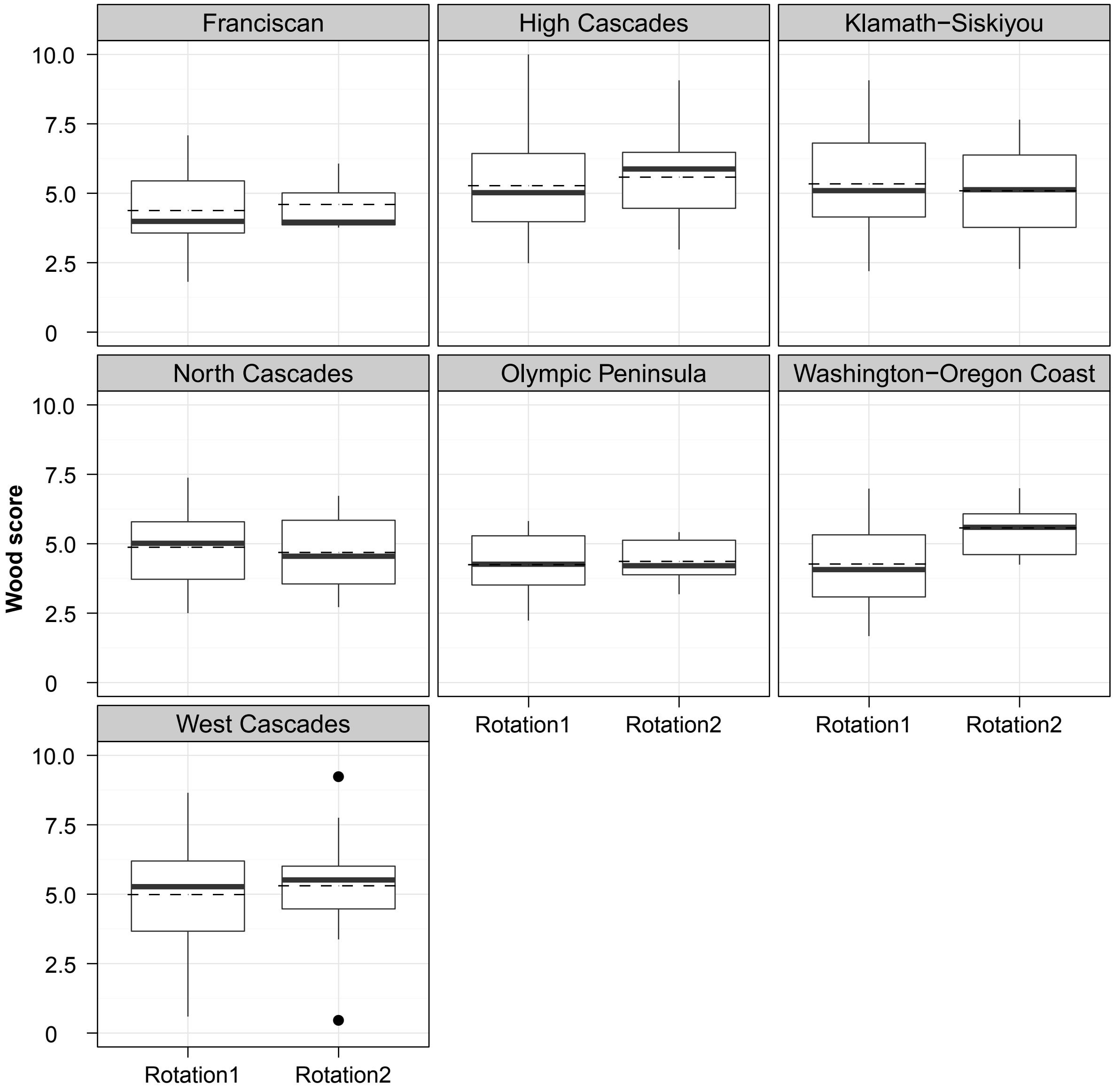


Figure 9—Distribution of stream wood scores (y-axis) for each rotation (x-axis) separately for each aquatic province. Median stream wood scores are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

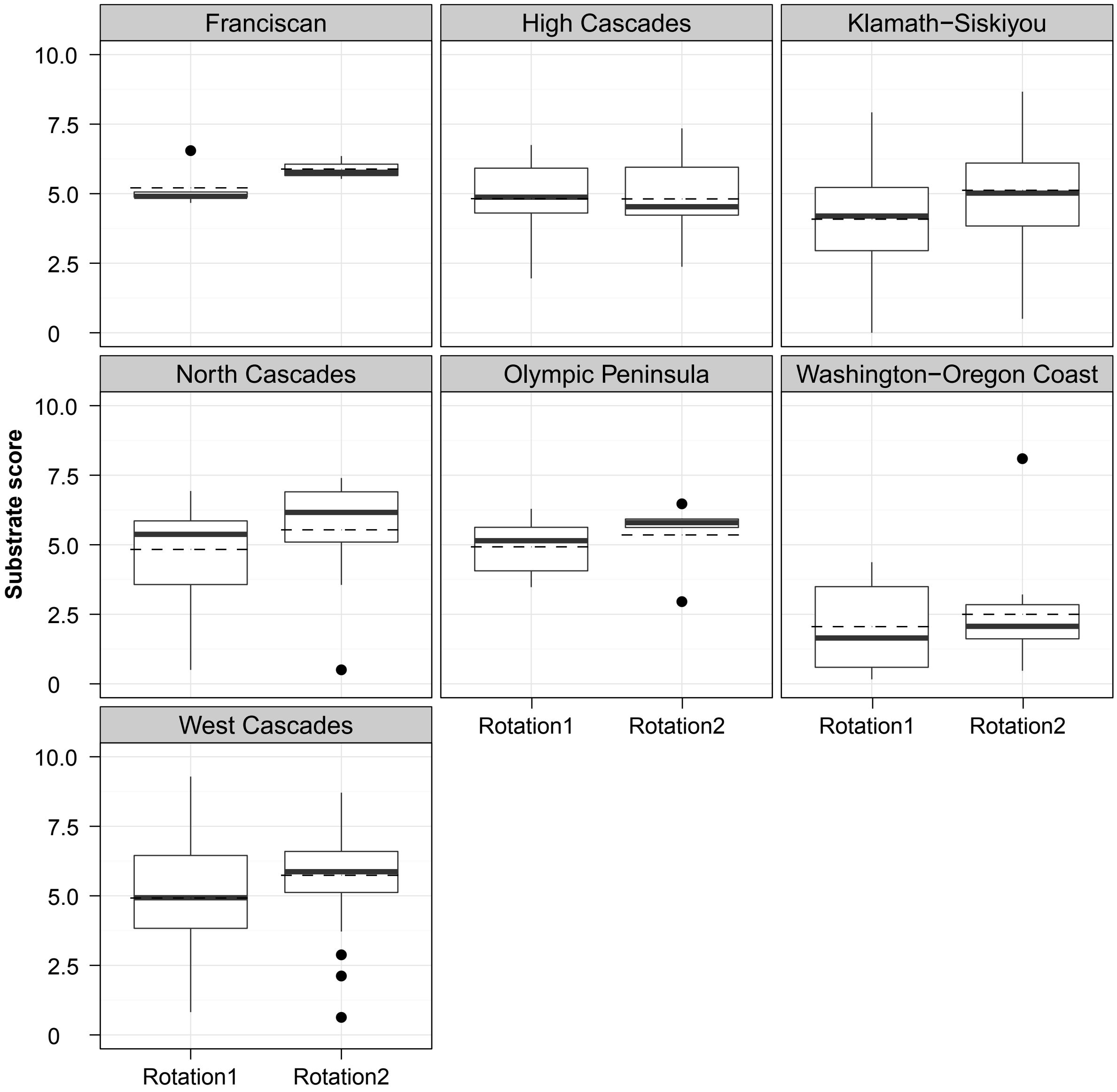


Figure 10—Distribution of stream substrate scores (y-axis) for each rotation (x-axis) separately for each aquatic province. Median stream substrate scores are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

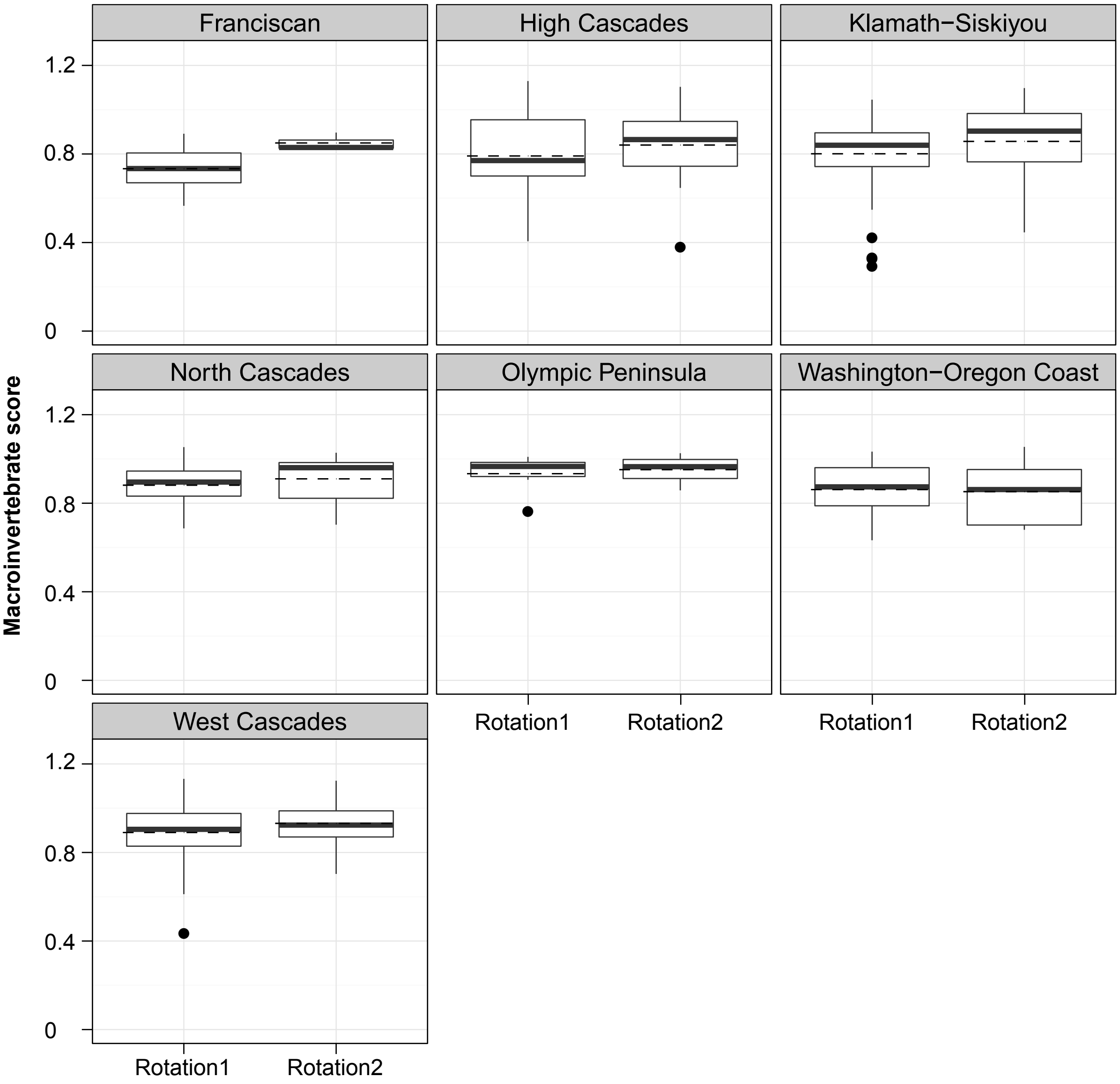


Figure 11—Distribution of stream macroinvertebrate observed-to-expected values (y-axis) for each rotation (x-axis) separately for each aquatic province. Median stream macroinvertebrate observed-to-expected values are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

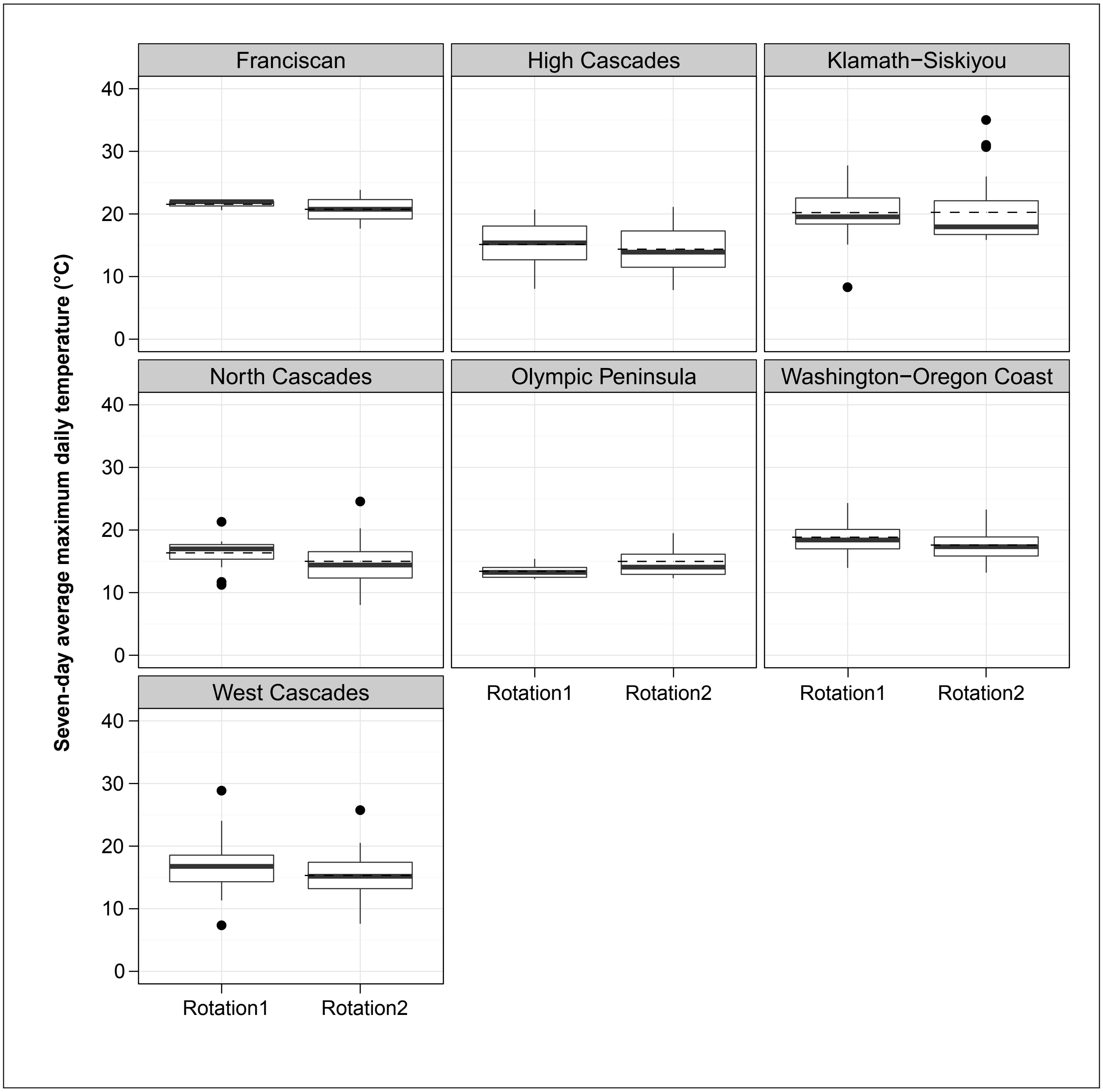


Figure 12—Distribution of stream 7-day average maximum daily temperature (°C) (y-axis) for each rotation (x-axis) separately for each aquatic province. Median stream 7-day average maximum daily temperatures are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

congressionally reserved lands had the smallest range of scores during both rotations (fig. 13). Examination of overall stream physical habitat score results in the context of land use allocations within rotations showed a statistically significant difference in cumulative frequency distributions between congressionally reserved lands and both LSR and matrix lands during the first rotation (table 8). No statistical tests between levels among land use categories were performed for the second rotation because the second rotation has not been completed.

There was not a statistically significant difference between the distributions of the key and non-key categories during the first rotation (table 8, fig. 14). Again, no statistical tests between levels and key and non-key categories were performed for the second rotation because this rotation has not been completed. In the first rotation,

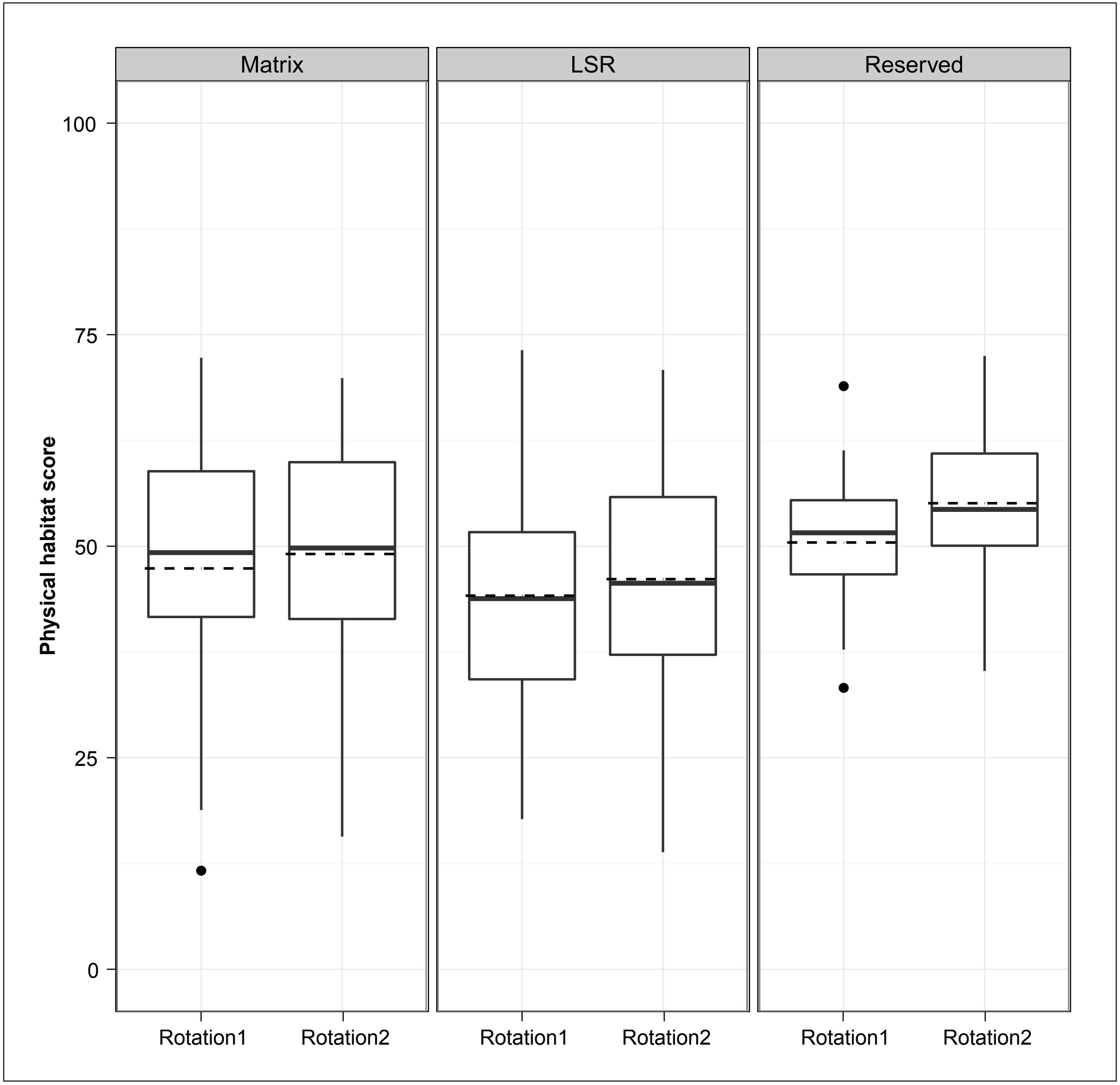


Figure 13—Distribution of stream physical habitat condition scores (y-axis) for each rotation (x-axis) separately for each land use allocation. Median stream physical habitat scores are represented by the solid line; dashed line represents mean values. (LSR = late-successional reserves; reserved = Congressional reserves). Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

scores ranged from 12 to 69 for non-key watersheds and ranged from 25 to 73 for key watersheds (fig. 14).

The distributions of individual attribute scores (e.g., pool tail fines, wood, substrate) were more variable in regard to land use categories (fig. 15). Statistically significant differences in mean cumulative frequency distributions between attribute scores by land use category are summarized in table 8. Pool tail fines score mean estimates were highest in congressionally reserved lands during both rotations (table 7). No evidence of differences in pool tail fines or wood score was found between key and non-key watersheds in the first rotation (table 7). No differences in wood distributions were confirmed between the three categories during the first rotation. There was no evidence that substrate score distributions differed between key and non-key watersheds; however, the distribution of substrate

Table 8—Results from testing mean cumulative frequency distributions among the land use categories and key and non-key watershed, 2002–2009

Metric	Land use category		Wald F	df	P-value
Physical habitat	LSR	Matrix	3.40	133	**0.04**
	LSR	Reserve	7.63	103	**<0.01**
	Matrix	Reserve	2.34	109	0.10
	Non-key	Key	1.75	176	0.18
Pool tail fines	LSR	Matrix	3.87	133	**0.02**
	LSR	Reserve	4.15	103	**0.02**
	Matrix	Reserve	0.22	109	0.81
	Non-key	Key	1.27	176	0.28
Wood	LSR	Matrix	0.64	133	0.53
	LSR	Reserve	2.38	103	0.10
	Matrix	Reserve	2.16	109	0.12
	Non-key	Key	1.80	176	0.17
Substrate	LSR	Matrix	0.56	133	0.57
	LSR	Reserve	5.16	103	**0.01**
	Matrix	Reserve	4.62	109	**0.01**
	Non-key	Key	1.65	176	0.20
Macroinvertebrates	LSR	Matrix	1.50	132	0.23
	LSR	Reserve	0.89	104	0.41
	Matrix	Reserve	0.64	109	0.53
	Non-key	Key	1.26	176	0.29

df = degrees of freedom; LSR = late-successional reserve.

These tests were performed only within the first rotation. Significant differences in cumulative frequency distributions between categories for physical habitat scores and individual metric elements are noted in boldface ($\alpha = 0.05$).

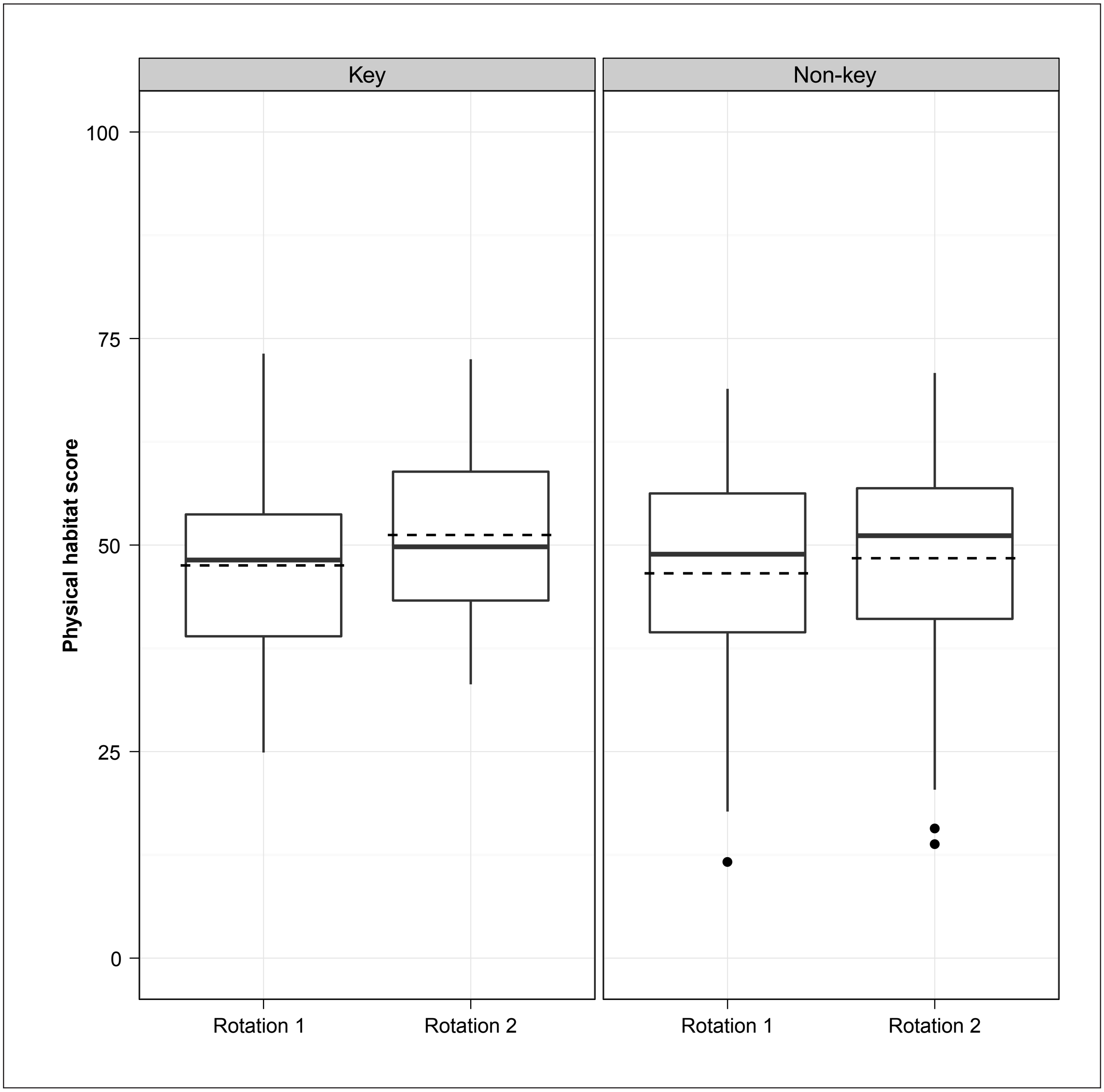


Figure 14—Distribution of stream physical habitat condition scores (y-axis) for each rotation (x-axis) separately for key and non-key watersheds. Median stream physical habitat scores are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

scores significantly differed in congressionally reserved lands from LSR and matrix lands during the first rotation (table 8). Substrate score mean estimates in congressionally reserved lands were higher than all other land use categories during both rotations (table 7).

Examining the distribution of aquatic invertebrate observed to expected (O/E) scores by land use allocation indicated that, in the first rotation, land use categories and key and non-key watershed did not differ (table 8; figs. 15 and 16).

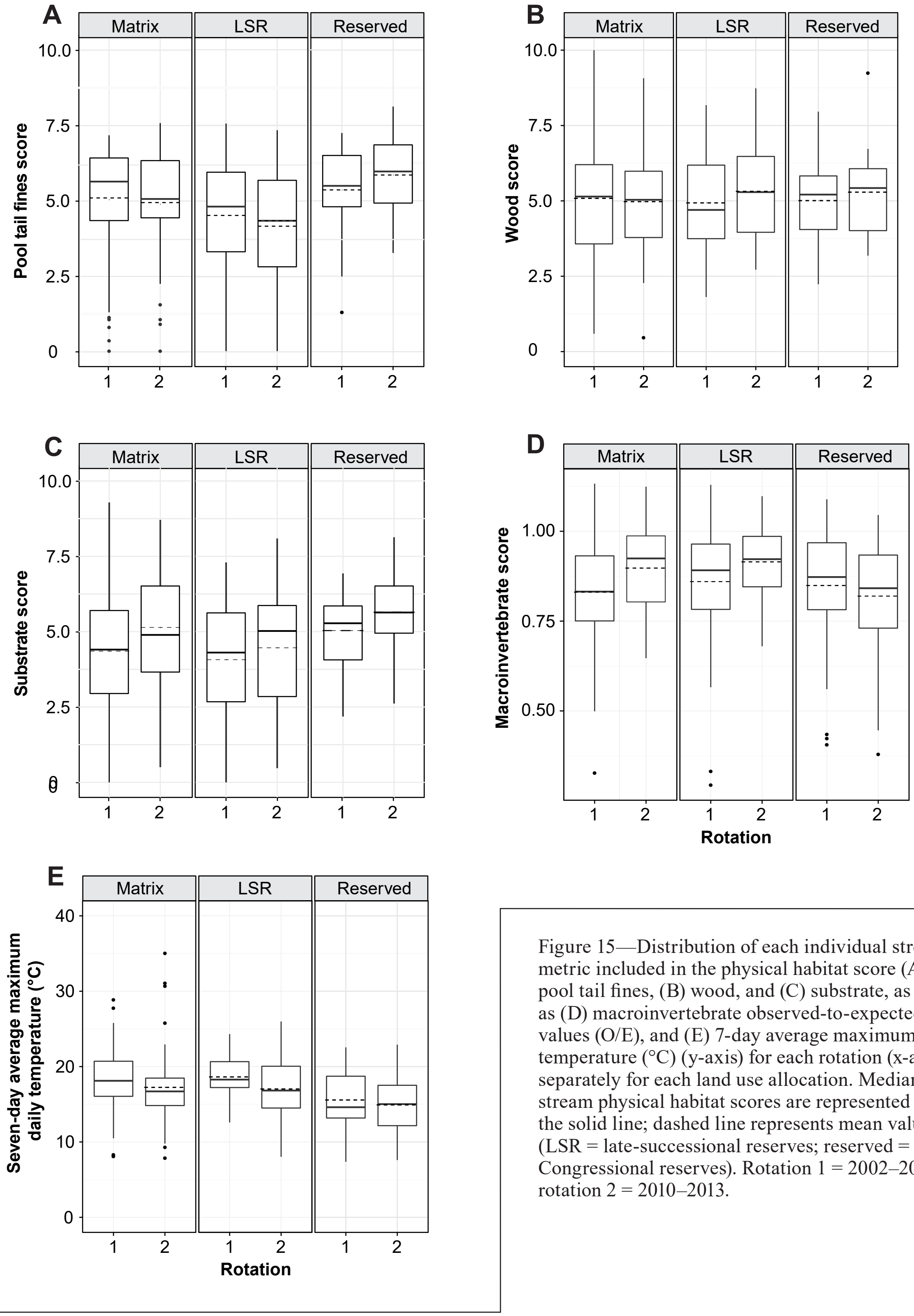


Figure 15—Distribution of each individual stream metric included in the physical habitat score (A) pool tail fines, (B) wood, and (C) substrate, as well as (D) macroinvertebrate observed-to-expected values (O/E), and (E) 7-day average maximum temperature (°C) (y-axis) for each rotation (x-axis) separately for each land use allocation. Median stream physical habitat scores are represented by the solid line; dashed line represents mean values. (LSR = late-successional reserves; reserved = Congressional reserves). Rotation 1 = 2002–2009; rotation 2 = 2010–2013.

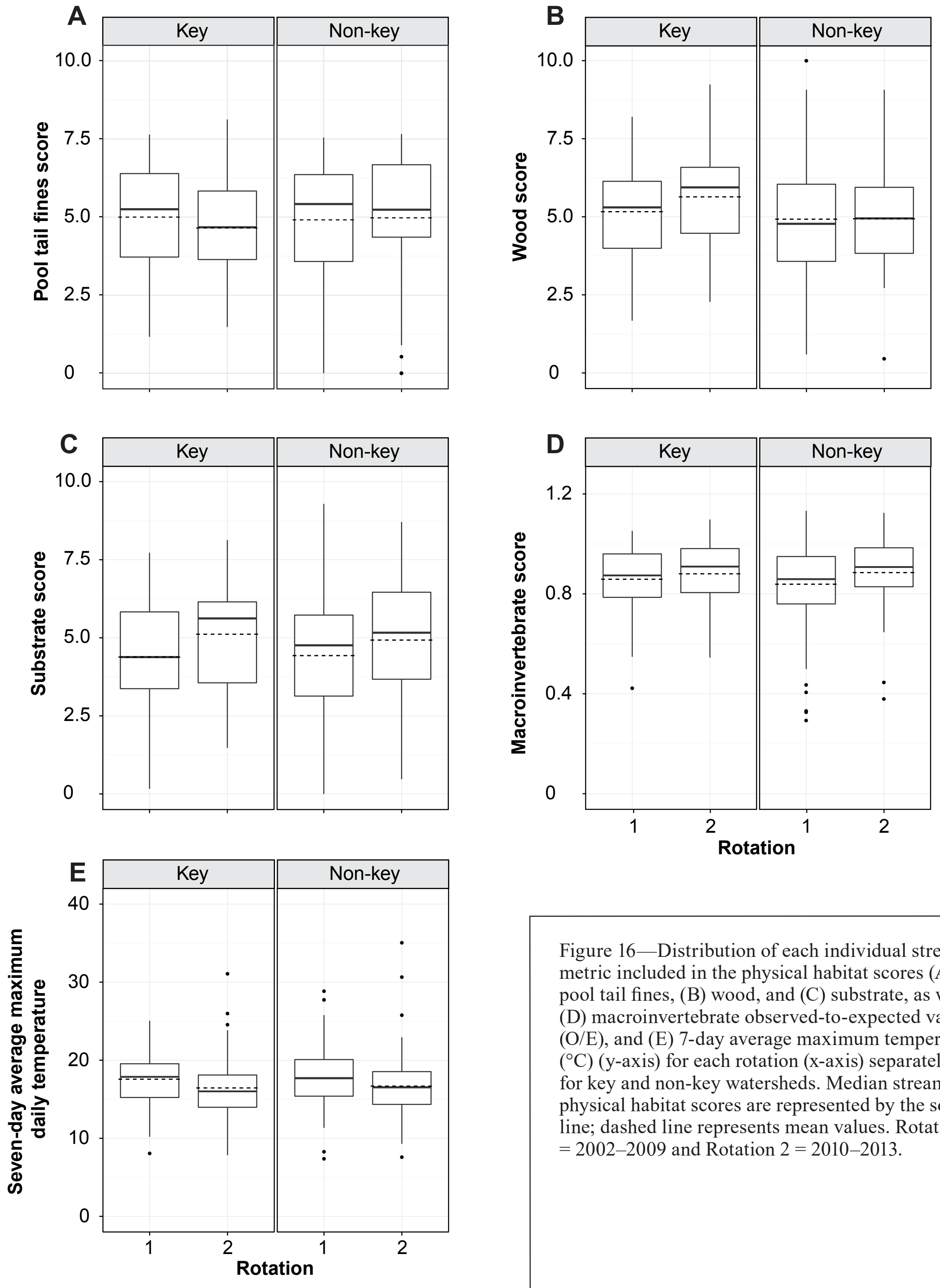


Figure 16—Distribution of each individual stream metric included in the physical habitat scores (A) pool tail fines, (B) wood, and (C) substrate, as well as (D) macroinvertebrate observed-to-expected values (O/E), and (E) 7-day average maximum temperature (°C) (y-axis) for each rotation (x-axis) separately for key and non-key watersheds. Median stream physical habitat scores are represented by the solid line; dashed line represents mean values. Rotation 1 = 2002–2009 and Rotation 2 = 2010–2013.

Scores for 7-day average maximum temperature statistically differed in distributions among all land use categories during the first rotation (table 9; figs. 15 and 16). No differences in distributions were seen between key and non-key watersheds (table 9). Estimated mean 7-day average temperatures were lowest on congressionally reserved lands in both rotations (table 7).

Table 9—Results from testing mean cumulative frequency distributions among the land use categories and key and non-key watershed based on 7-day average maximum temperature, 2002–2013

Rotation	Metric	Land use category		Wald F	df	P-value
1	Temperature	LSR	Matrix	4.47	121	**0.01**
		LSR	Reserve	16.06	87	**0**
		Matrix	Reserve	8.57	99	**0**
		Non-key	Key	0.04	157	0.96
2	Temperature	LSR	Matrix	0.98	93	0.38
		LSR	Reserve	5.97	78	**0**
		Matrix	Reserve	5.45	74	**0.01**
		Non-key	Key	0.12	125	0.89

df = degrees of freedom; LSR = late-successional reserve.

Data from a climate-change vulnerability project were used to augment samples which increased sample size to levels adequate to test for differences within categories. Significant differences in cumulative frequency distributions between categories are noted in boldface ($\alpha = 0.05$).

2. What Is the Status and Trend of Upslope/Riparian Conditions?

The conditions of upslope/riparian processes were estimated by scoring and integrating a variety of indicators derived from remote sensing and other mapped datasets. Data were aggregated by hydrologic unit, ownership, and land use allocation and were reported as area-weighted scores rather than watershed counts (some watersheds contained very little federal land). Data on every watershed in the target population were analyzed, so typical estimates of statistical sampling error do not apply. Measurement error inherent in the attributes was still an issue; however, error estimates for the attributes were not known and so are only addressed in general terms.

Overall, there was a very slight positive change in upslope/riparian condition scores, from a mean score (±standard deviation) of 68 ± 20 in 1993 to 69 ± 19 in 2012. An increase in scores (a shift to the right) was especially noticeable as scores in the low to mid-range (15 to 50) shifted to the higher range (60 to 90) (fig. 17). The area in the high ranges (> 90) actually decreased slightly. Excluding minor changes, which may be due to error inherent in the satellite imagery classification process, we also calculated a conservative estimate looking at only condition score changes of greater than ±5. After we used this threshold, 16 percent of the area showed an increase in watershed condition versus 7 percent that showed a decrease in watershed condition.

The spatial distribution of upslope/riparian condition scores showed some noticeable patterns (fig. 18). The highest scores (>80) were found in the central Olympic Peninsula (Olympic National Park), the north-central Cascades, and scattered along the Cascade Range in Oregon and Washington, often corresponding to designated wilderness areas. Other high-scoring areas occurred in the Siuslaw National Forest, in the northeast and southwest areas of the Rogue River-Siskiyou National Forest, and in scattered wilderness areas in the Klamath Mountains in northern California. Low scores (<40) were seen in the southern Olympic Peninsula region and along the eastern flank of the Oregon Coast Range and western flanks of the Cascade Range in Oregon and Washington, generally in lower elevation areas that are closer to transportation routes, with many roads from past timber harvesting activities.

The upslope/riparian condition trend map used seven categories (instead of five used in the status maps), along with smaller central categories to better discriminate changes in scores, because trend scores tended to be more tightly grouped than status scores. Areas that showed a downward trend included north-central California, southwestern Oregon, and patches in the central Oregon Cascades and along the eastern edge of the North Cascades in Washington. The pattern in positive changes was similar

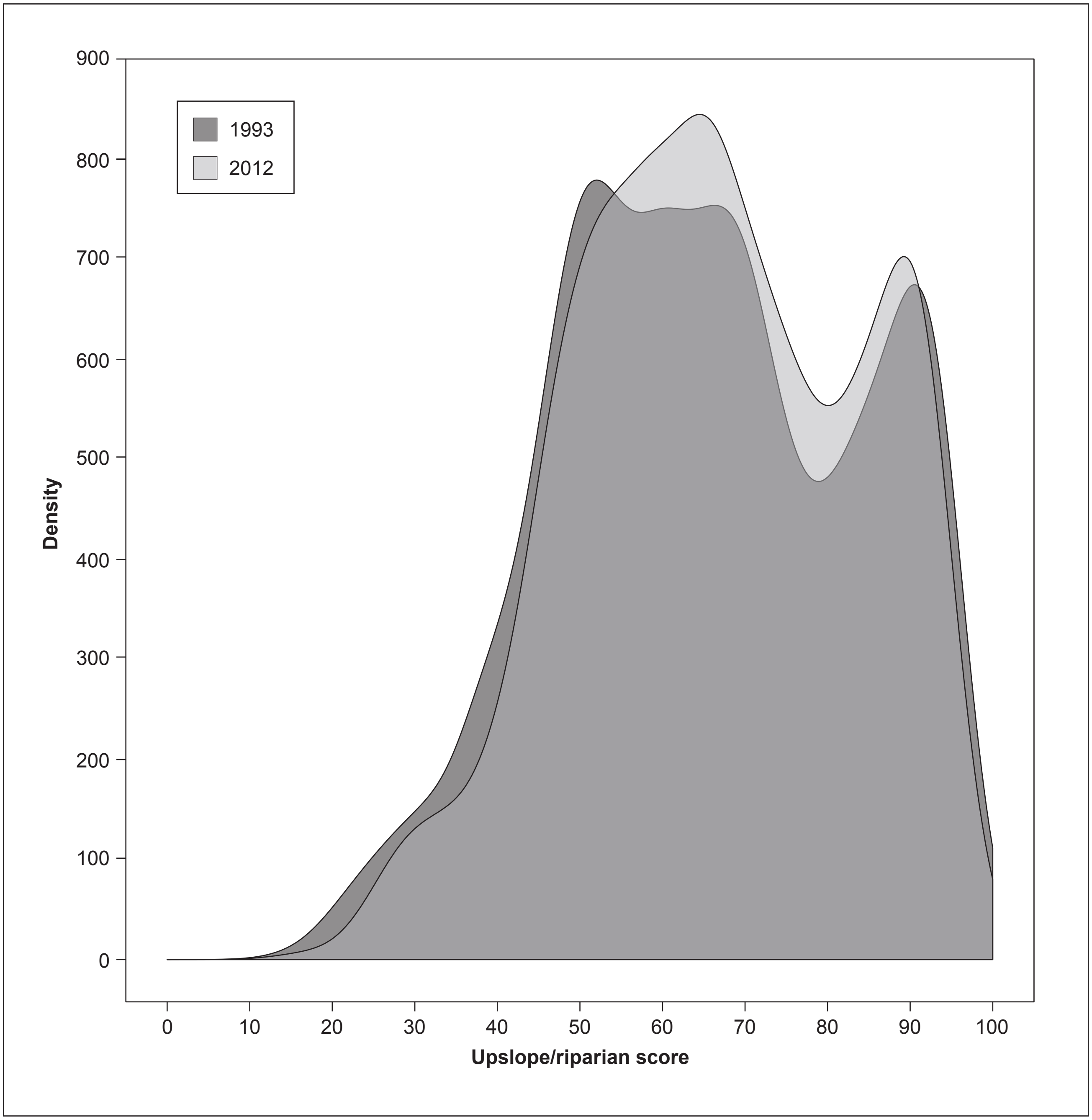


Figure 17—Upslope/riparian status and trend scores. Density represents a continuous probability distribution based on the percentage of watersheds.

to the pattern of lower scores mentioned above: the southern Olympic region, the Oregon Coast Range and along the western flanks of the Cascade Range in Oregon and Washington.

Breaking watershed condition scores down by aquatic province revealed some small differences (fig. 19). Most provinces had scores very near the regional average of 68 ± 19, (although the Olympic, Franciscan, and North Cascades provinces showed somewhat higher scores 76 ± 18, 74 ± 19, 73 ± 17, respectively) and the Klamath-Siskiyou somewhat lower (64 ± 20). The Washington-Oregon Coast Range had the largest increase in scores (from 61 ± 20 to 66 ± 18).

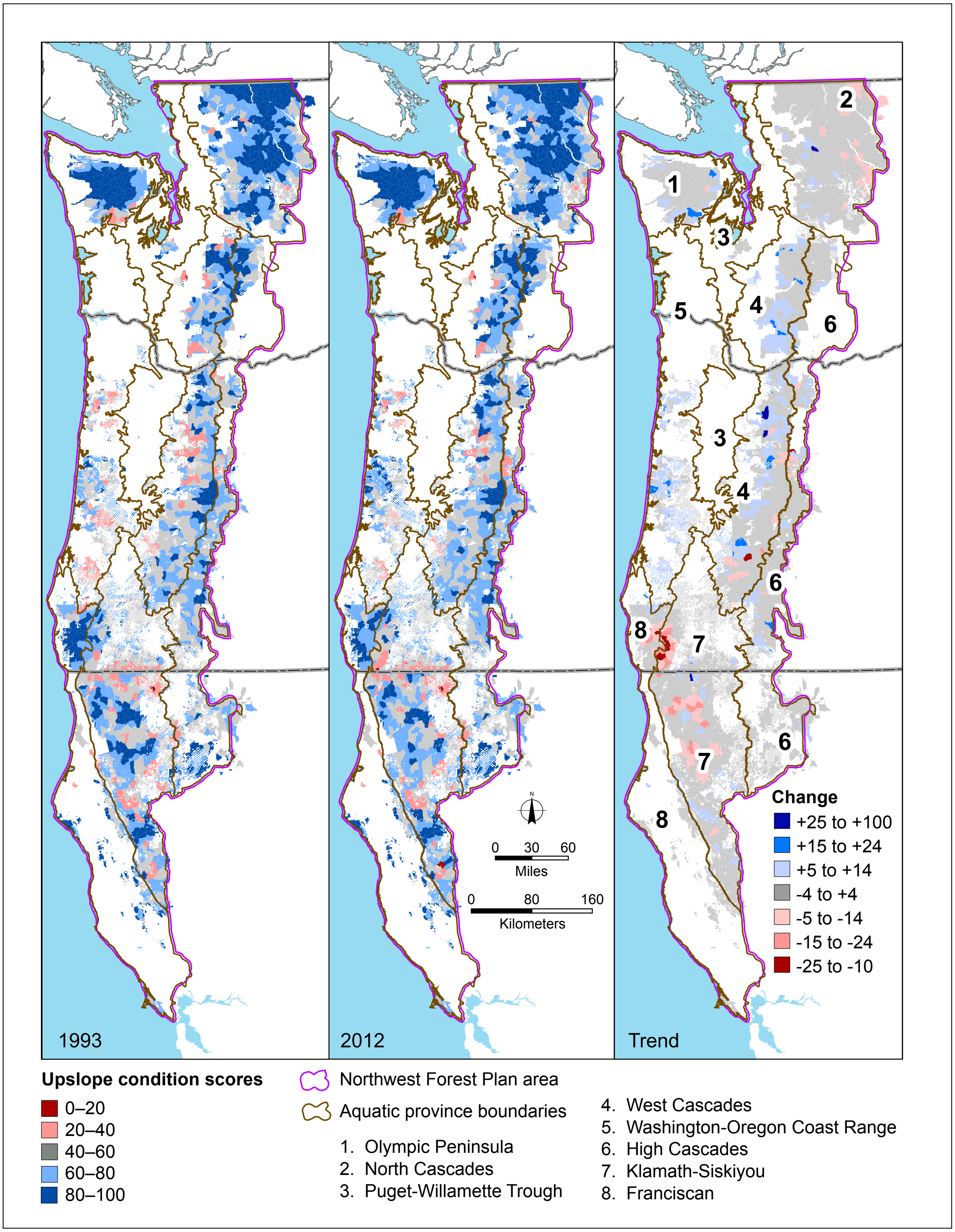


Figure 18—Upslope/riparian status and trend score maps.

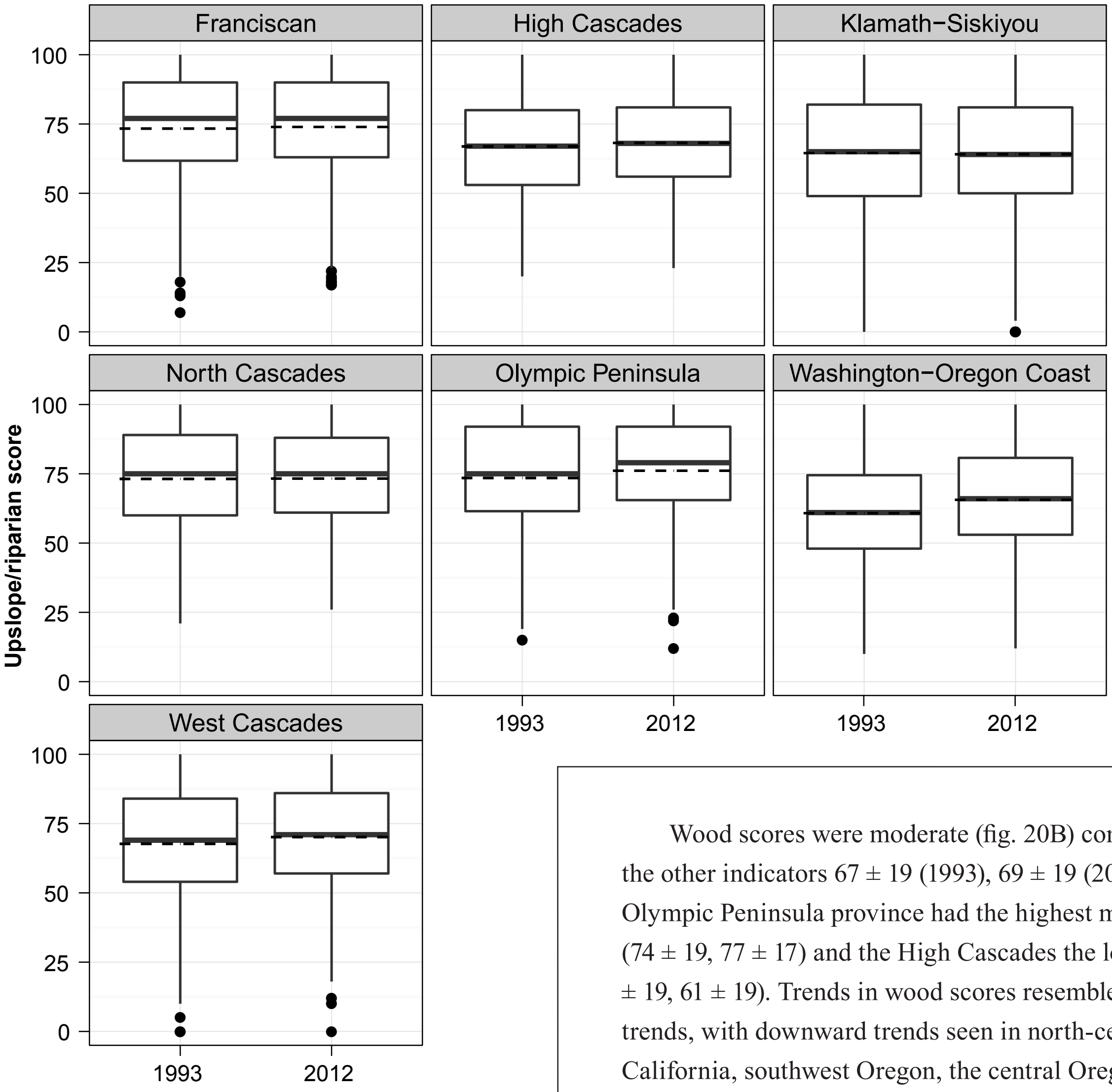


Figure 19—Upslope/riparian score distributions by aquatic province. Mean upslope/riparian scores are represented by the dashed line; solid line represents median values.

In terms of the individual process indicators contributing to the overall upslope/riparian condition score, sediment scores were generally high (fig. 20A), with overall mean scores of 77±36 and 78±35 for 1993 and 2012, respectively. The West, High, and North Cascades and the Olympic Peninsula had greater than 50 percent of scores at the maximum level (100). The Franciscan, Klamath-Siskiyou, and Washington-Oregon Coast provinces had higher variability and more scores in the mid to low range.

Wood scores were moderate (fig. 20B) compared to the other indicators 67 ± 19 (1993), 69 ± 19 (2012). The Olympic Peninsula province had the highest mean scores (74 ± 19, 77 ± 17) and the High Cascades the lowest (59 ± 19, 61 ± 19). Trends in wood scores resembled overall trends, with downward trends seen in north-central California, southwest Oregon, the central Oregon Cascades, and the eastern edge of the northern Cascades in Washington, and positive trends in the southern Olympic region and along the Oregon Coast Range and western flanks of the Cascade Range in Oregon and Washington (see app. 4).

Riparian scores, a combination of riparian vegetation and riparian road indicators, averaged 62 ± 25, 64 ± 24 across the Plan area (fig. 20C). Scores in the Franciscan and Olympic Peninsula provinces were the highest, while scores in the High Cascades, Klamath-Siskiyou, and Washington-Oregon Coast were lower and more variable. Spatial patterns showed the distinct effect of roads, with high scores in the Olympic Peninsula and

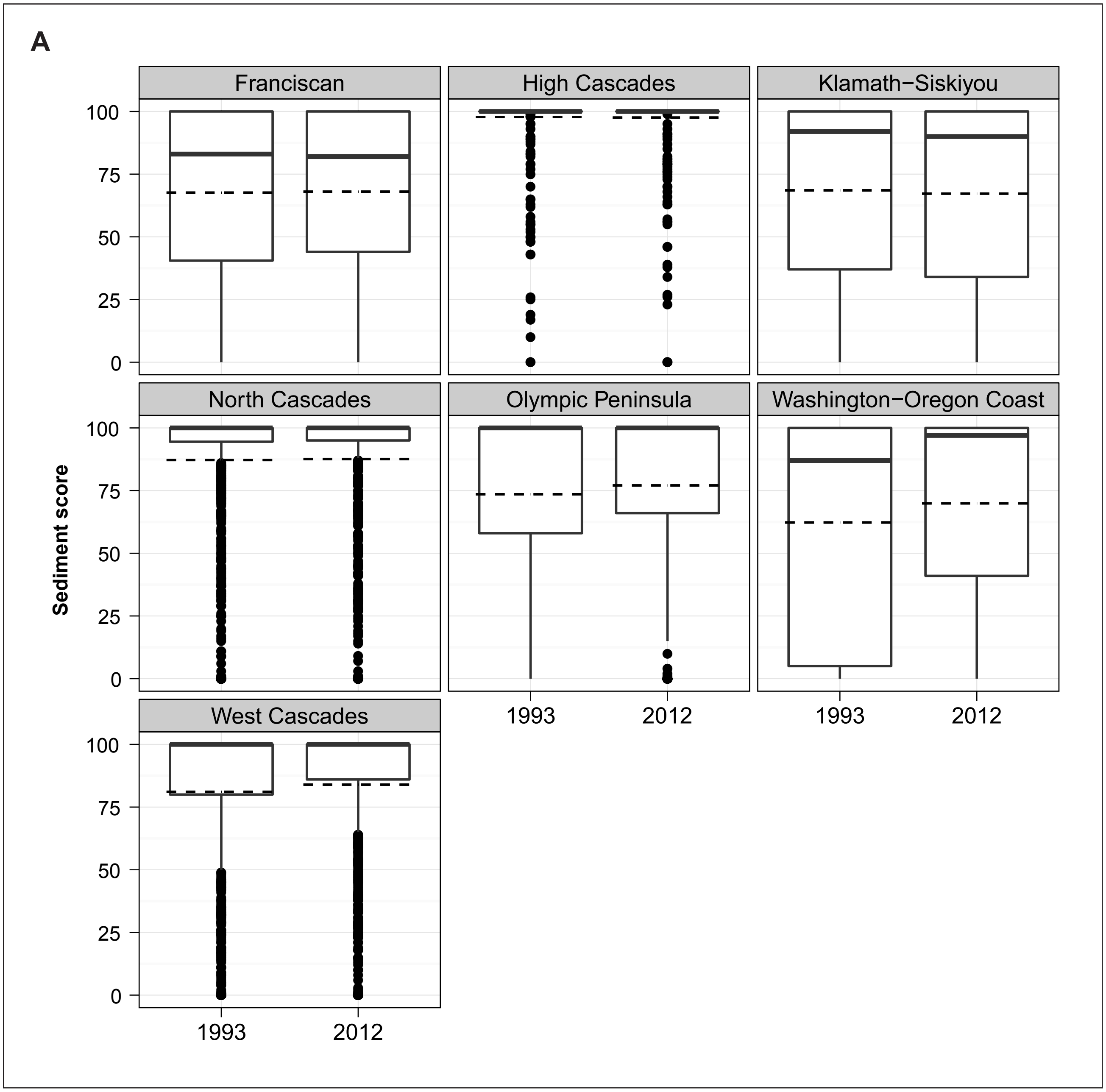


Figure 20—Upslope/riparian process indicator scores by province:(A) sediment; (B) wood; (C) riparian; (D) hydrology; (E) fish passage. Mean upslope/riparian scores are represented by the dashed line; solid line represents median values.

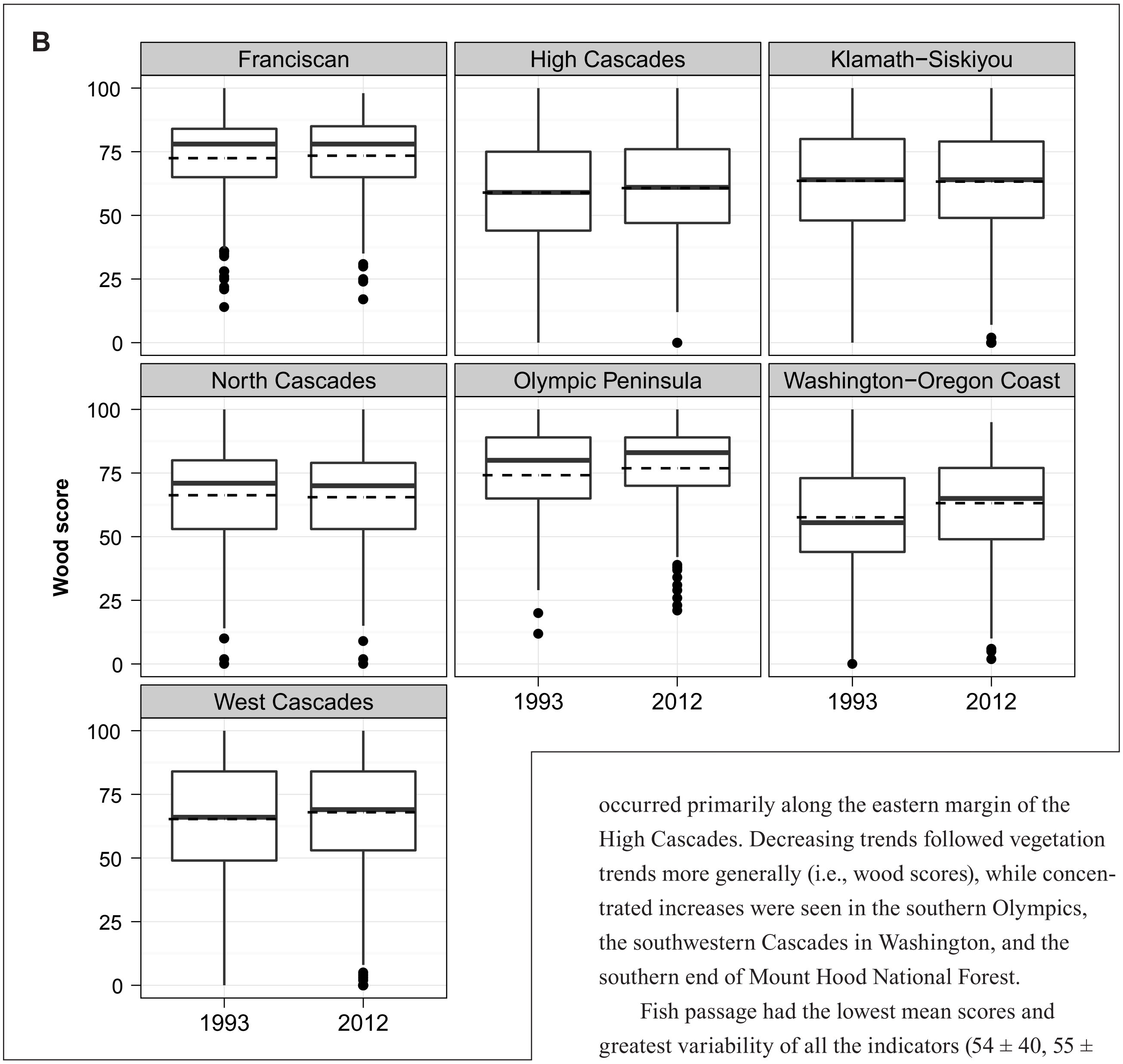
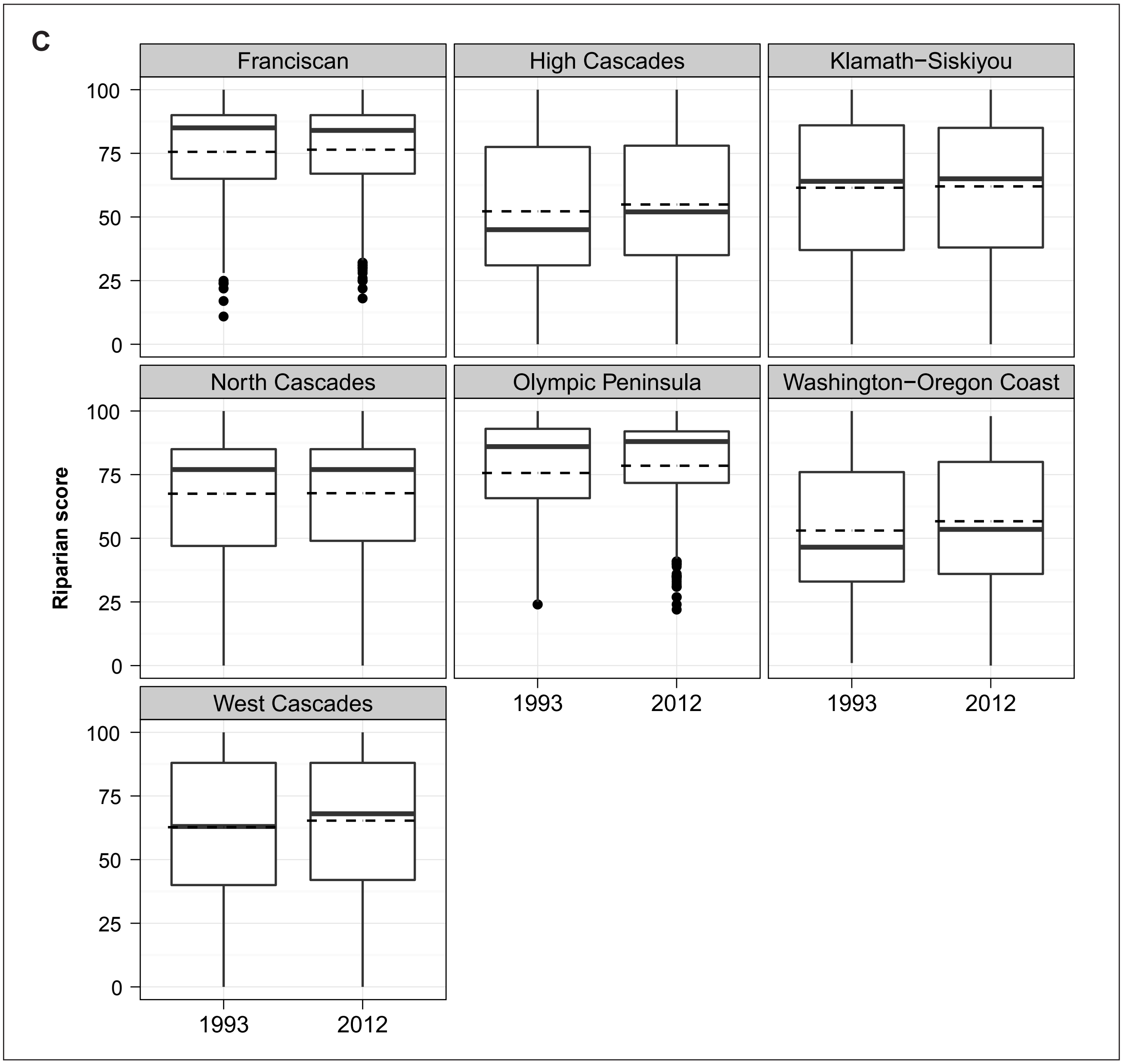


Figure 20—Continued.

North Cascades and low scores along the eastern side of the Oregon Coast Range and the western and eastern sides of the Cascade Range from Washington to northern California.

Hydrology scores, derived from overall road density and vegetation condition, were the highest of the process indicators (81 ± 26, 83 ± 25) (fig. 20D). Scores in the Franciscan, North Cascades, and Olympic Peninsula were noticeably higher than the other four provinces. Low scores occurred primarily along the eastern margin of the High Cascades. Decreasing trends followed vegetation trends more generally (i.e., wood scores), while concentrated increases were seen in the southern Olympics, the southwestern Cascades in Washington, and the southern end of Mount Hood National Forest.

Fish passage had the lowest mean scores and greatest variability of all the indicators (54 ± 40, 55 ± 40) (fig. 20E). Scores differed considerably between provinces. The Franciscan, North Cascades, and Olympic Peninsula provinces all had mean scores greater than 60, whereas the West and High Cascades had the lowest scores (ranging from 33 to 46). Broader spatial patterns again followed road densities, with low scores along the eastern margin of the Plan area and in the area around the central valley between the Coast Range and the Cascades. No declines in scores occurred, and increases were highly dispersed over the Plan area.



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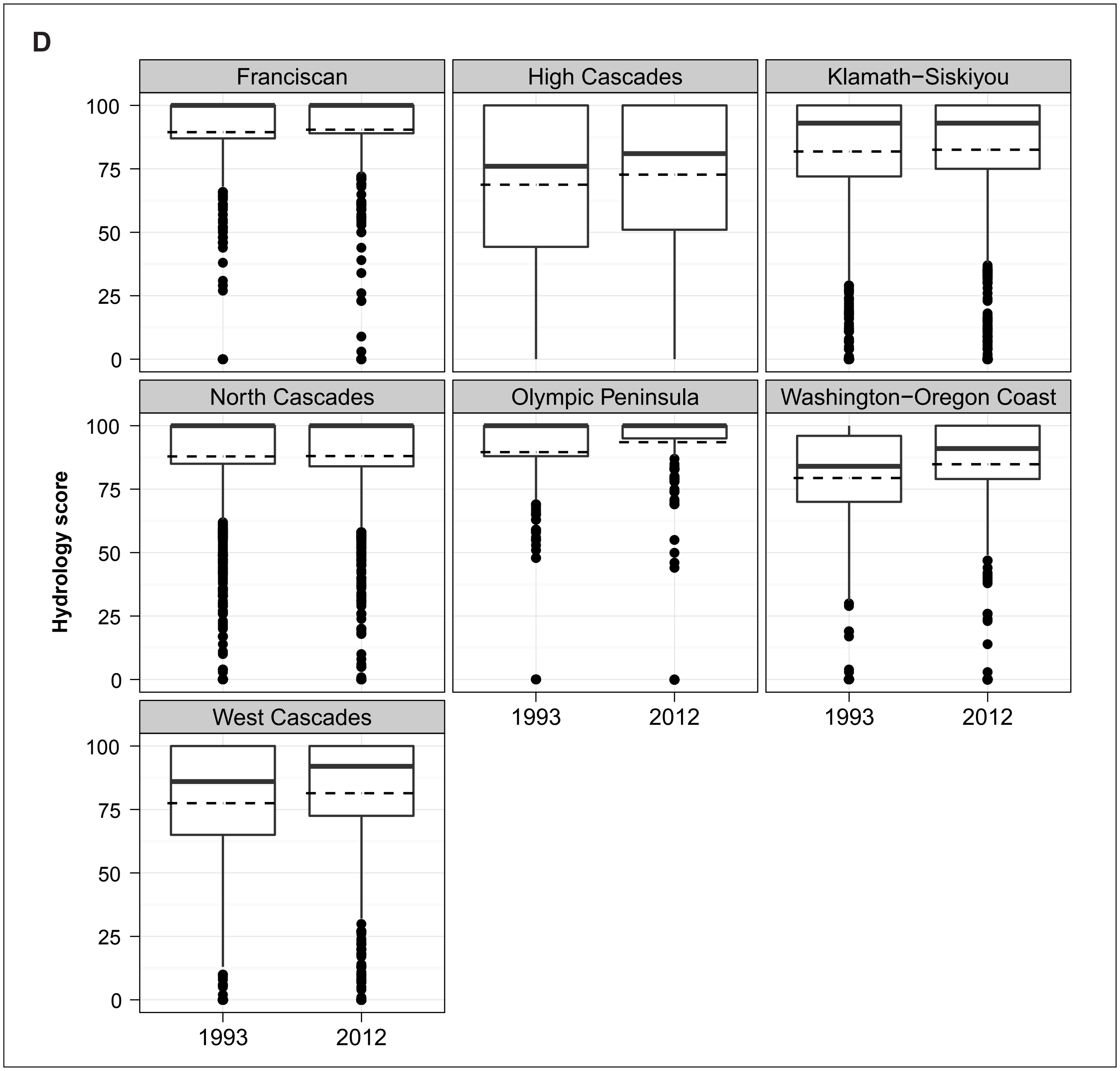

Figure 20—Continued.

Land Use Categories

There were noticeable differences in overall upslope/riparian scores between land use allocations. Congressionally reserved (CR) areas had the highest scores (75 ± 18, 74 ± 18), followed by LSR (mean = 66 ± 20, 68 ± 19) and matrix lands (62 ± 19, 65 ± 19) (fig. 21A). Changes over the 20-year period were slight, with CR showing a very slight decline (-1 ± 7), while LSR and matrix lands had small increases (+2 ± 8 and +3 ± 6).

Looking at the contributing process indicators (figs. 21B through F), average scores for wood, riparian and hydrology indicators followed the general pattern of resource protection levels (CR > LSR > matrix); however, for sediment and passage, reserved areas still had the highest scores, but matrix scores were higher than LSR scores. In terms of trend, matrix lands had the greatest average increases (+3 for hydrology, riparian and wood; +2 for sediment; +1 for passage). LSR areas showed similar gains

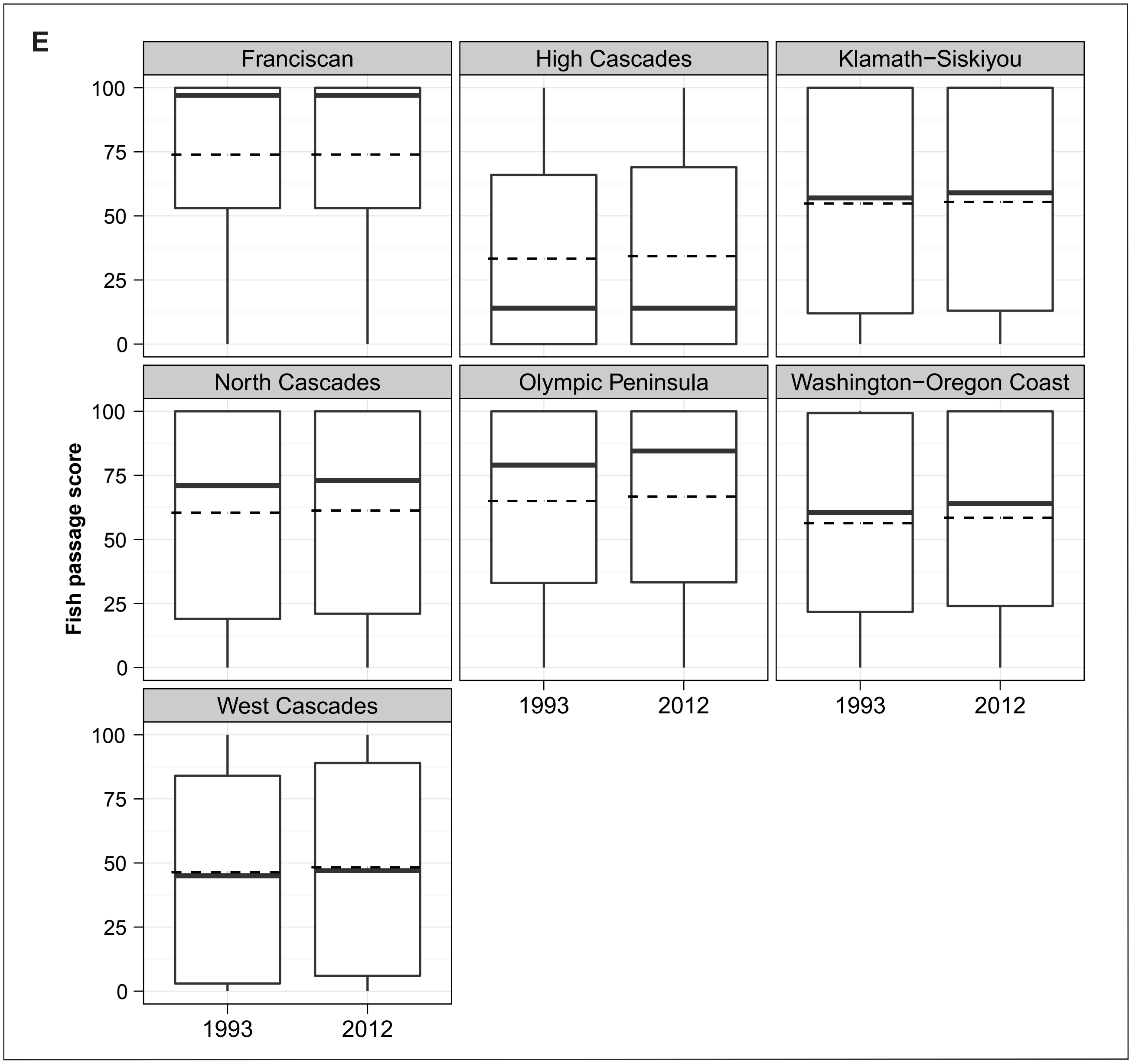

Figure 20—Continued.

(+3 for hydrology and sediment; +2 for riparian and wood; +1 for passage). In reserved areas, only passage increased slightly (+1), while riparian showed no change and sediment and wood scores actually declined slightly (-2 and -1).

There were only very slight differences in average upslope/riparian condition scores between key and non-key watersheds in 1993 and 2012 (mean = 68 ± 20, 68 ± 19 versus 67 ± 20, 69 ± 19), but non-key watersheds did show a slight increase (+2 ± 6) while key watersheds did not (0 ± 9) (fig. 22A). Wood, riparian and hydrology process indictors all were higher in key watersheds (+2 to +4, standard deviation = 19 to 26 in 2012), while passage and sediment scores were actually higher in non-key watersheds (+4 and +5, standard deviation = 40, 34) (figs. 22B through F). Hydrology, riparian, and passage scores all increased slightly in both designations, but sediment and wood scores increased only in non-key watersheds. None of the indicators showed an overall decline in either designation.

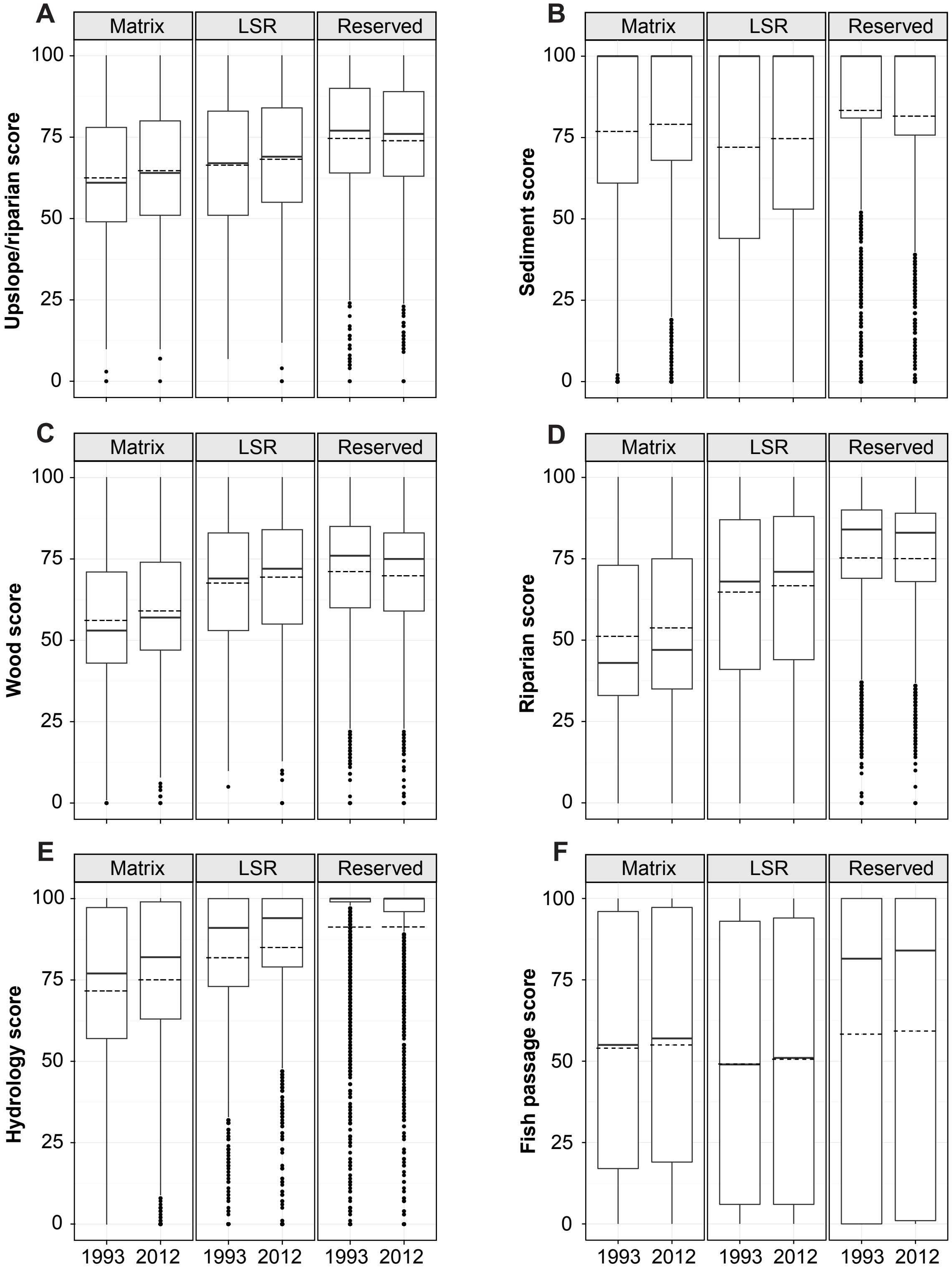

Figure 21—Upslope/riparian scores by land use allocation: (A) overall upslope/riparian scores; (B) sediment; (C) wood; (D) riparian; (E) hydrology; (F) fish passage. Mean upslope/riparian scores are represented by the dashed line; solid line represents median values.

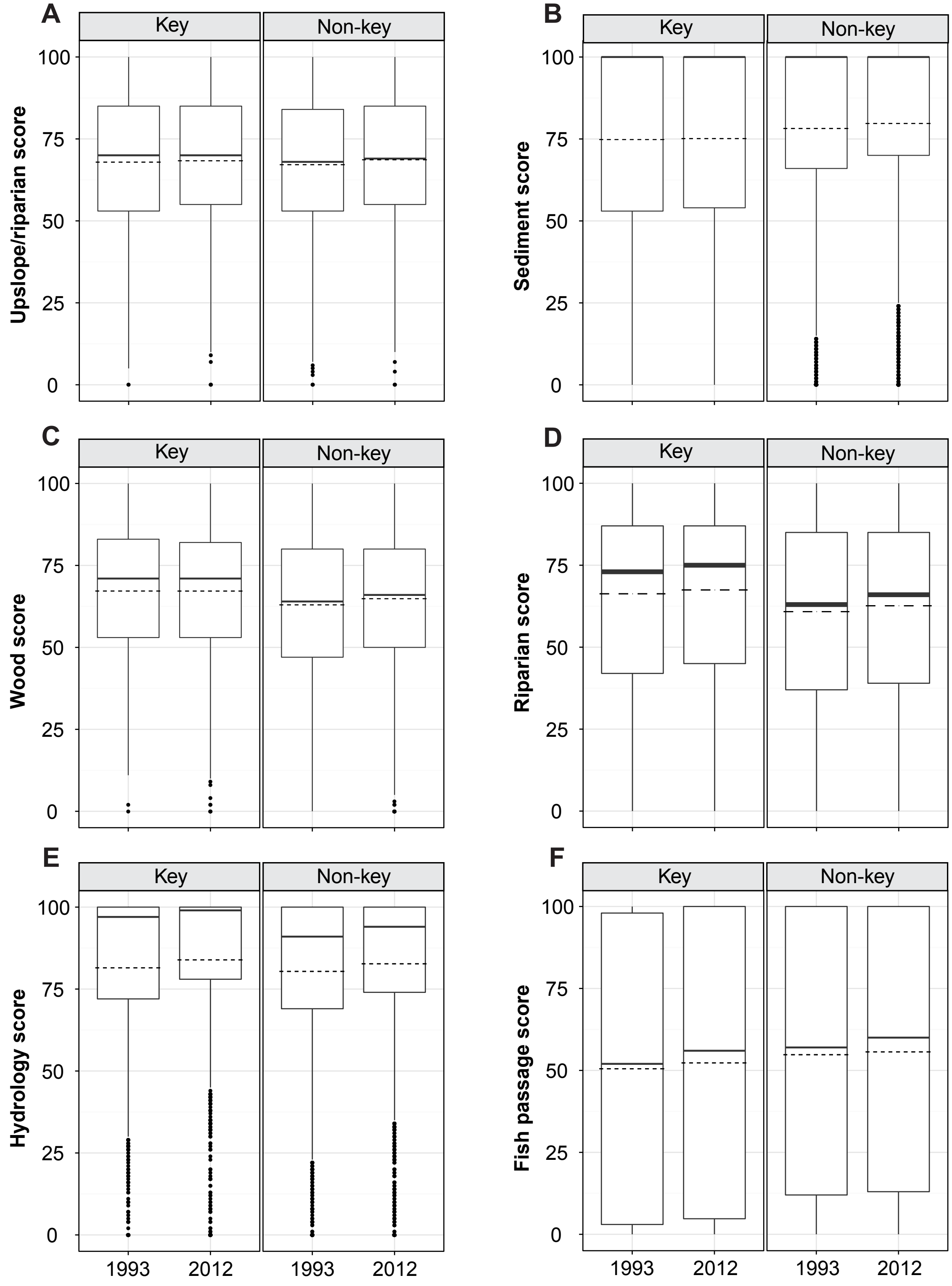

Figure 22—Upslope/riparian scores by key/non-key watershed designation: (A) overall upslope/riparian scores; (B) sediment; (C) wood; (D) riparian; (E) hydrology; (F) fish passage. Mean upslope/riparian scores are represented by the dashed line; solid line represents median values.

Becky Gehri

Tree canopy provides instream shade.

Chapter 4: Discussion

Assessment of watershed condition over such a broad area involves considerable challenges, such as an adequate level of field sampling, the quality and consistency of available geographic information system (GIS) datasets, and the setting of meaningful assessment thresholds and scoring systems. A number of methodological advances were employed for this report compared to the 15-year report, including deriving empirical reference distributions of conditions that describe expectations in areas with the least amount of human disturbance, as well as the consolidation of diverse provincial models into common unified approaches for both stream and upslope assessment. Novel approaches here warrant continued testing and comparison with alternatives, with refinement expected as new knowledge accrues. In particular, the approach of using a reference distribution for what might be expected under alternative past histories is fundamentally challenging. It is difficult to incorporate natural dynamics and disturbance regimes that often occur over very long time scales. Here we used a reference distribution to describe conditions in those watersheds with the least direct human impacts since the Northwest Forest Plan (NWFP) was implemented, while including natural disturbances such as wildfire and landslides. How best to incorporate other natural dynamics and disturbance regimes, in particular rare or long-term events, and the effects of fire exclusion into what we might have expected in managed areas, is an area for continued work.

Stream Assessment

Stream condition was based on three separate elements: physical habitat, macroinvertebrates, and water temperature. Changes in stream condition will likely be detectable only after multiple rotations are completed, particularly in areas that were highly affected by disturbance prior to the inception of the NWFP (Reeves et al. 2004). Recovery may take decades and, in fact, was not expected in fewer than three or four sampling rotations (25 years or more) (Reeves et al. 2004); we are currently in year 13. A slight but statistically significant positive trend in physical habitat condition may signify that these systems are recovering from historical disturbance(s). Low watershed scores were primarily driven by substrate and pool tail fines. Substrate scores increased in matrix and reserved land use allocation categories but no significant trends in pool tail fines were detected. These results are consistent with expectations under FEMAT (1993). Completing future rotations should increase our ability to detect what changes are occurring and where.

Repeat sampling began in 2009 for the stream data. As of 2013, we have completed half of the second rotation. We will not be able to truly estimate any changes in watershed condition until 2017 when all watersheds have been revisited. In this analysis, we assess trend in yearly status estimates rather than repeated watersheds because we have not yet completed all resampling. In the meantime, comparing the first rotation of visits (2002–2009) to the first 4 years of the second rotation (2010–2013) gives a general idea of current patterns. The number of watersheds visited each year does not represent the number paired for the 4-year comparison because not all watersheds visited during the first 4 years of the rotation were revisited during the second rotation, and vice versa. Events such as wildfires, illegal marijuana plantations, high-water events, and other safety issues warranted use of alternate watersheds.

In this study, we did not consider aspects of pools other than pool tail fines in our evaluation (e.g., pool frequency, pool spacing, percent of pools) for several reasons. First, pools are very difficult to measure consistently. Many monitoring programs tend to simplify their approach to quantifying pools, which likely underestimates the actual number of pools (i.e., methodology that considers only channel-spanning pools). Second, the mechanisms by which pools are formed differ tremendously within a stream. Some pools are formed by geological condition while others through are formed through wood inputs, or the combination. Although management can affect the amount of wood in a stream, thus affecting pool formation, management is unlikely to have much impact in streams where pools are geologically formed (e.g., step cascade systems). We found no indication that stream wood differed between rotations. However, it is important to note that wood protocols for 2002–2003 did not specifically count wood pieces in jams, so wood counts for these years are somewhat lower than for later years.

Until 2012, the Aquatic and Riparian Effectiveness Monitoring Program (AREMP) measured only pools that extended across the entire wetted width of the channel, and with the exception of pool tail fines, no other data were collected about each pool. To better understand whether a pool has the complexity necessary to provide cover, food, and thermal refuge, we have implemented additional data collection measures to quantify smaller pools within each reach, as well as the amount and size of wood pieces within each pool. Data collection protocols have been refined over time and we are working to more comprehensively include wood pieces in jams and other pool components within future assessments. With these additional refinements, we can easily calculate the original attributes for consistency in comparison over time, while also using the new components for a better estimate of pool and wood condition in the future. As with any assessment of condition, it depends on the knowledge base at the time of development. As we refine our understanding of watershed processes, we are able to better assess condition (Reeves et al. 2004).

Previous provincial models also included macroinvertebrates and amphibians in the overall stream condition score. In 2012, amphibian surveys were dropped from our survey program owing to the unreliability of presence/absence data. AREMP continues to collect macroinvertebrates but, at present, does not collect any other biological data. Although macroinvertebrates are commonly used as measures of environmental health, using a single metric to describe watershed biological integrity can lead to erroneous interpretation of biological condition, particularly if that estimate is to represent multiple organisms (Barbour et al. 1999, Carlisle and Hawkins 2008). As such, we report macroinvertebrates separately from physical habitat condition and temperature in order to provide additional information to more comprehensively evaluate different components of the system, exerting caution as each separate metric is considered and compared with others

We detected a positive trend in the status of observed-to-expected macroinvertebrate scores between rotations. For macroinvertebrates, the level of biological degradation is often determined by the number of sites within an area that fall below a species loss threshold (Barbour et al. 1999). In the NWFP area, macroinvertebrate biological integrity was quite high. Only about 25 percent of sites had scores below 0.6, indicating only a 40-percent difference in stream invertebrate assemblages as expected from reference. The majority of watersheds with scores below 0.6 occurred in non-key watersheds. A consistent pattern of a 40-percent difference in stream invertebrate assemblages from reference expectations may indicate that these systems have not fully recovered from some disturbance. A small percentage of scores were above 1, indicating stream invertebrate assemblages that were more diverse than expected. Although one could consider this to be an area of high biological diversity, this score could also represent poor model representation, or be an early warning sign that the system is moving into a state of disturbance. More investigation is needed to understand why these areas score higher than expected by reference conditions.

Although the macroinvertebrate score is used as a separate line of evidence for the condition of a watershed, for several reasons we caution against the use of analyses that aim to correlate stream invertebrate scores with physical habitat scores. First, correlations are unlikely because data were collected across very different physical scales. Macroinvertebrates were collected in targeted random riffles and combined into a single sample, while physical habitat variables were collected at equally spaced transects and calculated as a percentage or frequency based on the reach length. Additionally, the physical habitat measures were not taken within the same microhabitat from which the macroinvertebrates were collected.

Several studies have shown that the relationship of macroinvertebrates to management actions is difficult to detect, especially within broad-scale assessments (Irvine et al. 2014). This is likely to be even more problematic within the NWFP area given that the cumulative effect of management is diffuse across the landscape. Macroinvertebrates often do not exhibit a strong signal to physical habitat until the habitat is strongly affected (Irvine et al. 2014, Vander Laan et al. 2013). Different aspects of the macroinvertebrate assemblage (i.e., biological condition versus taxon loss) are expected to be affected by different stressors (Paulsen et al. 2008). In general, O/E scores within the NWFP area show that the vast majority of the area has conditions in excess of 0.70. Macroinvertebrate scores are typically considered concerning at levels far below the scores recorded within the NWFP. These largely high scores were noted to increase between the two rotations, showing a positive trend. Given that it typically takes a strong negative effect to detect a negative response in macroinvertebrate scores, the results here appear fairly typical. Macroinvertebrate assessments are used as only one line of evidence for the condition of a watershed.

In prior provincial models, water temperature carried more weight than other attributes because it was measured only once (at the lowest elevation on federal land) for each watershed, in contrast to the other attributes, which were averaged over 4 to 11 sites. Because placement of the thermographs was separate from the site survey and reflected only the downstream point on federal land, we felt that it did not adequately characterize the variability of temperature for an entire watershed. Here, we chose to analyze temperature separately from physical habitat condition as independent information about watershed condition. Congressionally reserved (CR) lands had the fewest number of watersheds with temperatures exceeding 15 °C, while matrix lands had the most in both rotations. The overall mean trend was significantly negative, reflecting an improvement (decrease) in 7-day average maximum water temperatures. The negative slope indicates that overall temperatures decreased between rotations in all lands. This pattern could correspond to higher levels of shading in streams resulting from increases in vegetation along riparian reserves (Moore et al. 2012). Despite the improvement in stream temperatures, we found that some lower reaches within these watersheds do not meet desired conditions based on both National Marine Fisheries and State of Oregon standards (fig. 12). Although these standards are the current guidelines for evaluating stream temperature, it is important to recognize that a single threshold without environmental context is inadequate for assessment (Moore et al. 2012). AREMP stream temperature assessment will continue to evolve as new assessment tools become available (e.g., NorWeST) and can serve as a baseline of spatially representative sites to evaluate trends (Arismendi et al. 2012).

Upslope/Riparian Assessment

Although the change in mean upslope/riparian condition scores was negligible, a clear increase was seen in areas with lower scores (30 to 60) at the beginning of the NWFP. Looking only at the mean scores, this increase was largely offset by declines in some areas that were in relatively high condition at the start of the Plan. These declines clearly follow the pattern of large fires during the assessment period, including the Biscuit Fire in southwest Oregon, the B&B Complex Fires in the central Oregon Cascades, and numerous fires along the eastern edge of the North Cascades in Washington. While we evaluate the short-term effect of fire as a loss in vegetation, and therefore as a negative impact, this is a simplistic view. Fires are an essential component of long-term stream ecosystem dynamics (Bisson et al. 2003, Reeves et al. 1995). AREMP will continue to work toward adjusting scores to account for the positive effects of fire as the science becomes available. In terms of area, and by using a conservative estimate of change (score change greater ±5), increases outweighed declines by 2 to 1 (16 percent versus 7 percent). The majority of these moderate positive changes occurred in areas that previously had been the most heavily roaded and harvested, including the southern Olympic Peninsula region and along the eastern flank of the Oregon Coast Range and western flanks of the Cascade Range in Oregon and Washington. Growth in vegetation and decommissioning of roads made a considerable positive impact on the upslope/riparian condition scores in these areas.

In terms of the process indicators, sediment and fish passage scores showed the broadest range, and drove scores lower in certain areas. Both of these indicators are largely driven by road densities, thus they showed considerable positive changes in watersheds in which roads had been decommissioned, but this effect was small in terms of Plan-wide averages. Wood production and transport, the only process weighted more on vegetation than road metrics, did help drive the distinct spatial pattern described above for the overall upslope scores. There were broad, moderate increases in previously low-scoring areas, and sharp declines in many areas that experienced large wildfires.

In terms of land use allocations, the general pattern of higher scores in the more protected categories still held true, but trends, although slight, continued to move these classes in opposite directions: matrix scores increased the most, whereas CR scores appeared to be declining. Given the dynamic nature of ecosystems, this decline is not unexpected, and because many of these CR lands are at the top of the scoring range, they can only maintain condition or decrease due to disturbance events such as fire.

Stream Versus Upslope/Riparian Evaluations

Scores from the stream and upslope evaluations were not strictly comparable because they were based on different types of evaluation thresholds. Stream scores were relative to least human disturbed reference networks, whereas upslope scores were a combination of deviation from reference expectations and expert-derived impact thresholds. Further, the upslope-riparian model was assessed only for the years 1993 and 2012, while stream condition was assessed over an 8-year rotating pattern; this creates temporal incongruence. The overall distributions of the scores likely reflect this difference, with the majority of stream scores falling between 40 and 60, while the majority of upslope scores were above 60. In terms of land use categories, both upslope and stream condition scores generally followed a pattern consistent with the amount of allowable vegetation management (i.e., timber harvest). Mean upslope and stream physical habitat scores were highest in the congressional reserves. Stream scores were lower in late-successional reserves (LSR) than in matrix lands (in the first rotation), but the upslope model rated LSR lands higher. No difference was detected in distributions for key versus non-key watersheds based on stream scores, and upslope key watershed scores were only slightly different (±1). We are currently halfway through the second rotation of watershed visitations for the stream component of the program, and as a result, the reported results are incomplete until the rotation can be finished in 2017.

Management Implications

The Aquatic and Riparian Effectiveness Monitoring Program was designed as a broad-scale monitoring and assessment program. Trends are expected to be difficult to detect because of relatively small sample sizes, and in this case an incomplete second round of sampling, high levels of natural variability, and the inevitable measurement errors. Broad-scale land use protections offered by the NWFP and the aquatic conservation strategy (ACS) are the bedrock of our regional efforts to restore aquatic ecosystems. Change occurs slowly but will be realized by restoring processes over regional extents, not just features in stream channels (Roni et al. 2002). Restoration management actions (e.g., wood additions, barrier removal, etc.) are short-term solutions, but they cannot substitute for the broader extent of passive efforts such as land use protections. As such, it should be realized that restoration actions and local-level projects are planned and implemented at finer scales and can provide higher resolution data more sensitive to the local context.

At the regional level under current landscape level aggregated management practices, we detected a slight positive trend in stream physical habitat conditions, as well as improvements in macroinvertebrate score and temperature. Improvement in these scores does suggest positive shifts since the inception of the Plan. However, understanding whether these positive shifts are a response to specific management actions is difficult to ascertain given that the program was designed to measure regional trends and not individual projects. For example, over the last 20 years, managers have been using additions of large wood to streams. Yet, at the scale of the NWFP area, we did not detect a positive trend in large-wood frequency. Project-specific wood placement is unlikely to be accounted for in AREMP sample design unless a site happens to fall within a wood placement restoration area. Furthermore, placing wood in the stream does not affect the mechanism by which wood enters the stream, which is typically through trees from the riparian area falling into the stream. Thus, maintaining a healthy riparian area capable of providing wood additions is a key process that does not change through wood additions but rather through management or restoration of riparian areas.

To identify whether any relationships exist between specific landscape-level management practices and stream attributes (see Hough-Snee et al. 2014 and Meredith et al. 2014 as examples), we are analyzing existing AREMP data using GIS-defined management actions, road density, and road/stream crossing to predict stream sediment and wood at varying spatial extents. The results of this future analysis could serve to illustrate how well typical measures of GIS-defined management actions can predict stream conditions at varying spatial scales. When possible, AREMP will continue to use our regionally collected field data to focus on these types of iterative explicit hypotheses about large-scale cause-effect relationships to further our understanding of management of stream systems on federal lands (Frissell et al. 2014).

According to the upslope model, sediment and impacts to fish passage drove low scores over the broadest area. Sediment delivery increases with roads and vegetation loss on steeper slopes and erosion-prone geologies that are topographically positioned to deliver material to streams. As part of this analysis, AREMP helped build a regional landslide risk model, which better defines these vulnerable areas and could contribute to broader ongoing discussions on the refinement of riparian buffers. Based on our model, protecting riparian buffers by minimizing vegetation loss and road density are strategies that are likely to increase scores for all the process indicators. Our estimate of fish passage was based on the existence of road-stream crossings, so the removal of these crossings is the only management action that will have an effect, and benefits are highly conditional. The beneficial effects of numerous aquatic organism passage projects occurring over the last decade on existing roads was not accounted for. However, our metric may be improved in the near future with the completion of regional fish-passage databases that will recognize passable and semi-passable crossings, account for corrected barriers, and allow more targeted barrier-removal strategies. According to our model, the decommissioning of roads in riparian areas has multiple benefits, including improving the riparian scores directly and typically the sedimentation scores.

Future of Monitoring

Although the AREMP was designed with the goal of assessing the effectiveness of the NWFP as a region, we have actively worked on providing more localized reports for individual national forests, Bureau of Land Management districts, and national parks. To do this, we summarize our findings at various local levels and are able to provide customized reports. We are working to ensure that these reports can be used for monitoring requirements under any new planning rules or records of decision as the agencies move forward with revisions of forest and resource management plans within the area of the NWFP.

We can draw some management implications from this type of broad-scale monitoring and assessment, but it must be realized that the intent was to inform at a landscape level. If a local unit has a management question or would like a site-level evaluation of stream metrics, current physical habitat and macroinvertebrate tools are capable of making site-level assessments of condition. However, it is important to recognize that this depends on the goals of the project and the types of processes that the individuals would like to better understand. The reference network that was developed allows for assessment at the individual site against sites with similar environmental characteristics. In particular, macroinvertebrate data collected by local units can be directly processed through the AREMP observed-to-expected (O/E) tool and easily assessed for expected aquatic invertebrate assemblages. This tool is available for any organization that collects macroinvertebrate data using a minimum set of standard sampling requirements. At a minimum, these tools can help inform practitioners as to whether a site is outside the range of reference expectation. The evaluation capabilities of these tools could be used to update ACS resource monitoring objectives by evaluating sites and comparing them to reference sites for environmental similarity. However, additional site-level information would be required to determine a cause if a site deviated from expectation.

Similarly, although the resolution of the upslope/riparian data is coarser than some locally available sources, it is well-suited for forest or district level analyses and initial project-level assessments. The evaluation model itself was constructed on a platform (ArcGIS®)[1] commonly used by most of the agencies involved in the NWFP, so it can be easily transferred and modified to meet different assessment needs. Further work is anticipated to better integrate AREMP data and results with the Forest Service national watershed condition class framework and efforts from other agencies. In particular, compiling the science to set well-justified evaluation criteria for different indicators is important for generating common expectations and goals across agencies. AREMP will continue to work on improvements to the upslope process indicators, such as sediment delivery, hydrology, and vegetation reference conditions, which have utility beyond watershed assessment. Currently, many of the GIS sources that are used by AREMP to evaluate upslope/riparian condition are available nationwide. Some customized datasets such as landslide risk can be applied to areas outside the NWFP area.

AREMP collects a core set of metrics consistent with other monitoring programs, and evaluates data based on a reference network framework. Furthermore, other monitoring programs that collect similar aquatic sampling metrics could potentially be leveraged with AREMP data to conduct integrated assessments across broader multi-ownership landscapes. Investigations into these possibilities may illustrate a potential framework for broad scale monitoring for Forest Service forests under forest plan revisions or integration into BLM national monitoring efforts such as the Western River and Stream Assessment program (WRSA), a BLM national monitoring program. In summer 2015, we performed a protocol overlap study to assess differences in data-collection protocols, but more importantly provide us with the framework to integrate data between AREMP and the WRSA for a BLM-wide assessment of streams within the Pacific Northwest. Data are being compiled for future analysis.

AREMP is already working with other organizations (Oregon Department of Environmental Quality and the Department of Fish and Wildlife) as well as other federal agency monitoring programs such as WRSA to standardize physical habitat data to increase the ability to share and develop high-level categorical metrics. Integrating monitoring programs across the region will allow for a greater understanding of the condition of our aquatic systems at multiple spatial extents.

The principal purpose of AREMP is to evaluate the change in aquatic ecosystems at the regional level (i.e., the area of the NWFP). This is done using data collected from a statistically derived sampling program with sites distributed across the areas of interest, and more recently, with the integration of data from other sources. Data collected by AREMP are the primary data source, and the amount of data and number of monitoring sites have continually increased since the program's inception. Coordination with other entities has increased the potential usefulness of the data to and from AREMP and has expanded the amount of available data. AREMP now has a robust dataset, expertise, and tools from which to assess broad-scale changes in aquatic ecosystems on federal lands and to provide insights into factors that influence aquatic ecosystems. These capabilities will be invaluable for the development and evaluation of new management and policy options for aquatic ecosystems in the NWFP area and elsewhere, including nonfederal lands.

Metric and U.S. Equivalents

Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	0.305	Meters
Acres (ac)	0.405	Hectares
Square miles (mi^2)	2.59	Square kilometers
Miles (mi)	1.609	Kilometers
Trees per acre	2.47	Trees per hectare
Degrees Fahrenheit (°F)	0.55(°F – 32)	Degrees Celsius

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

U.S. Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Square kilometers (km^2)	0.386	Square miles
Kilometers (km)	0.621	Miles
Trees per hectare	0.405	Trees per acre
Degrees Celsius (°C)	1.8 °C + 32	Degrees Fahrenheit

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Appendix 1: Natural Gradient Variables Used for Examining the Range of Natural Variation Among Reference Sites

All variables were calculated as the mean value for the true watershed, in which the lowest downstream point was an individual site, except for those at the site level.

Table 10—Environmental variables used for examining the range of natural variation among reference sites

Type	Environmental characteristic	Source	Unit
Climate	Precipitation (mean of annual monthly means 2000–2009)	*a*	cm
	Precipitation (mean of annual monthly means 1971–2000)	*a*	cm
	Precipitation (mean of annual maximum monthly 1971–2000)	*a*	cm
	Precipitation (mean of annual minimum monthly 1971–2000)	*a*	cm
	Air temperature (mean of annual monthly mean 2000–2009)	*a*	°C
	Air temperature (mean of annual monthly mean 1971–2000)	*a*	°C
	Air temperature (mean of annual maximum monthly 1971–2000)	*a*	°C
	Air temperature (mean of annual minimum monthly 1971–2000)	*a*	°C
	Wet days (mean annual monthly 1961–1990)	*a*	# days
	Wet days (maximum annual monthly 1994–2006)	*a*	# days
Atmospheric deposition	Atmospheric calcium (mean annual precipitation-weighted 1994–2006)	*b*	mg/L
	Atmospheric magnesium (mean annual precipitation-weighted 1994–2006)	*b*	mg/L
	Atmospheric SO_4 (mean annual precipitation-weighted 1994–2006)	*b*	mg/L
Geology	Calcite mineral content	*c*	%
	Magnesium oxide mineral content	*c*	%
	Nitrogenous mineral content	*c*	%
	Phosphorus mineral content	*c*	%
	Sulphur mineral content	*c*	%
	Hydraulic conductivity (log geometric mean)	*d*	10^{-6} m/s
	Unconfined compressive strength	*d*	MPa
Soil	Bulk density	*d*	g/cm^3
	Erodibility	*d*	K factor
	Permeability	*d*	in/hour
Vegetation	Quadratic mean diameter of conifers	*e*	cm
	Conifers with quadratic mean diameter >50.8 cm (percentage of area)	*e*	%
Catchment	Catchment area	*e*	km^2
	Catchment total stream length divided by area of catchment	*e*	km/km^2
Site	Elevation	*e*	m
	Latitude, longitude	*e*	deg
	Stream bankfull width	*e*	m
	Water electrical conductivity (predicted)	*c*	µS/cm

[a] PRISM (http://www.prism.oregonstate.edu).

[b] National Atmospheric Deposition Program National Trends Network (http://nadp.sws.uiuc.edu/ntn/).

[c] Olson and Hawkins (2012).

[d] Baker et al. (2003).

[e] Unpublished AREMP calculations.

Appendix 2: Natural Environmental Characteristic Variables Used to Define Nearest Neighbor Reference Network

All natural gradient variables (app. 1) were included in nearest-neighbor analysis; however, the environmental characteristic variables in this table represent those that were best able to define similarity among sites for each individual attribute. K represents the number of neighbors (network of least human-disturbed reference sites).

Table 11—Natural environmental characteristic variables used to define nearest-neighbor reference network

Attribute	Environmental characteristics	K
Percentage of pool tail fines	Gradient, percent sedimentary, mean bankfull width, maximum annual air temperature, stream density, latitude, watershed area, quadratic mean diameter of conifers, maximum monthly precipitation, magnesium oxide mineral content	7
Percentage of fines < 6 mm	Gradient, percent sedimentary, site elevation, 1994–2006 annual weighted atmospheric mean calcium, stream density, watershed area, mean bankfull width	5
Wood 12 inches × 25 feet	Latitude, mean bankfull width, water conductivity, watershed area	7
Wood 18 inches × 25 feet	Latitude, mean bankfull width, watershed area, water conductivity	6

Appendix 3: Spatial Distribution Maps of Stream Model Components

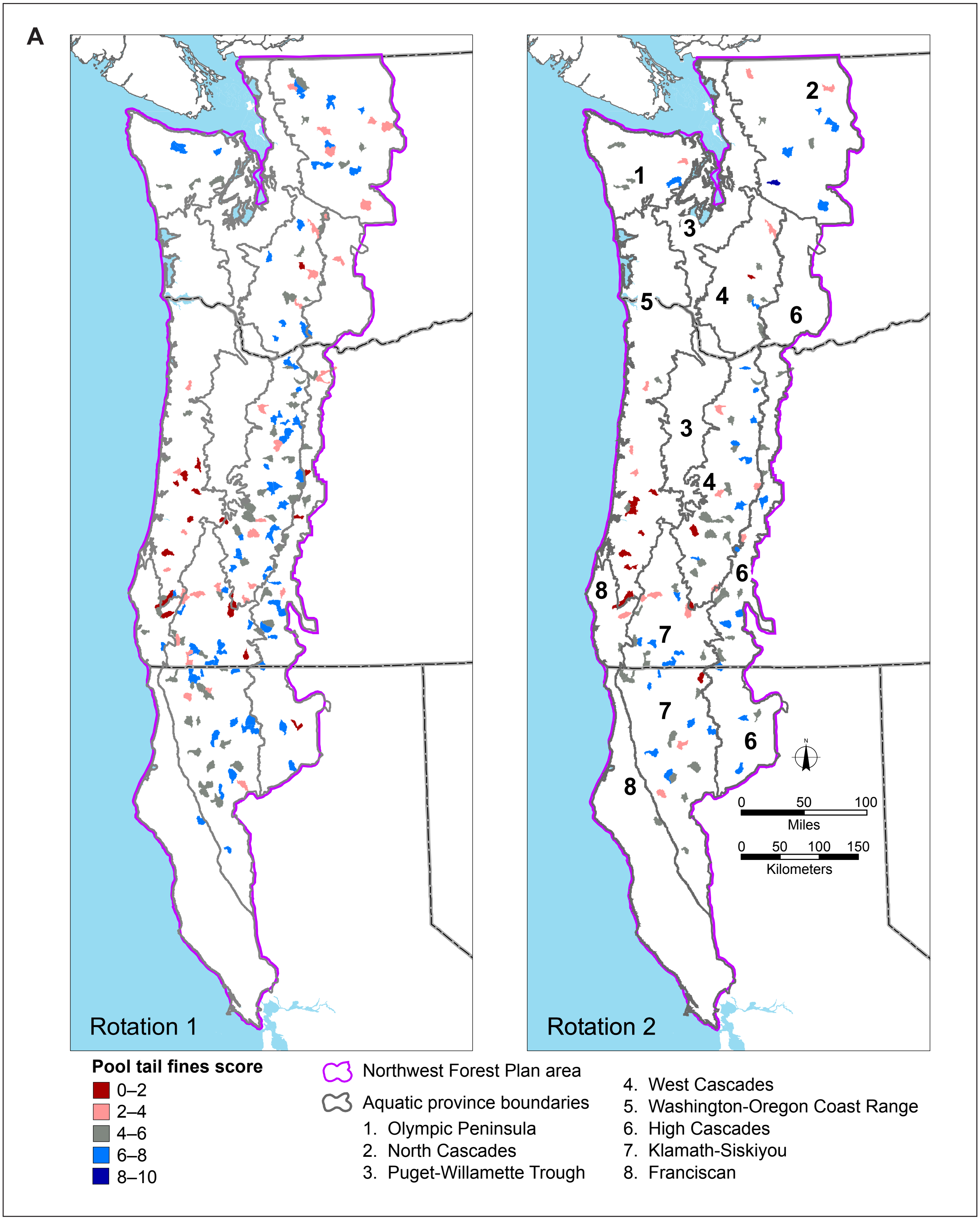

Figure 23—Spatial distribution of each individual stream metric included in the physical habitat score: (A) pool tail fines, (B) wood, (C) substrate, as well as (D) macroinvertebrate observed-to-expected values (O/E), and (e) 7-day average maximum temperature.

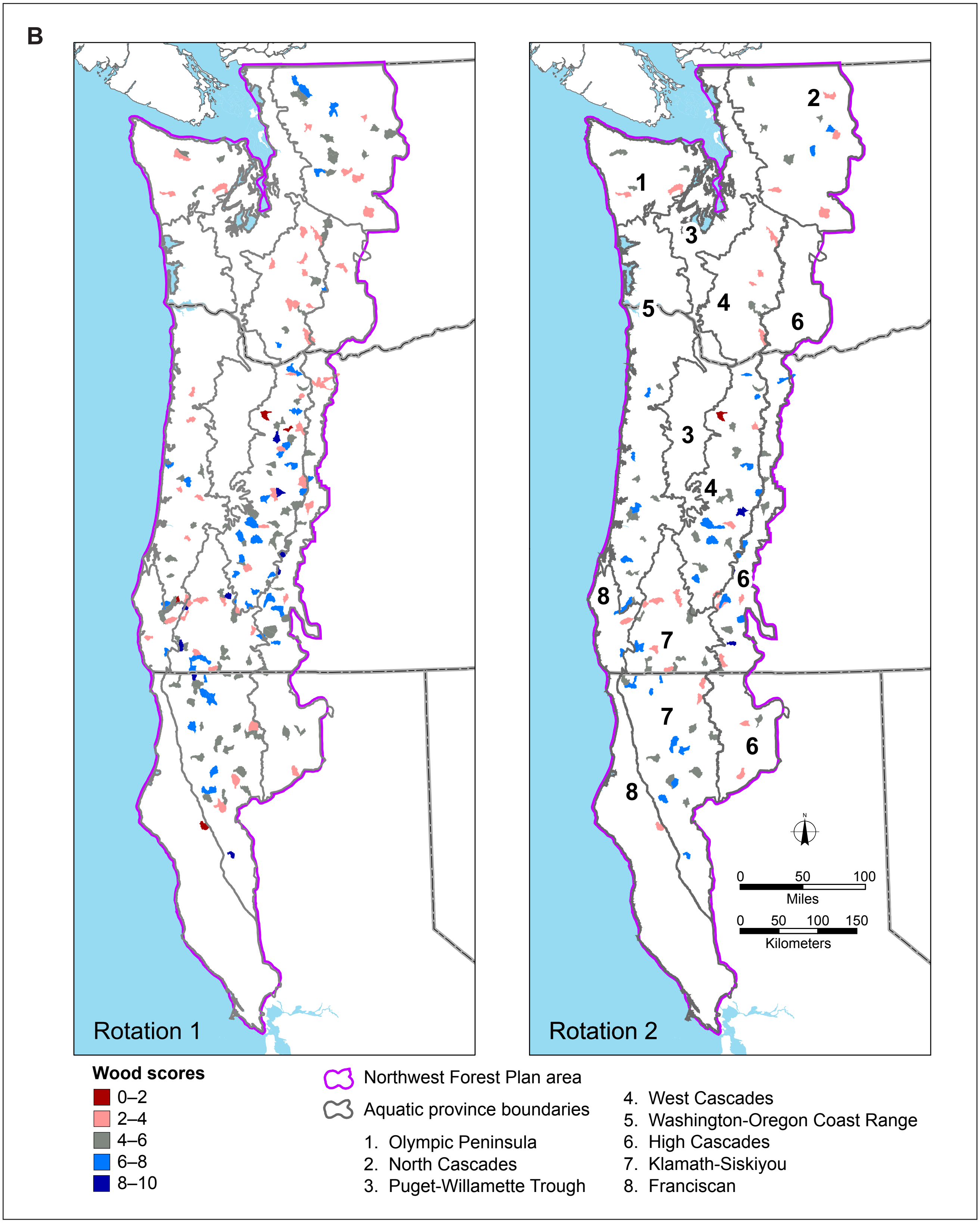

Figure 23—Continued.

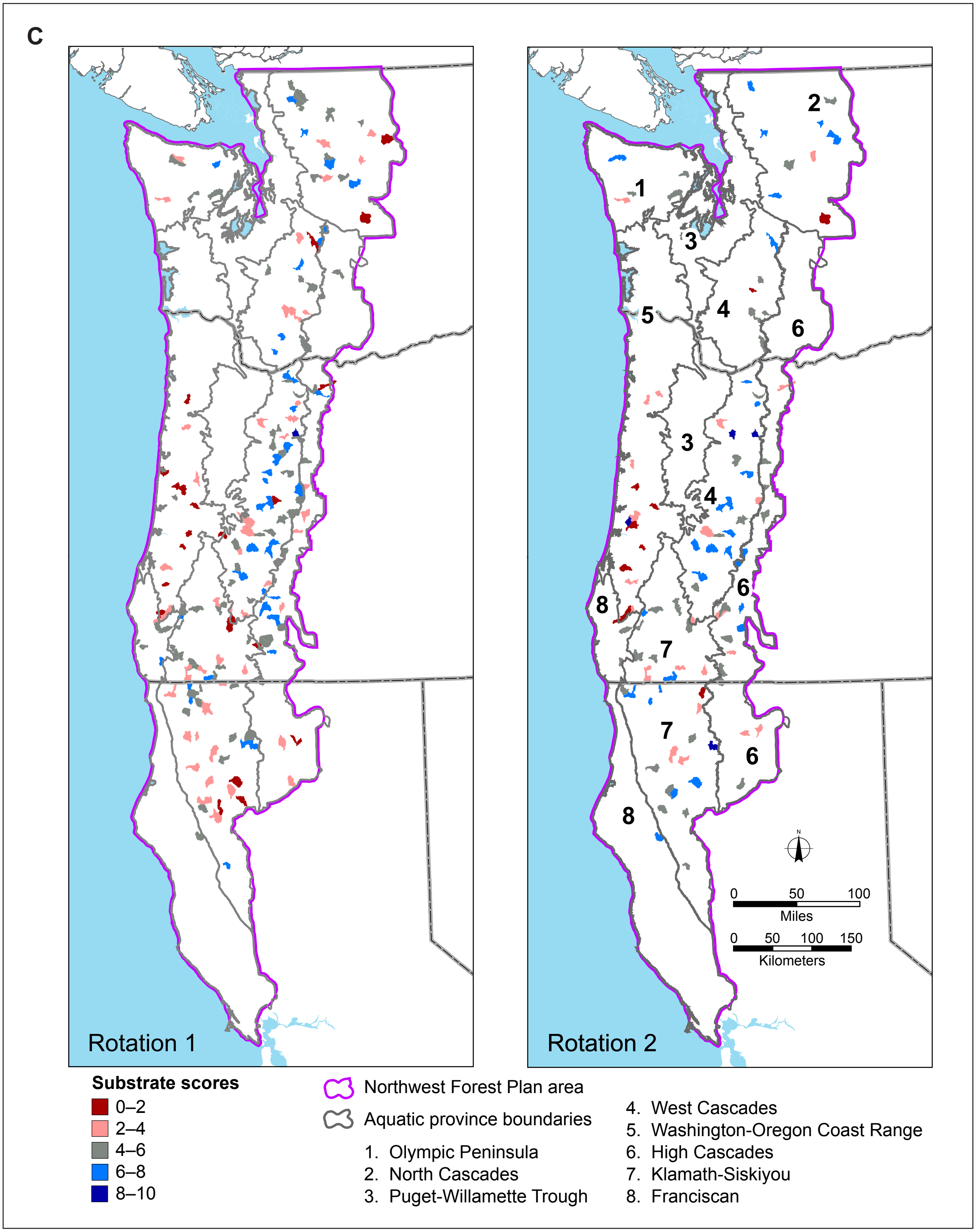

Figure 23—Continued.

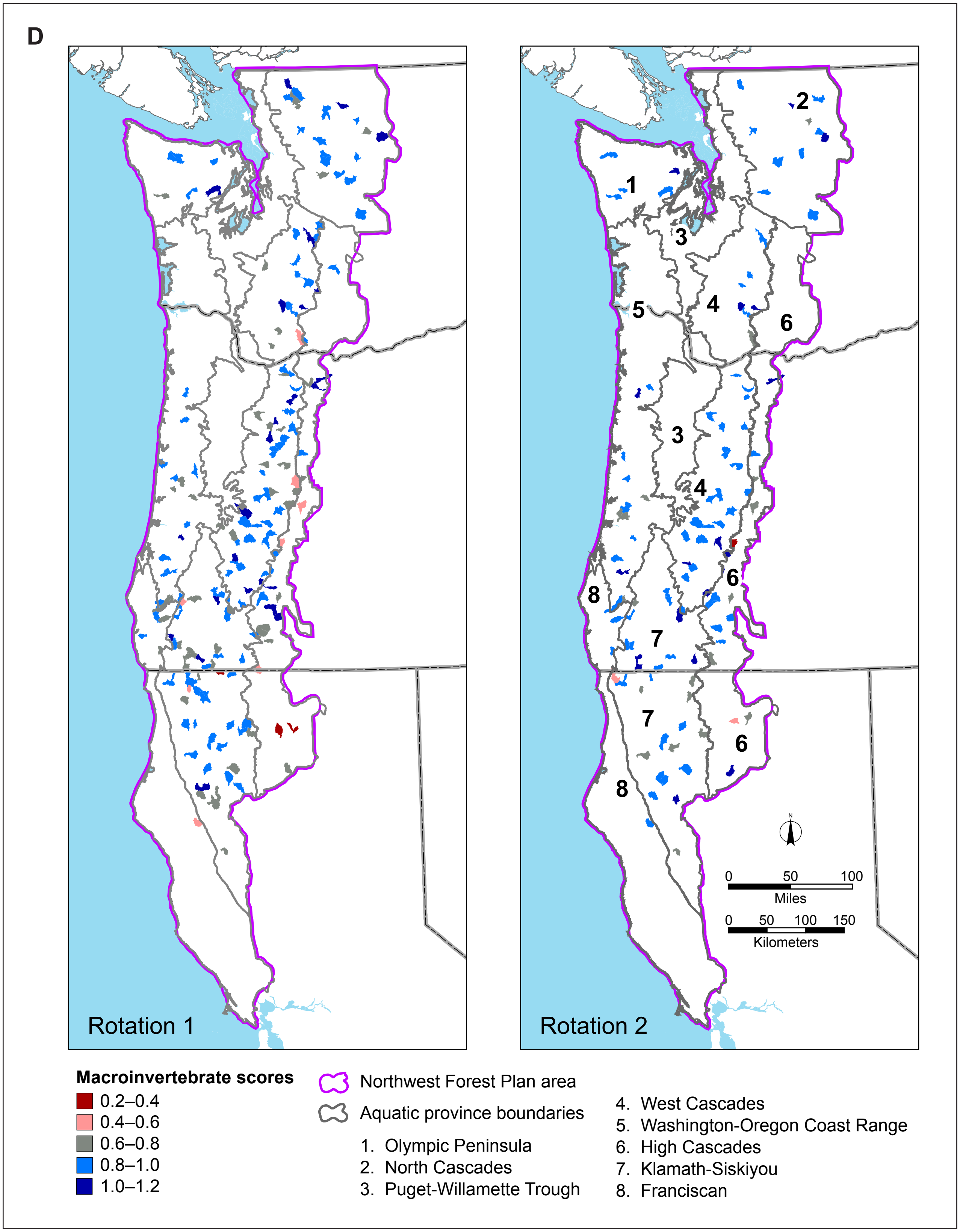

Figure 23—Continued.

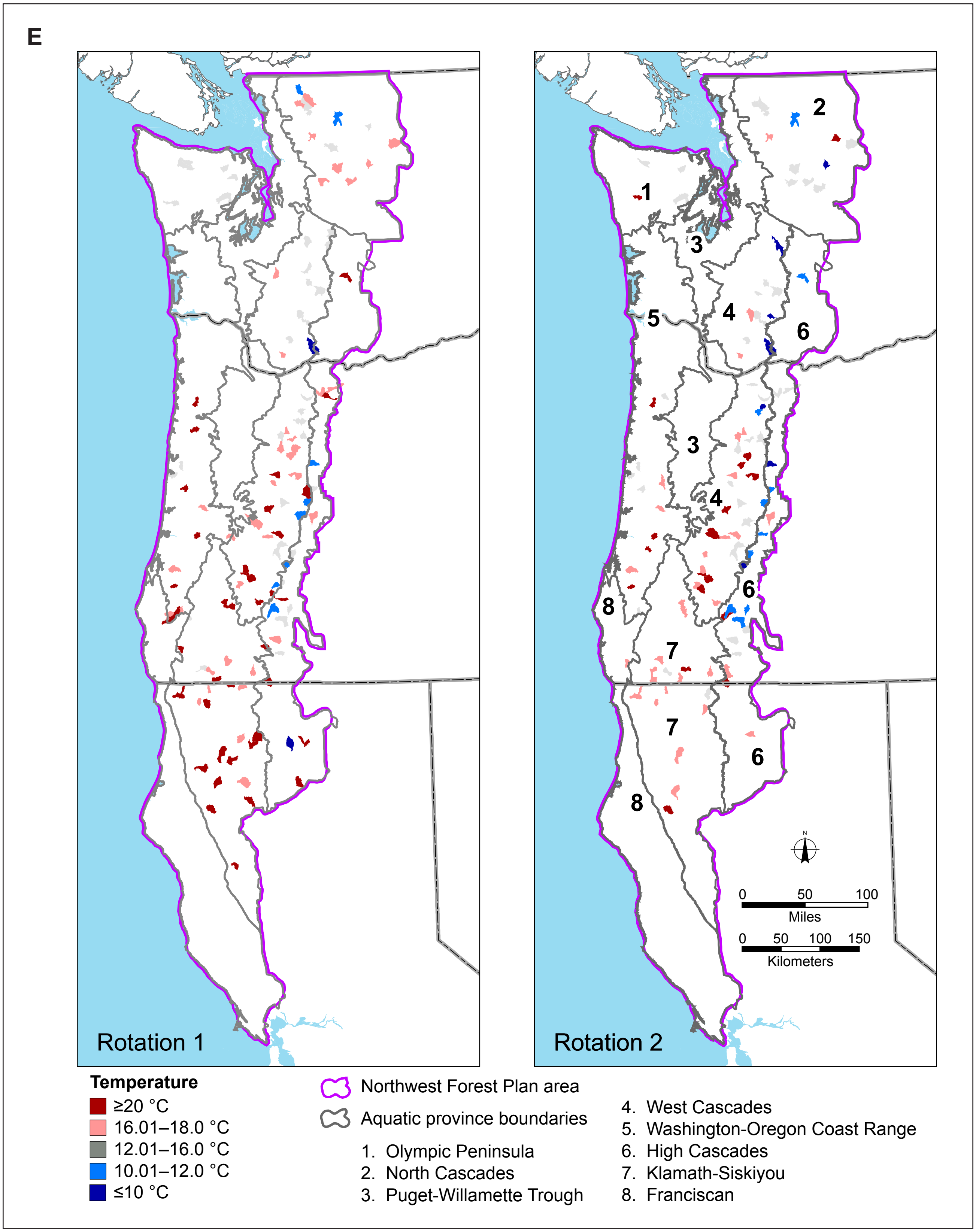

Figure 23—Continued.

Appendix 4: Spatial Distribution Maps of Upslope/Riparian Model Components

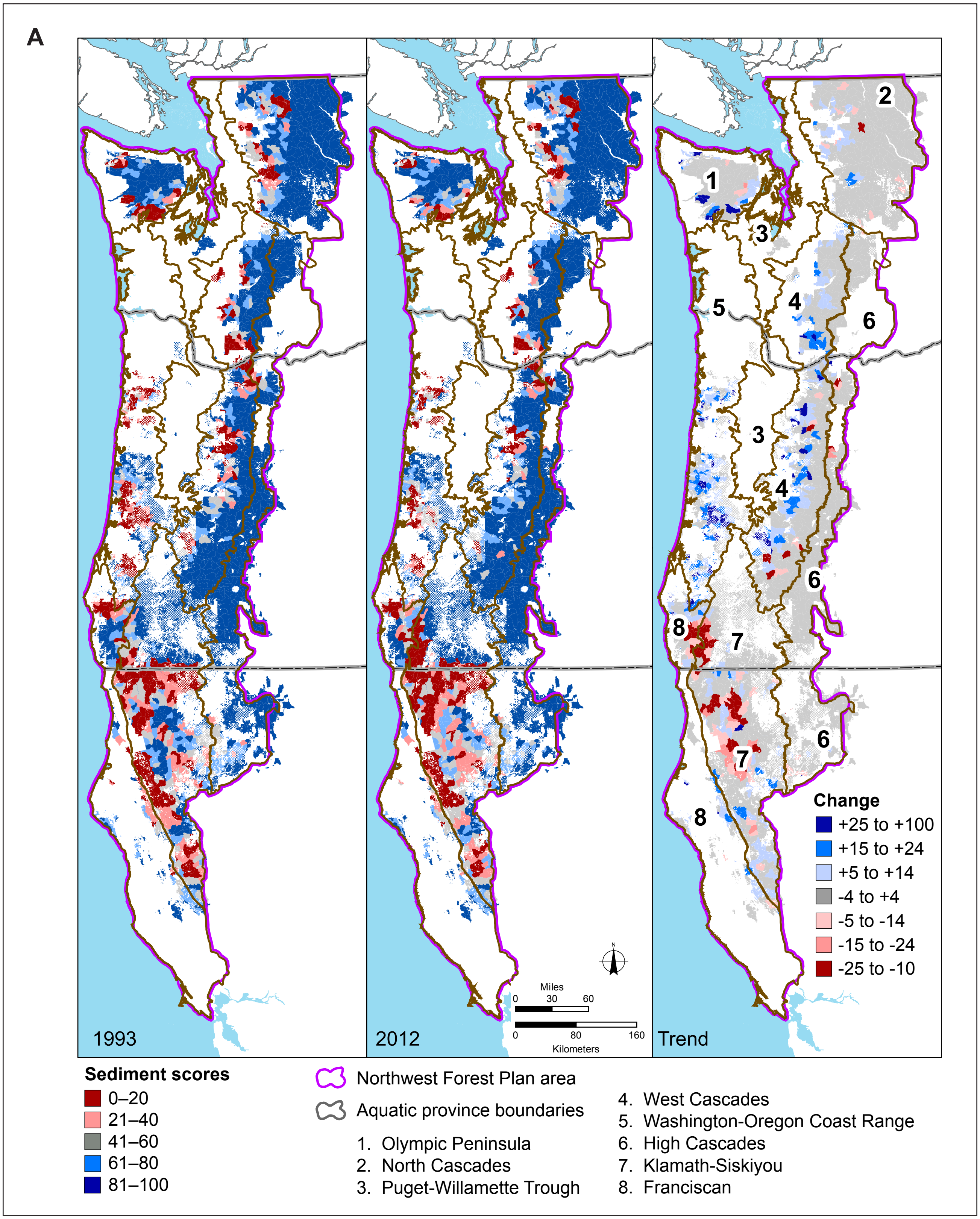

Figure 24—Spatial distribution of each individual upslope/riparian process indicators included in the watershed condition score: (A) sediment, (B) wood, (C) riparian habitat (D) hydrology, and (E) fish passage.

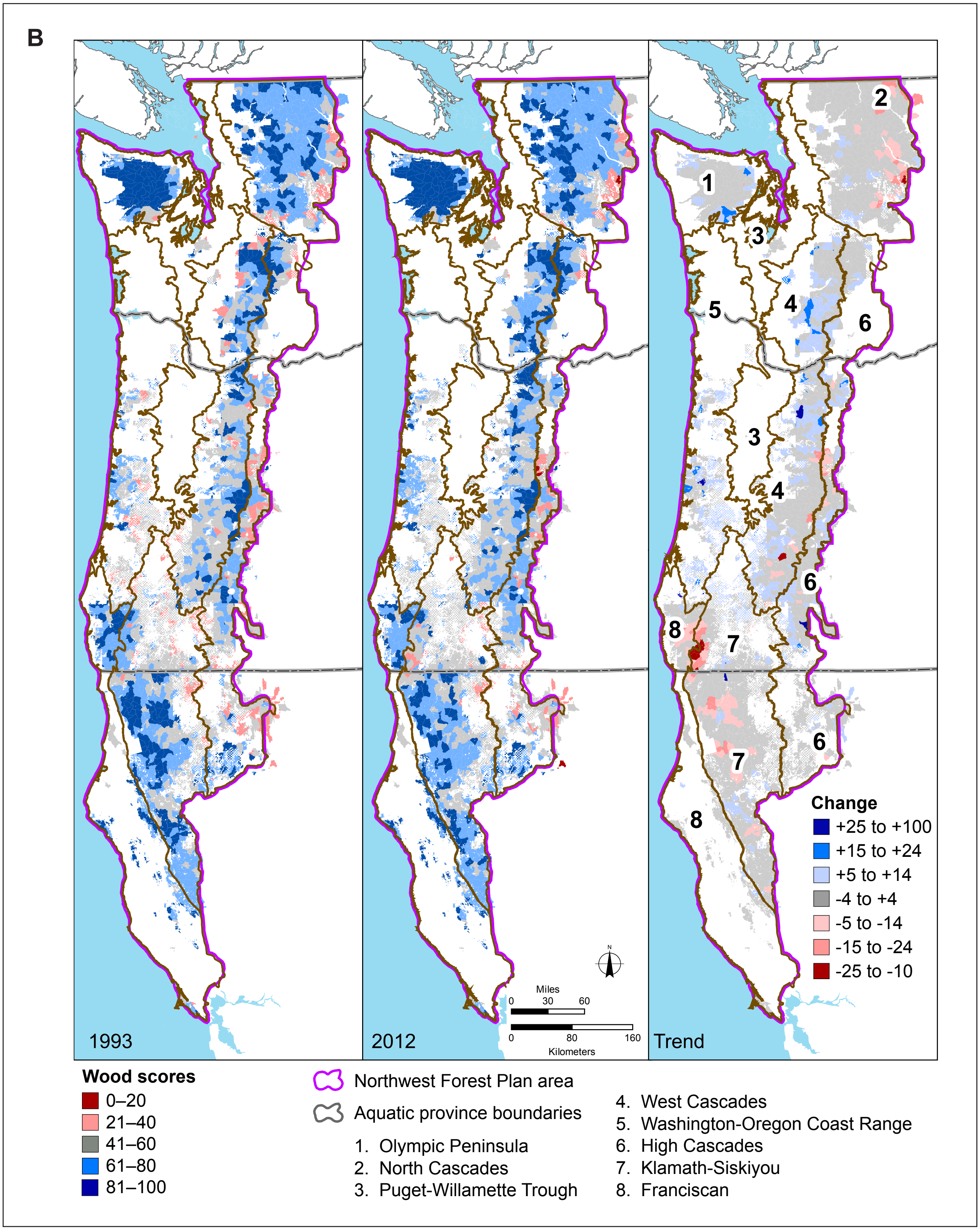

Figure 24—Continued.

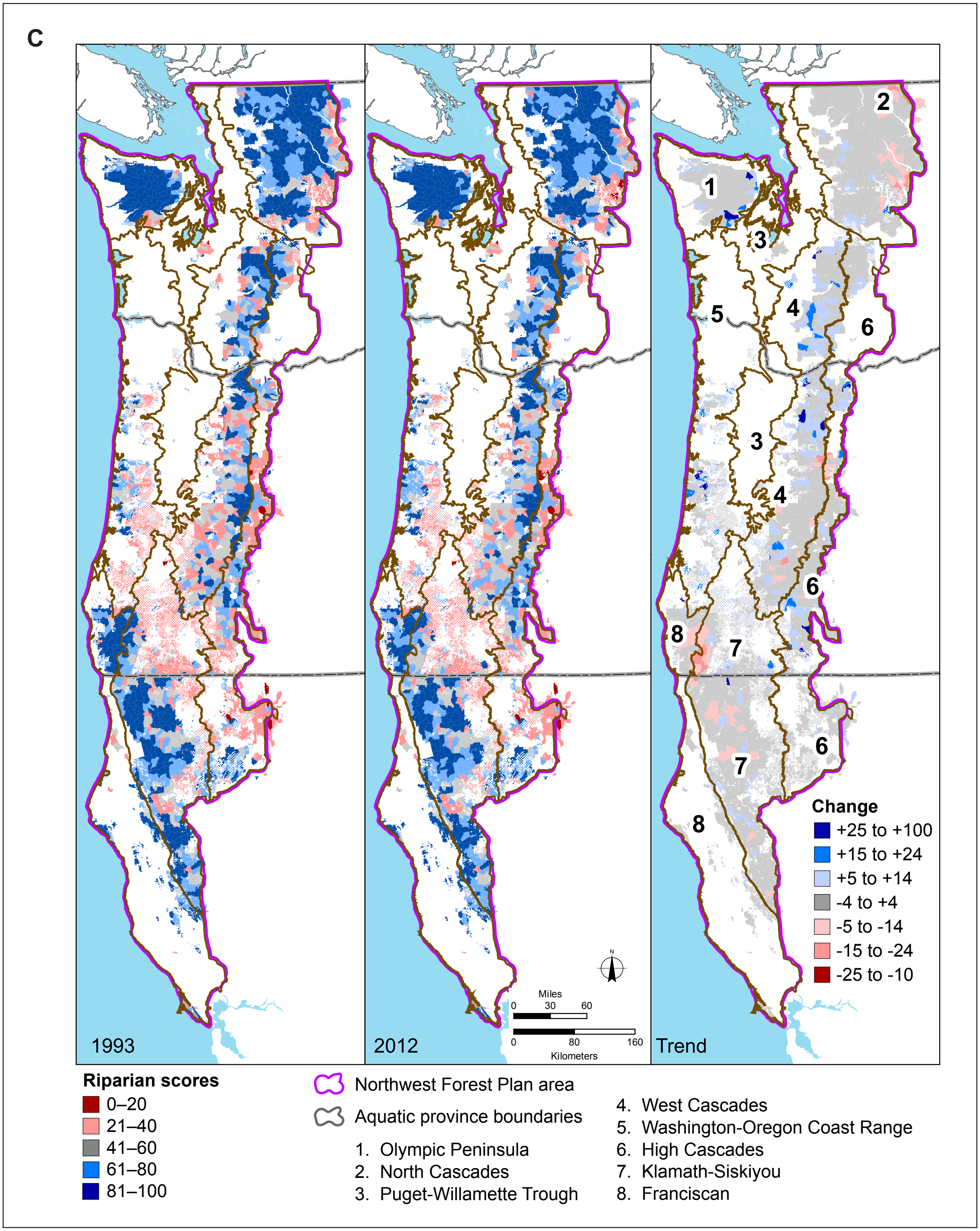

Figure 24—Continued.

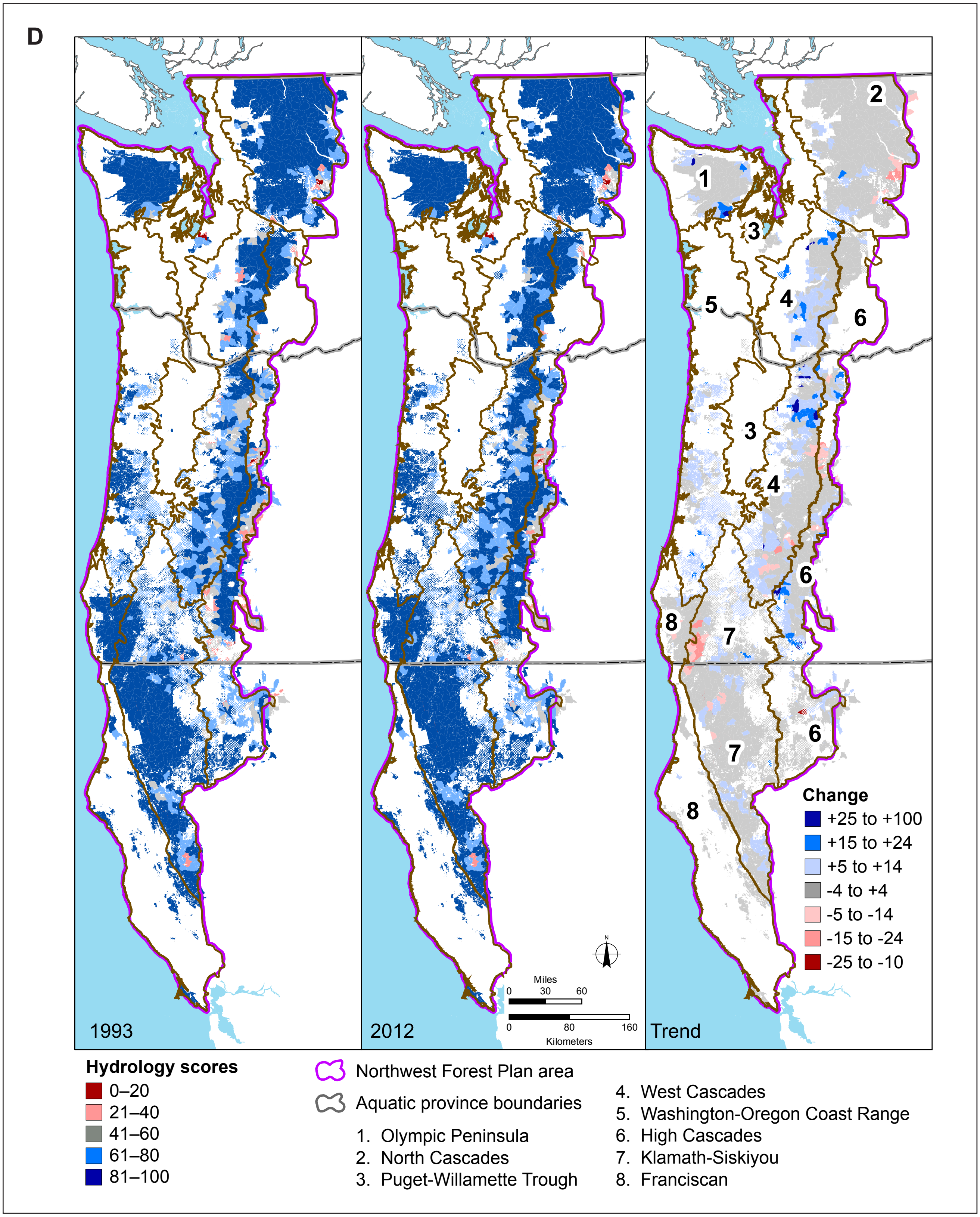

Figure 24—Continued.

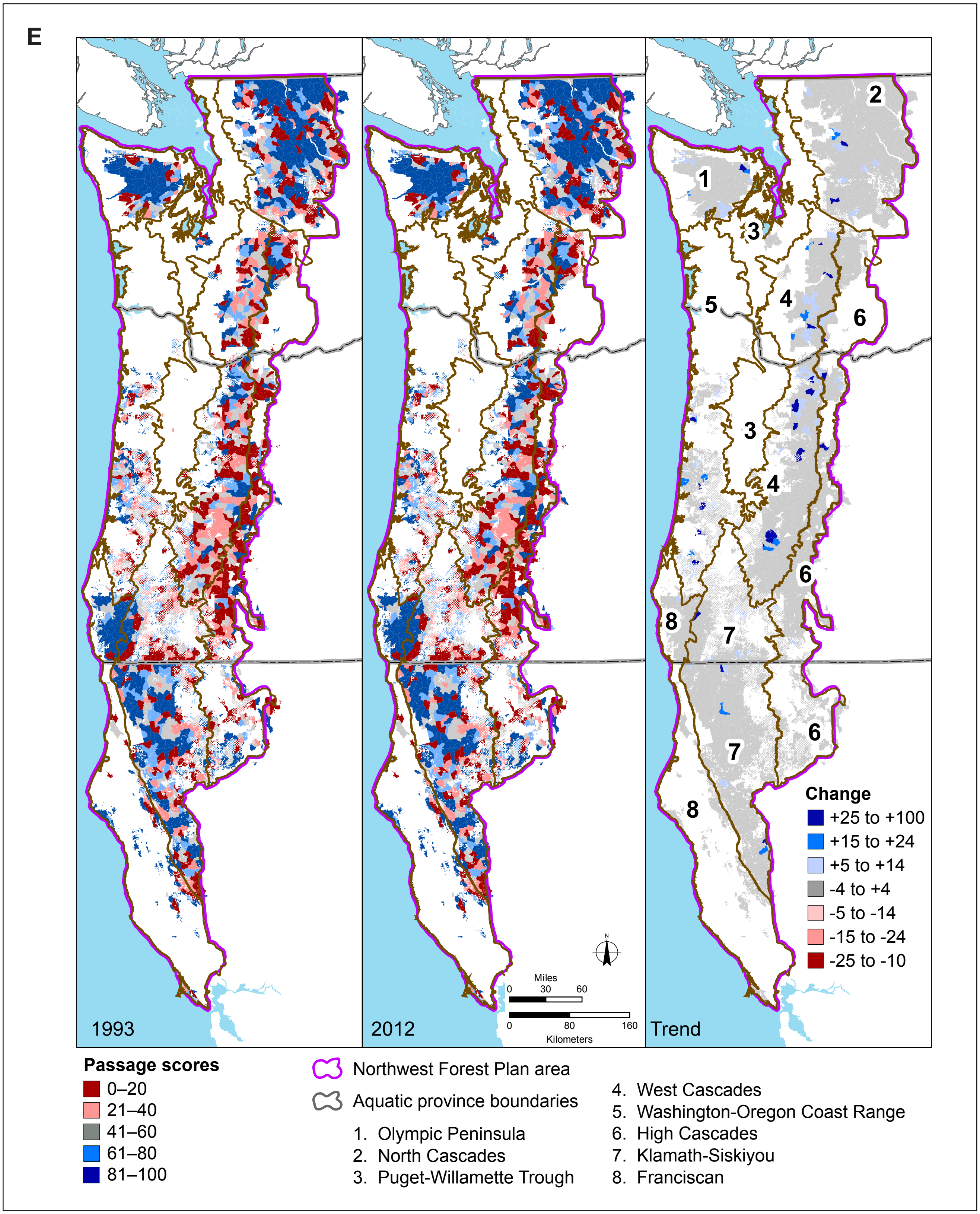

Figure 24—Continued.

Appendix 5: Contact Information

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