NATURAL RESOURCES

Status and Trends Monitoring of Riparian and Aquatic Habitat in the Olympic Experimental State Forest

Habitat Status Report and 2015 Project Progress Report

November 2016

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
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Acknowledgements

Authors

Teodora Minkova, Research and Monitoring Manager for the Olympic Experimental State Forest (OESF), Washington Department of Natural Resources (WADNR)
Warren Devine, OESF Data Management Specialist, WADNR

Principal Contributors and Reviewers

Alex Foster, Ecologist, USDA Forest Service, Pacific Northwest Research Station
Kyle Martens, OESF Fish Biologist, WADNR
Scott Horton, Olympic Region Biologist, WADNR
Jeffrey Ricklefs, GIS Analyst WADNR
Richard Bigley, Silviculturist, WADNR

Other Contributors

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Washington State Department of Natural Resources
Forest Resources Division
1111 Washington St. SE
PO Box 47014
Olympia, WA 98504
www.dnr.wa.gov

Copies of this report may be obtained from Teodora Minkova: teodora.minkova@dnr.wa.gov or (360) 902-1175

Acronyms and Abbreviations

7-DADmax – 7-Day Average Daily Maximum Temperature

BFW – Bankfull Width

DBH – Diameter at Breast Height

EPA – Environmental Protection Agency

FPW – Floodplain Width

GIS – Geographic Information System

GPS – Global Positioning System

HCP – Habitat Conservation Plan

LiDAR – Light Detection and Ranging (a remote sensing method)

NOAA – National Oceanic and Atmospheric Administration

OESF – Olympic Experimental State Forest

ONP – Olympic National Park

PNW – USDA Forest Service Pacific Northwest Research Station

TFW – Timber, Fish, and Wildlife

USGS – United States Geological Survey

WADNR – Washington Department of Natural Resources

WADOE – Washington Department of Ecology

Executive Summary

The purpose of status and trends monitoring of riparian and aquatic habitat in the Olympic Experimental State Forest (OESF) is to document changes to riparian and in-stream conditions in watersheds managed by Washington State Department of Natural Resources (WADNR) for timber, fish and wildlife habitat, and other ecosystem values. The working hypothesis for riparian management in the OESF is that the current stream protection, guided by the riparian conservation strategy in the state trust lands Habitat Conservation Plan and implemented by the OESF Forest Land Plan allows natural processes of ecological succession and disturbance to gradually improve habitat conditions in managed watersheds over time.

This report contains an annual progress report covering calendar year 2015 and a habitat status report summarizing the current condition of all monitored watersheds.

Monitoring is conducted in 50 watersheds of small fish-bearing streams across the OESF and in four reference (unmanaged) watersheds in the Olympic National Park (ONP). Nine aquatic and riparian indicators are sampled at the reach level at the outlet of each watershed: channel morphology, channel substrate, in-stream large wood, habitat units, stream shade, water temperature, stream discharge (monitored in 14 reaches), riparian microclimate (monitored at 10 reaches), and riparian forest vegetation. In addition to the field sampling, the watersheds are monitored remotely or through operational records for management activities (timber harvest and road construction) and natural disturbances (wind throw and landslides).

Multiple habitat metrics are calculated from the first round of field sampling conducted in 2013-2015 and are analyzed as distributions across the 50 OESF sample reaches and 4 reference reaches. In addition to comparing to reference reaches, the OESF habitat data are compared to regulatory thresholds and to values reported for unmanaged watersheds in other regional studies.

The comparative analyses suggest two conclusions about the current status of in-stream habitat quality in the OESF sample reaches: 1) the 50 sample reaches represent a broad range of habitat conditions, and 2) overall, the sample reaches appear to have relatively good habitat quality.

Several inherent challenges when interpreting the habitat status results are discussed: uncertainties how well the four reference reaches represent unmanaged systems, whether the existing regulatory standards for stream habitat are accurate for this area, the project scope of inference, and the need to use fish response as the ultimate habitat indicator.

The document includes summaries of watershed conditions based on remote sensing data, discussion of future trend analysis and the value of monitoring data, and a list of project priorities for next year.

The project has been funded by WADNR with in-kind contributions of equipment and staff time by the USDA Forest Service Pacific Northwest Research Station. Past project reports and updates are posted on the WADNR website at: http://www.dnr.wa.gov/programs-and-services/forest-resources/olympic-experimental-forest/ongoing-research-and-monitoring

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Introduction

The purpose of status and trends monitoring of riparian and aquatic habitat in the Olympic Experimental State Forest (OESF) is to document changes in riparian and in-stream conditions in watersheds managed by Washington State Department of Natural Resources (WADNR) for timber, fish and wildlife habitat, and other ecosystem values. The working hypothesis for riparian management in the OESF is that the current stream protection, guided by the riparian conservation strategy in the state trust lands Habitat Conservation Plan (HCP) (WADNR 1997) and implemented by the OESF Forest Land Plan (WADNR 2016b), allows natural processes of ecological succession and disturbance to gradually improve habitat conditions in managed watersheds over time (WADNR 2016a).

WADNR has identified this project as a high priority because it will provide empirical data to reduce key uncertainties around the integration of habitat conservation and timber production and to evaluate the progress in meeting the HCP riparian conservation objectives. The project results will be used to assess the habitat projections in the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016a) and to test assumptions about ecological relationships between in-stream, riparian, and upland conditions, thus improving WADNR's forest management planning. When integrated with information on management activities in the OESF, the monitoring data will help make inferences about management effects on habitat, thus contributing to the effectiveness monitoring and adaptive management required by the HCP. Additionally, monitoring data will be used to characterize habitat conditions to study the fish response to managed landscapes, thus contributing to the HCP-required validation monitoring. The project is expected to provide valuable information to tribal, private, and federal land managers in the Pacific Northwest who face the challenge of managing forests for multiple uses.

WADNR published the project's study plan in 2012 (Minkova et al. 2012) and has been funding the project implementation since that time. The U.S. Department of Agriculture Forest Service Pacific Northwest Research Station (PNW) joined as a research collaborator in the summer of 2012, contributing scientific expertise, funding, and field staff time. The major implementation activities are summarized in Table 1.

This report contains an annual progress report covering calendar year 2015 and a habitat status report summarizing the current condition of all monitored watersheds. The progress report section includes field work completed, results of a quality control analysis (the full Quality Control Report (Devine and Minkova 2016) is available on the WADNR website), results of hydrology analysis (the full Hydrology Report (Korenowsky and Devine 2016) is available on the WADNR website), data management activities, outreach, communication and education, and project staff for the reporting period. The status report section presents the first assessment of the habitat conditions within the monitored watersheds, based on field data collected from 2013 to 2015, and evaluates the reliability of the monitoring metrics used in the project.

Table 1. Timeline of important milestones and reports produced and planned for the Status and Trends Monitoring of Riparian and Aquatic Habitat program.

Year	Activities	Reference*
2012	Identification of monitoring watersheds, delineation and permanent marking of 50 sample reaches in the OESF, initial field characterization of the sample sites, installation of stream temperature data loggers	Minkova and Vorwerk 2013
2013	Reallocation of some monitoring watersheds to improve sample representativeness, development of monitoring protocols, refinement of field procedures, installation of monitoring equipment, and field protocol implementation in 10 watersheds	Minkova and Vorwerk 2014
2014	Implementation of field protocols in 32 watersheds, downloading data from continuously recording field sensors, and managing field data	Minkova and Devine 2015
2015	Implementation of field protocols in remaining 12 watersheds, downloading data from continuously recording field sensors, analyzing hydrologic data, measuring riparian vegetation, comprehensive quality control analysis in five watersheds, hydrology analysis, first assessment of habitat status	This report
2016-2025	Annual field sampling, quality control, data management, refinement of field protocols, data analyses, and publications	
2020	Completion of the five-year habitat trend report including analysis of watershed-wide conditions and history of management and natural disturbances	
2025	Completion of the ten-year trend report including more conclusive results on the rate of habitat recovery and the effects of management, as well as potential recommendations for management adjustments	

* References are available on the WADNR website at http://www.dnr.wa.gov/programs-and-services/forest-resources/olympic-experimental-forest/ongoing-research-and-monitoring

Study Area and Study Design

The OESF includes 110,000 hectares (270,000 acres) of state trust lands on the western Olympic Peninsula in Washington State. The forest ranges in elevation from sea level to 1,155 m (3,790 ft) and is characterized by frequent steep, erodible terrain. The climate is strongly influenced by the Pacific Ocean, and the area receives heavy precipitation, ranging from 203 to 355 cm (80 to 140 in) per year, with the majority falling as rain during the winter. The dense network of streams cumulatively exceeds 4,000 km (2,500 mi) in length, with abundant small and headwater streams.

The OESF includes three climax vegetation zones (Franklin and Dyrness 1988). The low-elevation forests (0 to 150 m; 0 to 500 ft) typically near the coast are within the Sitka spruce vegetation zone. The majority of the OESF is within the western hemlock zone (150 to 550 m elevation; 500 to 1,800 ft). The Pacific silver fir zone occurs at higher elevations (550 to 1,300 m; 1,800 to 4,300 ft). Douglas-fir is a seral component in all zones; red alder is common in riparian zones and recently disturbed areas at lower elevations. The entire area is characterized by a very high tree-growth rate. Old growth forest, which once dominated the landscape, is present on 11 percent of the OESF. About half of the OESF is dominated by young (0- to 50-year-old) stands.

Riparian areas in the OESF provide habitat for a diversity of fish including nine resident salmonid species: sockeye salmon, pink salmon, chum salmon, Chinook salmon, Coho salmon, steelhead trout, cutthroat trout, bull trout, and mountain whitefish. In addition, seventeen species of non-game fish, including dace (*Cyprinidae spp.*), lampreys (*Lampetra spp.*), minnows (*Phoxinus spp*.), suckers (*Catostomus spp*.), and sculpins (*Cottus spp.)*, may also be found in the OESF (WADNR 2016a). Bull trout and the Lake Ozette sockeye are the only local fish species listed as threatened under the Endangered Species Act (ESA).

High winds from the Pacific Ocean are the most prevalent natural disturbance in the OESF because moist conditions generally limit wildfires. However, wildfire is expected to be an increasing disturbance mechanism on the Olympic Peninsula under current climate change projections (Halofsky et al. 2011). Soil erosion, landslides, and debris flows are typical disturbances in stream valleys.

WADNR manages state trust lands in the OESF for revenue production (primarily from timber harvest) and ecological values (primarily habitat conservation) through an approach called "integrated management." This is an experimental management approach based on the principle that a forested landscape can be managed by blending active management (such as tree planting, thinning, and stand-replacement harvest) with habitat conservation (such as provision for salmonid and spotted owl habitat) across the landscape. Integrated management is rooted in the concept of disturbance ecology, which recognizes a natural mosaic of successional stages that shift in time through disturbances. This approach differs from the more common conservation-biology approach that divides forested areas into large blocks, each managed for a single purpose such as late-successional habitat in late-successional reserves or timber production in the forest matrix. A notable element of the integrated management approach in the OESF is the ability to vary the width of the riparian buffers based on the overall health of a watershed. Implementation of this approach is described in detail in the OESF Forest Land Plan (WADNR 2016b).

The current sustainable harvest level for the OESF is 576 million board feet per decade (WADNR 2007). An average of 1,475 ac (596 ha) of state trusts lands in the OESF (0.55% of the land base) have been harvested annually since the adoption of the HCP in 1997 (WADNR 1997). The main harvest methods on state lands in the OESF are variable retention harvest, commercial thinning, and variable density thinning. OESF conservation goals, described in the HCP, focus on restoring levels of habitat capable of supporting viable salmonid populations, spotted owls, and marbled murrelets, with the expectation that this will also provide habitat for other native fish and wildlife species (WADNR 1997).

Fifty Type 3 watersheds (watersheds around the smallest fish-bearing streams[1]) were selected for monitoring in the OESF (Figure 1). They were selected to be representative of the ecological conditions and management history across the forest. In addition to the 50 watersheds on the

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[1] The smallest fish-bearing stream as identified through biological criterion (fish presence) or through physical criteria (a stream ≥ 2 ft [0.7 m] wide and ≤16% gradient for watersheds up to 50 ac [20 ha] or with a gradient between 16% and 20% for watersheds larger than 50 ac [20 ha]).

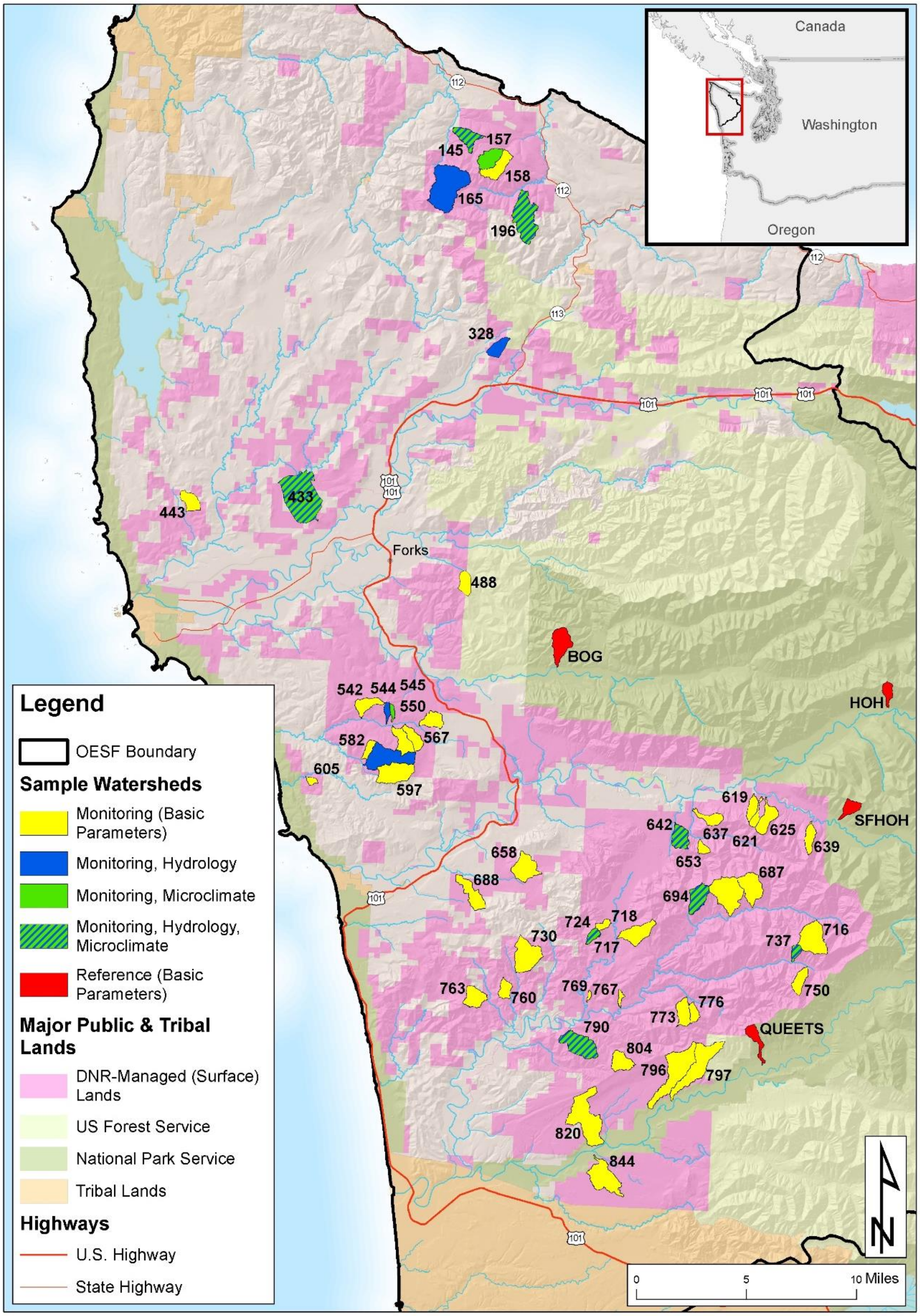


Figure 1. Map of the study area. Fifty monitored watersheds are located in the Olympic Experimental State Forest (OESF); four reference watersheds are located in Olympic National Park.

OESF, four reference watersheds are monitored in the adjacent Olympic National Park (ONP). These are Type 3 watersheds that drain into the Queets, Bogachiel, Hoh and South Fork Hoh rivers (Figure 1). The reference watersheds were selected to be ecologically similar to the OESF watersheds and readily accessible by established hiking trails. The purpose of the reference sites is to: 1) inform about habitat complexity in unmanaged (pristine) watersheds under natural disturbance regimes, and 2) help assess natural background variation that may impede detection of the OESF watersheds' response to management.

The aquatic and riparian habitat conditions of each watershed are monitored at the most downstream section of the Type 3 stream and the adjacent riparian area (Figure 2). The length of this sample reach is either 100 m or the equivalent of 20 bankfull widths (whichever is longer), starting above the 100-year floodplain of the mainstem stream into which it drains.

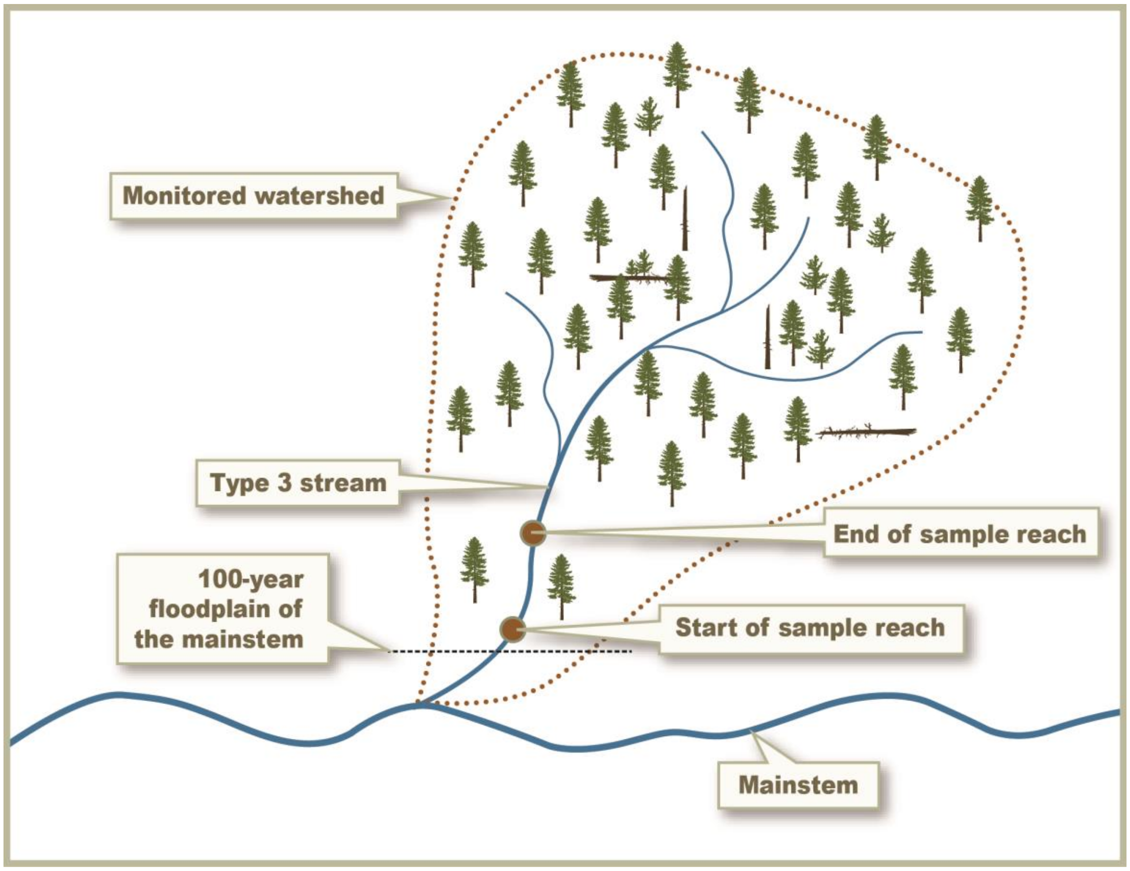
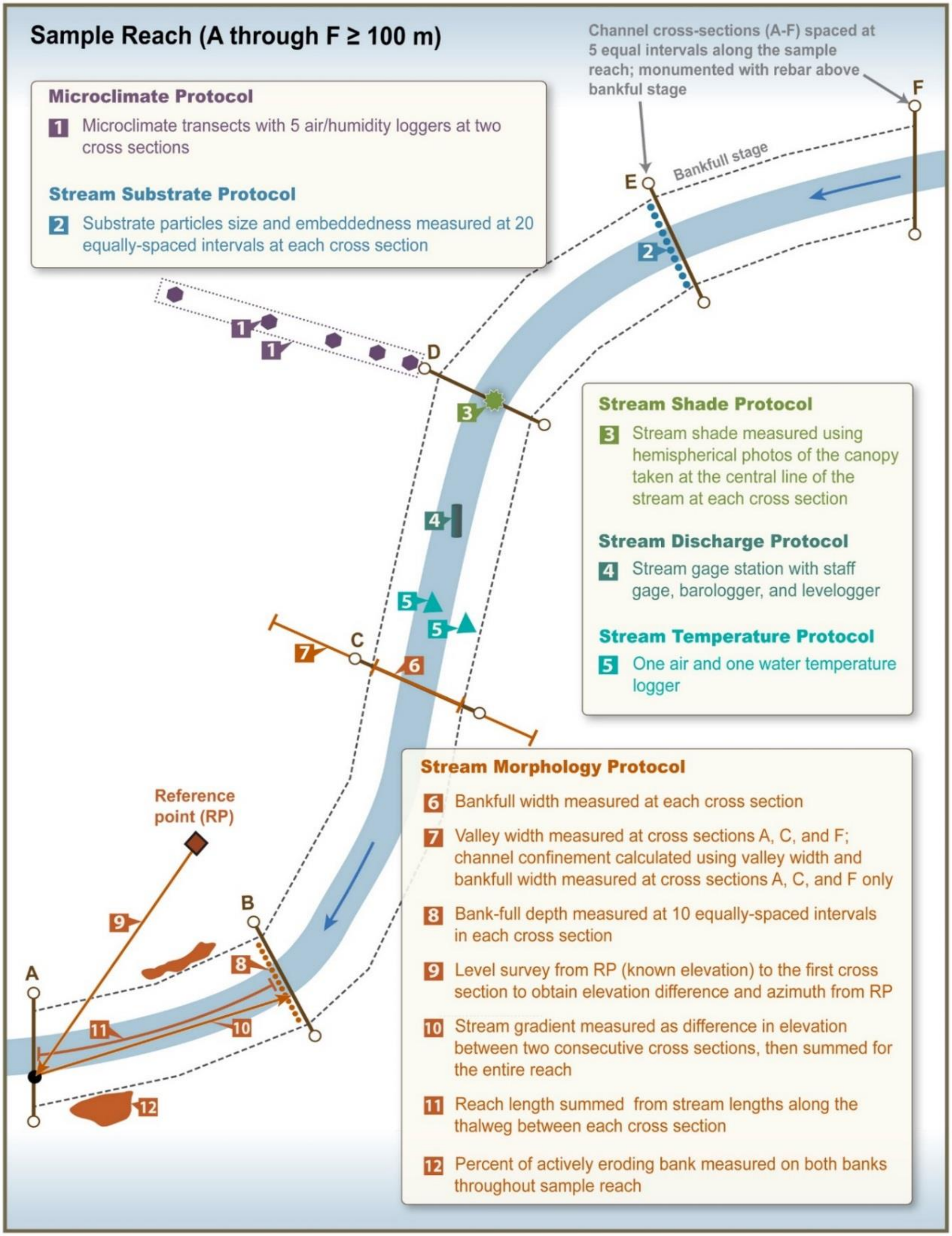


Figure 2. Schematic of a sample reach in a monitored watershed.

Nine aquatic and riparian indicators are sampled at the reach level: 1) channel morphology (including gradient, confinement, depth, and width), 2) channel substrate, 3) in-stream large wood, 4) habitat units (such as pools, rapids, and riffles), 5) stream shade, 6) water temperature, 7) stream discharge (monitored in 14 reaches), 8) riparian microclimate (monitored at 10 reaches), and 9) riparian forest vegetation. The layout of the sample reaches is illustrated in Figures 3 and 4.

Potential watershed-level “stressors” such as land management (e.g., timber harvest, road management, and road use) and natural disturbances (e.g., windthrow and landslides) are monitored within each of the 54 watersheds (Minkova et al. 2012). Data on these stressors are collected retrospectively and prospectively using operational records, remote-sensing tools, and field observations, with the objective of linking reach-level habitat data to watershed-wide changes using analytical approaches such as regression analysis and multi-model-based inference.



Sample Reach (A through F ≥ 100 m)

Channel cross-sections (A-F) spaced at 5 equal intervals along the sample reach; monumented with rebar above bankful stage

Microclimate Protocol

1 Microclimate transects with 5 air/humidity loggers at two cross sections

Stream Substrate Protocol

2 Substrate particles size and embeddedness measured at 20 equally-spaced intervals at each cross section

Stream Shade Protocol

3 Stream shade measured using hemispherical photos of the canopy taken at the central line of the stream at each cross section

Stream Discharge Protocol

4 Stream gage station with staff gage, barologger, and levelogger

Stream Temperature Protocol

5 One air and one water temperature logger

Stream Morphology Protocol

6 Bankfull width measured at each cross section

7 Valley width measured at cross sections A, C, and F; channel confinement calculated using valley width and bankfull width measured at cross sections A, C, and F only

8 Bank-full depth measured at 10 equally-spaced intervals in each cross section

9 Level survey from RP (known elevation) to the first cross section to obtain elevation difference and azimuth from RP

10 Stream gradient measured as difference in elevation between two consecutive cross sections, then summed for the entire reach

11 Reach length summed from stream lengths along the thalweg between each cross section

12 Percent of actively eroding bank measured on both banks throughout sample reach

Figure 3. Layout of a sample reach. The protocols for in-stream large wood, habitat units, and valley and channel type classification, which require continuous surveys along the sample reach, are not depicted. For layout of the riparian vegetation sampling, refer to Figure 4.

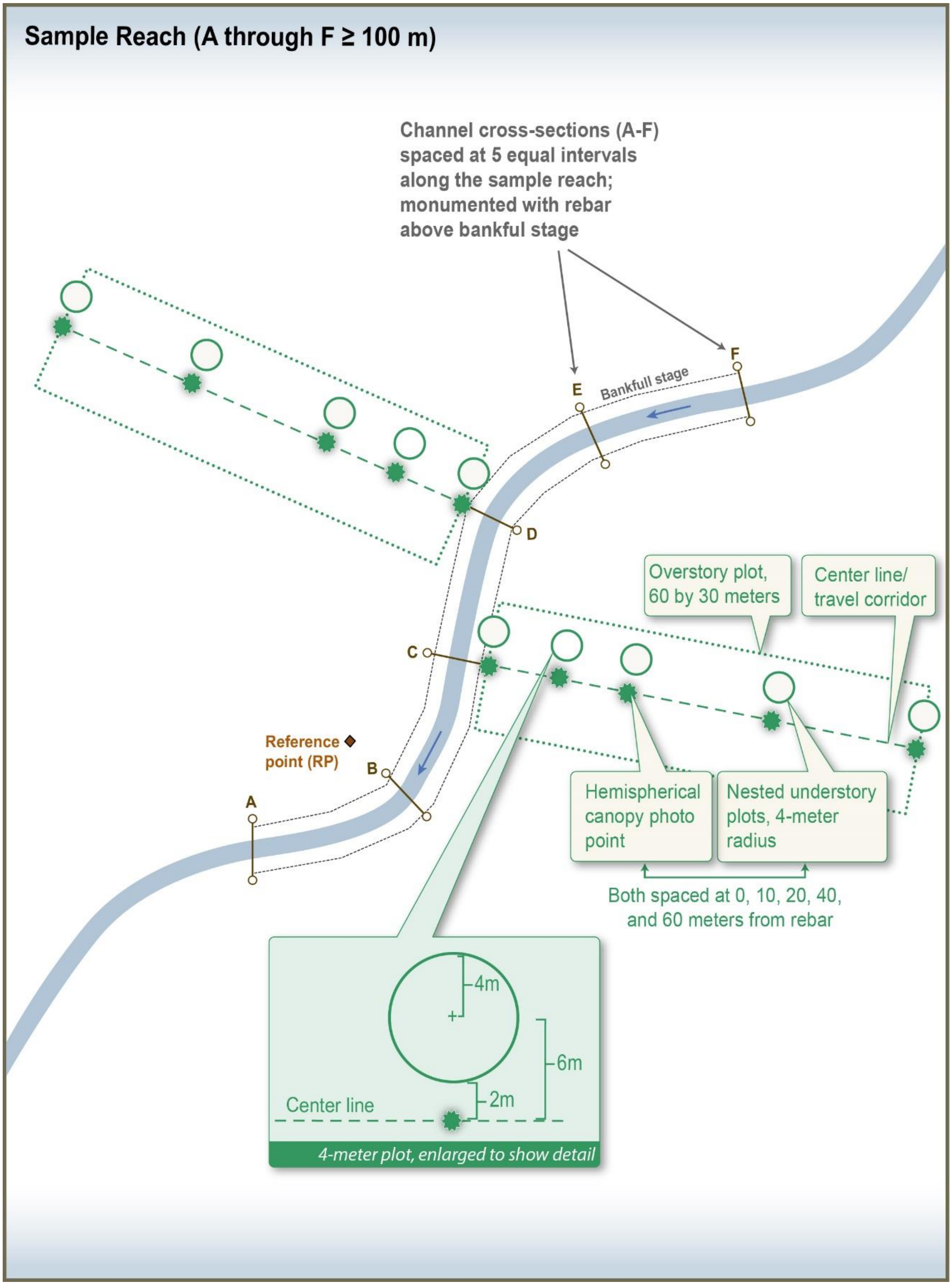


Figure 4. Schematic layout of the riparian vegetation sampling plots.

2015 Progress Report

In 2015, the status and trends monitoring project completed sampling of all remaining watersheds and conducted a quality control assessment for most field methods. This assessment helped to further refine field data collection methods prior to the 2016 field season. This progress report includes information on: 1) field work completed, 2) quality control analysis, 3) data management activities, 4) progress on a riparian validation monitoring plan, 5) watershed boundary revision, 6) project staff, and 7) communication, outreach, and education activities. The progress report covers the period 1 January 2015 to 31 December 2015. A summary table showing all of the completed field work for the period 2013-2015 is presented in Appendix 1.

Field Work Completed

Site Establishment

Long-term monitoring requires repeated visits to the sample sites; this work is often performed by different crews over a long period of time. Establishment of a permanent, monumented reference point (benchmark) and six evenly spaced cross-sections within each sample reach ensures consistency of measurements between years and crews which improves detection of changes in stream habitat attributes (Figure 3).

The geographic coordinates of each sample reach's reference point are recorded using a high-accuracy, resource-grade GPS (Trimble Pro XT, Trimble Pro XH, or Trimble Juno). Each recorded location is an average of at least 50 to 300 points, depending on satellite availability. All GPS data are differentially corrected to a GPS base station using Trimble Pathfinder Office.

Progress: Eight remaining sample reaches (4 in OESF; 4 reference reaches) were monumented in 2015 (the rest were monumented in 2013 and 2014). The National Park Service scientific research permit required that wooden stakes be used in place of rebar in the Olympic National Park.

In 2015, geographic coordinates were recorded for reference points in six of the seven sample reaches for which coordinates had not previously been recorded. The x- and y-coordinates of each reference point were determined by using GPS; elevations were determined by using x- and y-coordinates in conjunction with WADNR's LiDAR-derived ground surface digital elevation model. This approach was chosen because the elevation values recorded by the GPS were unreliable due to field conditions that often included dense forest canopy cover and steep topography.

Channel Morphology

Channel morphology is monitored for each sample reach by quantifying its gradient, bankfull width and depth, channel confinement, active erosion, and channel sinuosity.

Progress: In 2015, gradient, bankfull width and depth, and channel confinement were measured in the 12 previously unsampled reaches. Active erosion was measured in the 13 unsampled reaches. For these metrics, all OESF and reference reaches have now been measured.

Prior to 2015, sinuosity data had been collected for 39 of the 54 sample reaches. In 2015, data were collected for 12 of the 15 unsampled reaches, bringing the total number of sampled reaches to 51.

Channel Substrate

Channel substrate is classified into size bins using a gravelometer; 21 substrate sample locations are situated at each of the six cross sections for a total of 126 samples per reach.

Progress: During 2015, channel substrate was measured in the 12 reaches that were previously unsampled. All OESF and reference reaches have now been measured.

In-Stream Large Wood

In-stream large wood (every piece with a midpoint diameter >10 cm and a length >2 m) is measured in a continuous survey through the sample reach.

Progress: In 2015, in-stream large wood, including individual pieces and log jams, was measured in the 13 previously unsampled reaches. All OESF and reference sample reaches have now been measured.

Classification of Valley and Channel Types

Valley and Channel types are determined following the classification of Montgomery and Buffington (1993), using the field guide developed by Minkova and Vorwerk (2015).

Progress: During 2015, valley and channel types were classified in 12 reaches, bringing the total number of classified reaches to 43 (39 OESF and 4 reference reaches).

Habitat Units

Habitat units are identified following the modified classification of Bisson et al. (2006), using the field guide developed by Minkova and Vorwerk (2015). Length and average width is measured for each habitat unit; maximum and tail-crest depth are measured for each pool habitat unit.

Progress: During 2015, habitat units were identified in the 14 previously unsampled reaches. All OESF and reference sample reaches have now been measured.

Stream Shade

Hemispherical photos are taken in the center of the stream at the six monumented cross sections within each sample reach. Stream shade is then calculated from the average of the six hemispherical photos.

Progress: Stream shade was measured in eight sample reaches during 2015. The total number of OESF reaches photographed is now 43. Seven OESF and four references reaches have not been photographed.

Three factors have affected our ability to complete hemispherical photos at all of the sites. First, hemispherical photos cannot be taken on rainy days, which limits the sampling opportunities in a rainforest such as the OESF. Second, hemispherical photography cannot accurately represent summer shading after deciduous trees begin to drop their leaves. As a result of the unusually dry conditions during 2015, leaves began to fall by the end of August. Thus, our final hemispherical photographs of the 2015 field season were taken on 27 August, despite the fact that field work continued until 12 November. Third, a problem with the aperture setting on the camera rendered photos from four of the sample reaches unusable.

Stream Temperature

Stream temperature has been continuously monitored in all 54 sample reaches since 2013. The temperature loggers (Tidbit® UTBI-001, Onset Computer Corp.) record data every 60 minutes and are typically downloaded once per year, with additional site visits to assure that loggers were not dislodged by high flows or left dry by low flows. Channels change significantly over time, and temperature logger locations must be moved when the streambed migrates.

Progress: During 2015, all loggers were downloaded at least once. The first download occurred 11 June and the last occurred 11 November.

Five stream temperature loggers were discovered missing during 2015 (watersheds 568, 688, 737, 767, and 796); each of the missing loggers was replaced. Logger replacement due to lost or damaged equipment is expected with this type of monitoring. Loggers are most often lost as a result of high-flow events which, in these Type 3 watersheds, can dramatically alter the stream channel. In at least one instance (watershed 688), the large boulder on which the temperature logger had been mounted was washed downstream of the sample reach and could not be found. When a logger is lost, a replacement logger is installed using an alternative location or installation method designed to avoid the suspected cause of the loss.

Stream Discharge

Analysis of stream discharge requires four types of data: continuous water level (i.e., stage) readings recorded by automated sensors, discharge readings (collected manually), staff gage readings collected at the same time as the discharge readings, and cross-section and gage stability surveys. Continuous water level readings have been collected in 14 sample reaches since 2013; the other field measurements are conducted in the same watersheds several times per year.

Stream gage station (watershed 196)

Progress: Stream discharge measurements and staff gage readings were taken four times in 2015 (April, June, October, and December). The water level sensors were downloaded during the four stream discharge visits. Cross-section and gage stability surveys were conducted twice in 2015 (June and October).

During summer 2015, a graduate student from The Evergreen State College analyzed all stream discharge data collected through June 2015. This analysis included quality assessment of the data, adjustments to compensate for channel and equipment movements, and development of provisional rating curves. The work was documented in the 2015 Hydrology Report (Korenowsky and Devine 2016).

Some discrepancies were found in the survey data used to assess gage stability. These discrepancies were attributed to error in the stability survey, likely associated with the difficulty of surveying long distances between a watershed's reference point and the gage station. New reference points were established closer to the gage stations in 2015 to improve measurement precision.

To fully account for the geometry of the channel during very high flows, future cross-sectional stability surveys will include elevation measurements into the 100-yr floodplain.

Future hydrology monitoring should include an evaluation of the control reach and effects of objects that are not captured by the cross-sectional profiles (e.g., channel spanning logs below the gage station).

The stream gage stations proved to be very sturdy, even after experiencing very high flows. The results of the calibration check and the consistency of the data from the continuously recording pressure transducers indicate that the stage data are of high quality. Similarly, the flow meter produced data of high quality (based on consistent results from duplicate measurements) and was convenient to use in the field. These instruments will continue to be used in the future.

The hydrology data were effectively managed using a relational Access database developed in-house. Utilizing an interactive data visualization program such as JMP® proved to be very effective during the initial interpretation of data. The statistical package R was appropriate to create the final plots. At this point, there is no need to acquire custom software for hydrology data management and analyses.

Riparian Microclimate

Microclimate data loggers (air temperature and relative humidity) are installed in 10 of the monitored watersheds, in two transects of 5 loggers each, oriented perpendicularly to the stream on opposite banks (Figure 3). The loggers record measurements every 2 hours throughout the year. They are checked and downloaded twice per year.

Progress: During 2015, data loggers were downloaded in June and October. During these visits, numerous instances of animal damage were observed (presumably bears). In five cases, data loggers were replaced because of significant damage. Four loggers appeared to have teeth marks on them and fifth logger was missing and never recovered. In 15 additional instances, loggers were disturbed by animals but did not need to be replaced. In these instances, the loggers were either found lying on the ground with teeth marks or were found with teeth marks but still attached to the post.

Riparian Vegetation

Riparian overstory vegetation is sampled in two 0.18-ha (0.44-ac) rectangular fixed-area permanent plots located on opposite banks of each sample reach (Figure 4). Understory vegetation (percent cover of forbs, ferns, low shrubs, and tall shrubs, by species) is visually estimated on five 4.0-m radius circular subplots within each rectangular overstory plot. Canopy dynamics are sampled through hemispherical canopy photos taken at 0, 10, 20, 40 and 60 m distances from the stream.

Despite evidence of prior timber harvest, riparian areas near the sample reaches are now characterized by dense overstory and understory vegetation.

Progress: During the 2015 field season, overstory and understory riparian vegetation measurements were completed in 31 monitoring watersheds in the OESF. Combined with the 10 watersheds measured in 2014, a total of 41 OESF watersheds have been measured. The remaining 9 OESF watersheds and, if possible, the 4 reference watersheds, will be sampled in 2016. The sampling of reference watersheds depends on a research permit that allows tagging of trees in the ONP.

In addition, an assessment of riparian overstory in each of the monitoring watersheds was conducted using aerial photographs to explore the utility of this method for assessing the management history of OESF riparian buffers.

Quality Control Analysis

A quality control analysis was conducted for 33 of the metrics monitored under this project (Devine and Minkova 2016). The objectives of the analysis were: (1) quantify the variability in the measurements of stream attributes within a field crew and between field crews, (2) quantify the between-year (inter-annual) variability of monitoring metrics, and (3) provide recommendations for improvement of monitoring protocols, field training, temporal sampling design, and future status and trends analyses.

To collect data for the quality control analysis, stream survey field protocols completed in 2014 were repeated three times in five watersheds in 2015. Reaches were sampled twice by the same crew that measured them in 2014 and once by a different crew. Additionally, riparian overstory plots were remeasured in four of the watersheds.

The resulting datasets facilitated a series of comparisons that quantified the measurement error associated with the 33 metrics. The magnitude of three sources of measurement error (error within the same crew, between different crews, and between years) was quantified and reported for all metrics. Additionally, sampling precision was quantified by calculating signal-to-noise ratios for all continuous stream survey metrics (n=20). This analysis compared variance among streams (“signal”) with the variance between repeat stream visits or different crews (“measurement noise”) (Kaufman et al. 1999).

Finding: Seventeen of the 20 metrics for which signal-to-noise ratios were calculated met the recommended thresholds, indicating that our measurement of these metrics was moderately to highly consistent. Three metrics, all describing in-stream large wood, showed lower than desired ability to detect change. For 8 of the 20 metrics, it was possible to directly compare the measurement error in this project with that reported for other regional status-and-trend stream habitat monitoring projects (Roper et al. 2010). The levels of measurement error in this project were similar to, or lower than, those of other regional status-and-trend stream habitat monitoring projects (see the full quality control report for more details). This led to the conclusion that the QA/QC procedures in this project are sufficiently rigorous given the project objectives, geographic scale, and budget. Protocol-specific recommendations were provided for improvement of field sampling and, in some cases, it was recommended to modify or drop monitoring metrics prior to the 2016 field season. For example, the density and volume of in-stream large wood will not be calculated per channel zone but aggregated for all pieces of wood within the bankfull channel, resulting in a larger sample size for these metrics and therefore increased precision.

Data Management

Electronic data collection

In 2015, stream survey data collection transitioned from paper field sheets to an electronic data recorder. Prior to making this transition, we researched potential field data collection software. The data collected for this project is quite diverse and complex but is relatively small in scale (i.e., only 54 sample reaches), compared, for example, with statewide inventories. Owing to the complexity of the data, we required software that was highly customizable. But because of the scale of the project, we felt that significant time spent developing an application could not be justified. We determined that the best solution was to use Microsoft Access, which had the additional benefit of seamlessly interfacing with our existing databases, also created in Access. To run the full version of Microsoft Access, it was necessary to select a field data recorder that ran Microsoft Windows.

Ultimately, we selected the Panasonic ToughPad© FZ-M1, a lightweight, ruggedized tablet that can comfortably be held in one hand. The tablet was used to record all stream survey data during the 2015 field season. The tablet also was used to run data logger software and could download various project data loggers and sensors.

Benefits of collecting data electronically included less office time spent entering data, no data transcription errors, automated checks and calculations that occur as data are entered, and immediate access to data after it has been collected.

Database Management

Data management is a critical, yet often overlooked aspect of most field-based projects. It includes data verification, organization, archiving, summarizing and sharing. Timely and thoughtful management of field data is particularly critical for projects with massive amounts of data (e.g., data from continuously recording loggers).

During 2015, two new databases were created (the riparian vegetation database and the field tablet database), and five existing databases were expanded or revised to add new functionality (Table 2). New data collected during 2015 were added to seven databases, and quality control procedures were applied to these new data.

Table 2. Description of databases created and work done in 2015 for the Status and Trends Monitoring of Riparian and Aquatic Habitat program.

Database	Function	2015 Work
Stream temperature	Store, process, and summarize all stream temperature data	Revised periodically; new data added; quality control procedures integrated into database; quality control applied to new data.
Stream geomorphology	Store, process, and summarize stream geomorphology data (gradient, stream depth and width, substrate, erosion, sample reach metadata)	Revised periodically; new data added; quality control applied to new data.
Habitat unit and in-stream large wood	Store, process, and summarize all habitat unit and in-stream large wood data	Revised periodically; new data added; quality control applied to new data.
Riparian vegetation	Store, process, and summarize all riparian overstory and understory vegetation data	Database created; new data added; quality control applied to new data.
Hydrology	Store, process, and summarize all hydrology data	Expanded to perform various data transformations and summaries; revised periodically; new data added; quality control applied to new data.
Microclimate	Store, process, and summarize all air temperature and air humidity data	Revised periodically; new data added; quality control procedures integrated into database; quality control applied to new data.
Stream shade	Store, process, and summarize all stream shade data; includes a photo viewer to select and view hemispherical photos.	New data added; quality control applied to new data.
Tablet	Contains forms for field crew to enter all stream survey data via the field tablet	Database created; revised periodically.

Riparian Validation Monitoring

In 2015, WADNR started developing a long-term monitoring plan to assess the response of salmonid populations to managed forested watersheds in the OESF. This effort is in response to the department's commitment for validation monitoring of the HCP's riparian conservation strategy (WADNR 1997). The initial field work started in the summer of 2015 to determine the suitability of the OESF habitat monitoring sites for use in riparian validation monitoring. Backpack electrofishing was attempted within the OESF habitat watersheds between August and September to estimate fish species composition, relative abundance, and age structure.

Of the 54 watersheds in this project, 44 were visited for sampling in 2015. Of the 10 watersheds not visited, 8 were on National Park land and the specific sampling permit could not be acquired

(for 4 of these, the sample reaches were in the ONP even though the watersheds were primarily located on WADNR land); 1 watershed was previously sampled and found to have no fish; and 1 watershed was not reachable due to road construction. Salmonids were found in 39 of the 44 watersheds visited. Among the watersheds with salmonids, 82% had cutthroat trout, 62% had coho and 23% had steelhead or rainbow trout. Among the five watersheds in which salmonids were not found, two had no fish present (at least one of these had no fish because of a fish barrier) and three could not be sampled because of very low streamflow. The findings from this effort are available on WADNR's website at:
http://file.dnr.wa.gov/publications/lm_hcp_oesf_validation_monitoring.pdf

In the fall, a Scientific Advisory Group was formed to help develop a salmonid-based riparian validation study plan that incorporates the OESF habitat monitoring sites. Validation monitoring will not be possible without the habitat data provided through the OESF habitat monitoring project. The five member-group includes experts from National Oceanic and Atmospheric Agency (NOAA), United States Geological Survey (USGS), PNW, and WADNR. The draft study plan is under review as of summer 2016 (Martens 2016).

Watershed Boundary Revision

The boundaries of the monitoring watersheds were originally based on sub-watershed boundaries from the WADNR corporate GIS data. These boundaries were delineated manually, using topographic maps. During 2015, it was determined that the accuracy of the monitoring watershed boundaries should be verified by a GIS-based topographic analysis utilizing LiDAR (Light Detection And Ranging) data. For each of the 54 monitoring watersheds, the lower end of each sample reach was used as its "pour point", and the watershed upstream of this pour point was calculated and its boundary delineated.

Next, the boundaries of these new calculated watersheds were compared to the original boundaries from the WADNR corporate dataset. During this process, the latest LiDAR-derived DEM was used as a topographic reference. The original and the calculated boundaries of each watershed were carefully examined and discussed, with the objective of determining which boundary was most plausible as the true watershed boundary.

For most of the monitored watersheds, we dropped the original watershed boundaries in favor of the calculated boundaries because the latter were clearly more realistic and of a high resolution. In a small number of cases, portions of the calculated watershed boundaries were no more plausible than the original ones; where this occurred, these portions of the original boundaries were retained. Overall, the mean difference in area between the original, manually delineated watersheds and the calculated ones was a decrease of 4 percent. The greatest decrease in area was 69 percent (the Hoh reference watershed), and the greatest increase in area was 87 percent (watershed 642). It should be noted that watershed summary statistics, such as watershed size and median slope, changed when the watershed boundaries were revised. The revised watershed statistics are reported in the watershed summary (Appendix 3), and the new delineation of all 54 watersheds will be used for all future analyses performed at the watershed level.

Project Staff

The project team for 2015 consisted of a principle investigator, three researchers, a data management specialist, two scientific technicians, two interns, and volunteer field crews from the EarthCorps and the Student Conservation Association. The staff members and their primary roles in the project for the reported period are listed in Table 3.

Table 3. Project team and their primary roles during the reported period.

Name	Affiliation	Project Position	Primary role in 2015
Teodora Minkova	OESF Research and Monitoring Manager, WADNR	Principal Investigator, Project Manager	Planning and overseeing fieldwork, supervising project personnel, project management (budget, hiring, coordination, obtaining ONP permits), data analysis, preparation of reports, finalizing all monitoring protocols, outreach and communication of project findings
Alex Foster	Ecologist, PNW Research Station	Researcher	Scientific consultation, protocol revisions, training, fieldwork
Richard Bigley	Silviculturist, WADNR	Researcher	Development of riparian monitoring protocol, supervising intern, coordinating volunteers, fieldwork
Kyle Martens	Fish Biologist, WADNR	Researcher	Scientific consultation, developing validation monitoring plan, fieldwork
Warren Devine	Data Management Specialist, WADNR	Data Manager	Creating and maintaining databases for all monitoring protocols, summarizing data, data QA/QC, performing quality control analysis on stream monitoring protocols, working with intern on analysis of hydrology data, data analyses, preparation of reports
Mitchell Vorwerk	Scientific Technician, WADNR	Scientific Technician	Implementation of all field monitoring protocols, collection of GPS data; assisting with finalizing field protocols
Ellis Cropper	Scientific Technician, WADNR	Scientific Technician	Implementing hydrology monitoring protocol; implementing other field monitoring protocols; assisting with finalizing field protocols
Rebekah Korenowsky	The Evergreen State College	Intern	Performing analysis of hydrology data; collecting stream discharge data
Michele Boderck	The Evergreen State College	Intern	Leading field sampling of riparian vegetation, assessing riparian overstory using aerial photographs
6-member crew	EarthCorps	Volunteers	Field sampling of riparian vegetation
10-member crew	Student Conservation Association	Volunteers	Field sampling of riparian vegetation

The contributions by WADNR and other organizations for this period are as follows:

- WADNR provided funding for the agency researchers, data manager, and 12 staff months for scientific technicians; paid for lodging and travel expenses for the technical and research staff; and funded the purchase of necessary field equipment, supplies, and field gear.
- During the reported period, PNW contributed in-kind support through scientific expertise for training of the scientific technicians and through fieldwork estimated at about 510 hours.
- Greg Stewart, geomorphologist at Cooperative Monitoring, Evaluation and Research Committee (Washington Forest Practices) provided pro bono consultation on development of stream discharge rating curves.
- The WADNR Human Resources Summer Internship Program funded 3-month internships for two graduate students.
- Riparian vegetation sampling was conducted with the assistance of volunteer crews from EarthCorps and the Student Conservation Association.

Communication, Outreach, and Education

Scientific Communications

In March, Teodora Minkova and Kyle Martens gave a presentation on the Status and Trends Monitoring of Riparian and Aquatic Habitat program and future Riparian Validation Monitoring to the Washington Coast Sustainable Salmon Partnership board meeting.

In August, Teodora Minkova presented early stream temperature monitoring results at the annual meeting of the American Fisheries Society in Portland, Oregon. The title of the presentation was “Insights from full-year stream temperature data collected across a network of monitoring sites in the Olympic Experimental State Forest, Washington State,” authored by Teodora Minkova, Warren Devine and Kyle Martens from WADNR and Alex Foster and Ashley Steel from the Forest Service’s PNW lab.

Steam Temperature data from 2012 through 2015 were contributed to the NorWeST Regional Stream Temperature Database. The NorWeST project, hosted by the USDA Forest Service Rocky Mountain Research Station, compiles stream temperature data from a wide range of public agencies and makes it easily accessible online for research and other uses such as for tracking climate change and for climate envelope modeling.
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST/StreamTemperatureDataSummaries.shtml

In October, Teodora Minkova and Kyle Martens gave a presentation to the Quinault Nation biologists to introduce this project and discuss a monitoring partnership and sharing of environmental data.

Education

Two student interns from The Evergreen State College - Rebekah Korenowsky and Michele Boderck – were hired through WADNR's Human Resources summer internship program. Ms. Korenowsky's work focused on processing and analyzing hydrology data, and Ms. Boderck collected riparian vegetation data and supervised volunteer crews. Both interns regularly consulted with project staff including Teodora Minkova, Warren Devine, Richard Bigley (for riparian vegetation), and Greg Stewart (for hydrologic work).

More than 60 students and their professors from The Evergreen State College Masters of Environmental Studies (MES) program visited the OESF as part of a 3-day tour of the Olympic Peninsula in October, 2015 The visit included presentations by Richard Bigley and Teodora Minkova.

Students and professors from The Evergreen State College attend a presentation during an OESF tour in October 2015.

Website

A project website is maintained, and updates on the project are regularly posted. The study plan, annual progress reports, the 2015 quality control report, and recent presentations are available at: http://www.dnr.wa.gov/programs-and-services/forest-resources/olympic-experimental-state-forest Data and additional project information can be obtained from the project lead Teodora Minkova at teodora.minkova@dnr.wa.gov

Habitat Status Report

Introduction

The goal of this monitoring project is to assess the status and trends in aquatic and riparian conditions across the OESF. The study's main hypothesis is that riparian and aquatic habitat conditions in monitored watersheds will improve over time (Minkova et al. 2012). The improvement is relative to the habitat conditions before the adoption of the 1997 state lands HCP (WADNR 1997). Habitat conditions and the effects of forest management activities prior to adoption of the HCP were discussed in the environmental impact analysis for the HCP (WADNR 1996, Section 4.4.2.2). The main signs of habitat degradation were declines in volumes of in-stream large wood, road-related sedimentation, increased water temperature, reduction in stream shade, blowdown in riparian buffers, and structural and compositional homogeneity of riparian stands.

The HCP riparian conservation strategy for the OESF does not specify environmental thresholds and does not quantify desired future conditions as benchmarks for recovery. The conservation goal is to restore habitat complexity (including temperature, hydrologic and sediment regimes, and physical integrity of streams) to conditions afforded by natural disturbances (WADNR 1997, p. IV. 107). A key principle for managing riparian ecosystems for habitat complexity is to focus on natural processes and variability, rather than attempting to maintain or engineer a desired set of conditions through time (Bisson and Wondzell 2009). Therefore, the analyses of monitoring data in this project focus on describing the range of conditions for each monitored habitat attribute across a representative sample of OESF watersheds (i.e., status). Later, the trend analysis will track the shifts in these distributions over time. At a later stage of the project, habitat conditions in the sample reaches will be related to environmental conditions at the watershed level to infer potential effects of management and natural disturbances (Table 1). The study plan (Minkova et al. 2012) describes the proposed analytical approach.

In this first habitat status report, we summarize the aquatic and riparian habitat conditions of the sample reaches based on the field data collected during the period 2013-2015. A summary description of the sample reaches' geophysical template is presented in Appendix 2. A summary description of the monitored watersheds, including their geophysical and forest conditions and management activities is presented in Appendix 3.

Reporting Habitat Status

Our approach to estimating and summarizing monitoring data relies on statistical sampling: we report data from 50 monitored watersheds selected through a stratified random design to represent aquatic and riparian conditions across the OESF (Minkova et al. 2012). Nine habitat attributes have been identified for monitoring: stream temperature, channel morphology, channel substrate, in-stream large wood, habitat units, stream discharge, shade, microclimate, and riparian vegetation. One or more metrics were selected for each habitat attribute during the development of the monitoring protocols (Minkova and Foster *in prep*). For example, the total number of pieces of in-stream large wood per 100 m is one metric characterizing large wood in streams. In this document, we show the distribution of each habitat metric across the 50 OESF sample reaches and 4 reference reaches in nearby Olympic National Park.

The frequency distribution for each metric allows us to visualize and make inferences about the spatial variation across the OESF and between the OESF sample reaches and reference reaches for a certain point in time. Therefore, the graphs are usually followed by such interpretations in this report.

For each metric, we plot the values for the four reference reaches with the distribution of values for the 50 OESF reaches. We also compare the reference reaches to the quartiles of the 50-reach OESF distribution. For example, we describe reference reach values in the lowest 25% of the OESF distribution as being in the *lower quartile*. Values between 25% and 75% are described as being within the *interquartile range*, and values greater than 75% of the OESF data are described as being in the *upper quartile*.

Although the OESF riparian conservation strategy does not identify desired future conditions, we recognize that it is helpful to evaluate the reported distributions in the sense of good, marginal/fair and poor habitat categories. We do this by comparing the OESF conditions with existing regulatory thresholds (e.g., Washington Department of Ecology standards for stream temperature (WADOE 2016) or the habitat thresholds in the Forest Practices Watershed Analysis Manual (WADNR 2011) or comparing with results from studies conducted in similar ecological conditions. We make these comparisons while fully recognizing the challenges of such interpretations, as described in the next section.

The reliability of each reported metric was assessed during the 2015 quality control analysis (Devine and Minkova 2016). In the sections for the individual metrics that follow, we discuss measurement precision only if it is very low and requires a change in the field measurement protocol, a change in the calculation procedure, or other adjustments.

In this status report we do not evaluate potential relationships among habitat attributes (e.g., the influence of channel morphology on stream temperature), nor do we relate the monitoring results to watershed-scale stressors such as timber harvest, roads and natural disturbances. These analyses will be conducted later (see Table 1). An additional future task is to assess the importance of the reported habitat conditions to salmonids found in the OESF.

Challenges in Interpreting Data Summaries

When interpreting the habitat status results in this report, several widely-reported challenges with riparian and aquatic habitat variables (Bauer and Ralph 1999) need to be kept in mind:

High degree of spatial natural variability in aquatic systems

This affects the use of only four reference reaches to represent the diversity of unmanaged systems. These four reaches may not be sufficient to represent the full range of environmental conditions in unmanaged ecosystems in the area and therefore should not be automatically used to define “good” conditions. Although we report the values of the reference reaches for each habitat attribute, we do not statistically compare the 50 managed OESF reaches with the 4 unmanaged reference reaches. To statistically compare the two, a similar sample size and spatial sampling design would be needed for the reference reaches. Such intensive sampling is beyond the scope of WADNR’s monitoring. Our qualitative assessment shows how the reference reaches fit within the range and the shape of the distribution of all the reaches studied.

The high degree of natural variability introduces similar problems when attempting to compare our monitoring results with results from other studies, including regulatory thresholds. For example, differing ecological conditions result in differences in the amount and size of in-stream wood between the western Olympic Peninsula and the Snake River Basin in Eastern Washington. When such comparisons are made in the report, we specify the study area and potential caveats of the comparison.

Subjectivity of habitat thresholds

It is important to recognize that the existing habitat quality thresholds, even when site-specific, always have an element of subjectivity introduced by the biologists' perception of habitat quality, the negotiation process for the adopted thresholds' values, and many other factors. We expect that the distribution and population dynamics of native aquatic and riparian species such as salmonids is a more objective indicator of habitat quality. WADNR started long-term fish monitoring in the OESF monitoring watersheds in 2015. In the succeeding years we will provide fish population estimates and will develop fish-habitat relationships.

High degree of natural temporal variability in the aquatic systems

Watersheds are naturally dynamic systems: individual watersheds will cycle through conditions of high and low habitat quality. In unmanaged watersheds, the environmental dynamism is a result of natural disturbances such as wind, erosion and debris flows. In managed watersheds, anthropogenic pressures such as timber harvest are added to—and interact with—natural disturbances. But even in pristine landscapes, not all watersheds can be expected to be in optimal habitat condition at any one time, in terms of the various regulatory and management thresholds (Reeves et al. 2004). In this status report, we show the distribution of all monitored watersheds for each habitat metric at a

Formation of a gravel bar near the stream gage in watershed 433 between 2014 and 2016.

defined point in time and this distribution includes a continuum of habitat conditions. Over time, some watersheds will improve in habitat quality and others will decline. However, the expectation is that the overall distribution will be maintained or will improve over time by shifting in the direction of conditions in unmanaged watersheds.

Measurement quality

This includes issues with field measurement precision and transferability of the results across different studies. There is inherent variability in each field measurement, and it differs depending on the measurement. For example, the measurement of channel depth is more precise than the measurement of active bank erosion. We quantified the measurement error and partitioned the sources of variability (within field crew, between crews and between years) for 33 metrics and calculated the signal-to-noise ratio for all continuous stream metrics (Devine and Minkova 2016). This QC analysis provides context to assess the reliability of the reported data. As for the issue of transferability, which affects the comparison with environmental conditions or regulatory thresholds from other studies, we ensured, wherever we made such comparisons, that the definition of the habitat variables, the field measurement procedures, and the procedures for calculating the metrics were the same.

Selection of metrics to characterize status

A decision has to be made between detailed (separate) metrics (e.g., number of pieces of in-stream wood by channel zones) and aggregated metrics (in the same example, aggregate of all pieces of wood within the bankfull channel). The detailed metrics are usually less precise because of the smaller number of observations. The higher precision of the aggregate metrics is at the expense of decreased sensitivity to track change across space and time (Kaufmann et al. 1999). We considered the precision estimates from our 2015 quality control report (Devine and Minkova 2016) and made an informed choice of which metrics to report in order to characterize status.

Classification of Valley and Channel Types

Valley and channel classification provides a foundation for interpreting channel morphology, assessing channel condition, and predicting responses to natural and anthropogenic disturbances (Montgomery and Buffington 1993).

The field protocol follows the Valley and Channel Types classification system of Montgomery and Buffington (1993), which uses information on the nature of the valley fill, sediment transport process, channel transport capacity, and sediment supply to identify three valley segment types: colluvial, bedrock, and alluvial. Within the alluvial valley category, six channel types are distinguished: cascade, step-pool, plane-bed, pool-riffle, regime (dune-ripple), and braided. The channel types are classified using mostly qualitative criteria and therefore the observer error typically is higher compared to measurements (Kaufmann et al. 1999). To reduce the subjectivity and to speed up the classification, the field crews use a WADNR-developed field guide (Minkova and Vorwerk 2015).

Valley segment type has been classified for 46 of the sample reaches, and channel type has been classified for 44 reaches (Figure 5). Valley segments were classified as alluvial for all sample reaches. Channel types were classified as step-pool (n=16), pool-riffle (n=14), cascade (n=13), or braided (n=1) (Figure 5; see Appendix 2 for the type of each reach).

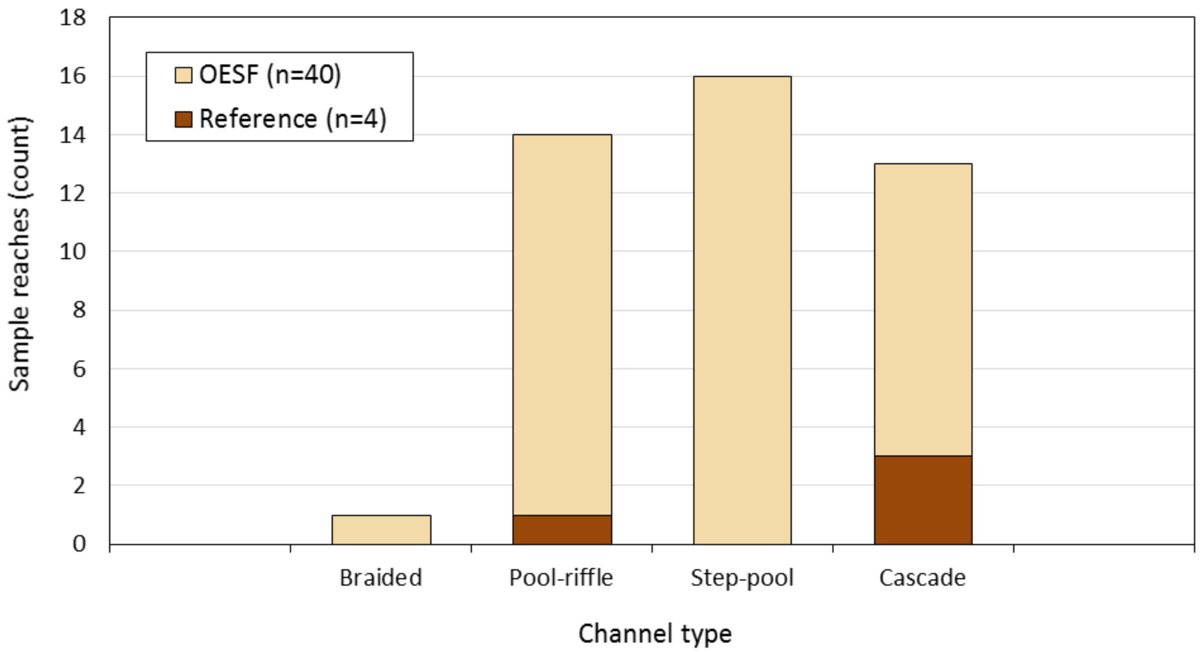


Figure 5. Number of sample reaches per channel type.

Channel Morphology

The monitoring protocol for channel morphology includes several habitat attributes: channel gradient, width and depth, confinement, sinuosity, and active erosion.

The morphology of the valley floor and stream channel are the primary controls on the flow of water through riparian aquifers (Harvey and Bencala 1993; Wroblicky et al. 1998; Wondzell 2006). By governing the characteristics of water flow and the capacity of streams to store sediment and transform organic matter, channel morphology influences the distribution and abundance of aquatic plants and animals (Bisson et al. 2006).

Channel morphology reflects stream-reach and watershed-level ecological processes and provides the basis for interpreting potential stream responses to perturbations such as sediment delivery and peak flows (Montgomery and Buffington 1993). For example, in the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016a), stream gradient and confinement were used to identify stream reaches (the smallest analysis unit) and to assign reach level sensitivity ratings for in-stream large wood, fine sediment, coarse sediment, and peak flow. Channel width was used in the stream shade model (to locate the channel edge and define a nonforested area immediately above the stream) and in the microclimate model (to locate the channel edge and assign a starting point for the equations that represent the microclimate gradients).

Gradient

Sample reach gradient is calculated as the difference in water surface elevation between the beginning and end of the reach and is reported as percent slope. Field measurements are taken with an auto level, tripod, and stadia rod following the protocol of Harrelson et al. (1994).

The slope for the sample reaches in the OESF ranged from 0.8 to 21.1 percent, with a mean of 5.4 percent (Figure 6; see Appendix 2 for gradient values of individual reaches). The distribution was skewed to the right, with a small number of high-gradient sample reaches. Three of the reference reaches fell within the upper quartile of the OESF data (≥7.0 percent slope); the fourth fell in the lower quartile (≤2.4 percent slope). See Appendix 2 for gradient values of individual reaches.

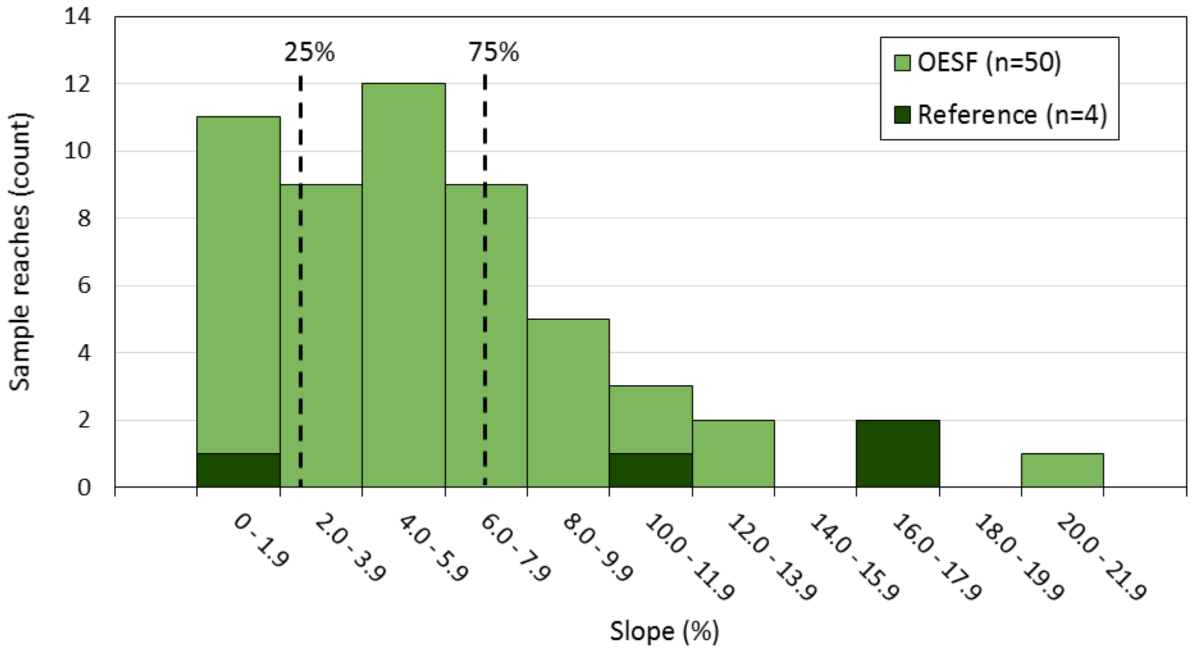


Figure 6. Distribution of channel gradient (percent slope) for OESF and reference sample reaches.

Channel width and depth

Channel width and depth are measured at each of the six cross sections per sample reach (Figure 3). Channel width, called *bankfull width,* is measured between the bankfull stage levels on each bank, which allows us to calculate stream width regardless of fluctuating stream water levels. Channel depth is measured at 11 equally spaced intervals per cross-section as the vertical distance between the bankfull stage and the streambed. The mean of these 11 values is the mean *bankfull depth* for the cross section. The bankfull width and bankfull depth values for the six cross sections are then averaged by sample reach. Additionally, a width-to-depth ratio is calculated for each cross section in each reach using bankfull width and bankfull depth measurements; ratios are then averaged by sample reach. This metric is used to assess channelization, which can indicate a negative habitat impact expressed as a low or decreasing width: depth ratio. The 100-year floodplain width is measured at three cross sections in each sample reach (A, C and F), and the three values are averaged.

For the 50 OESF sample reaches, bankfull width ranged from 1.9 to 9.9 m and averaged 4.9 m (Figure 7). Among the references reaches, one was in the lower quartile of the OESF distribution (<3.3 m), and three were within the interquartile range (3.3 to 6.0 m).

Bankfull depth ranged from 9 to 44 cm for the 50 OESF sample reaches, with a mean of 23 cm (Figure 8). Two of the reference reaches fell within the lower quartile (<17 cm) of the OESF distribution; one fell within the interquartile range (17 to 27 cm), and one fell within the upper quartile (>27 cm). See Appendix 2 for width and depth values of individual reaches.

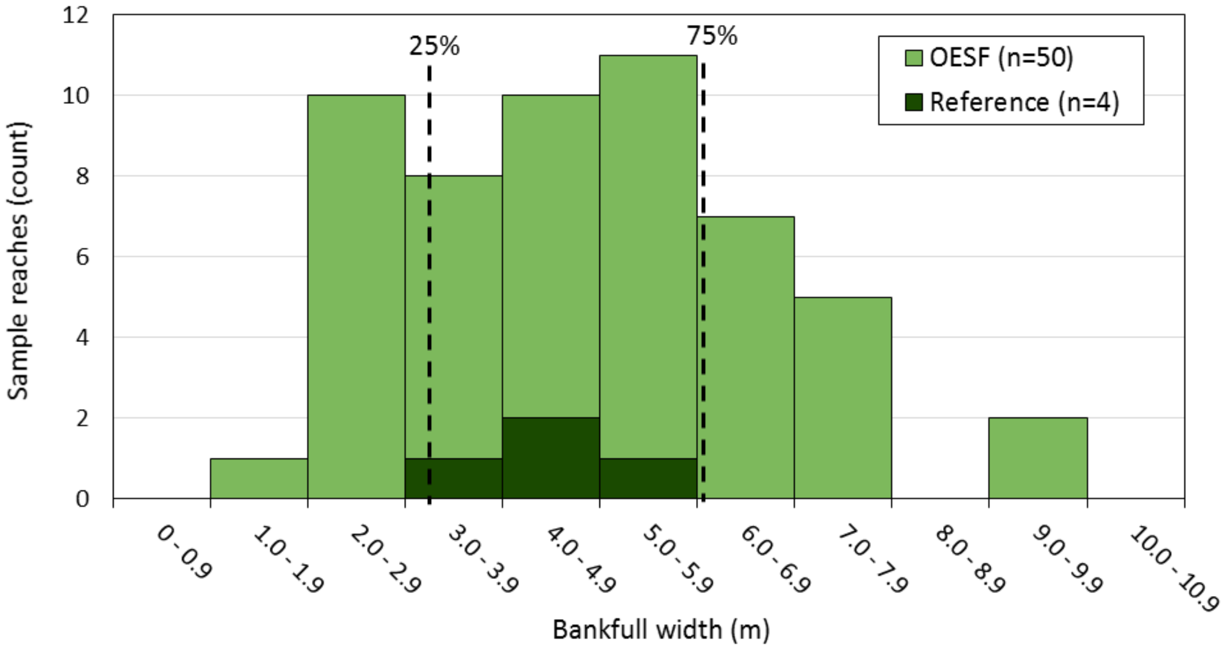


Figure 7. Distribution of mean bankfull width (m) for OESF and reference sample reaches.

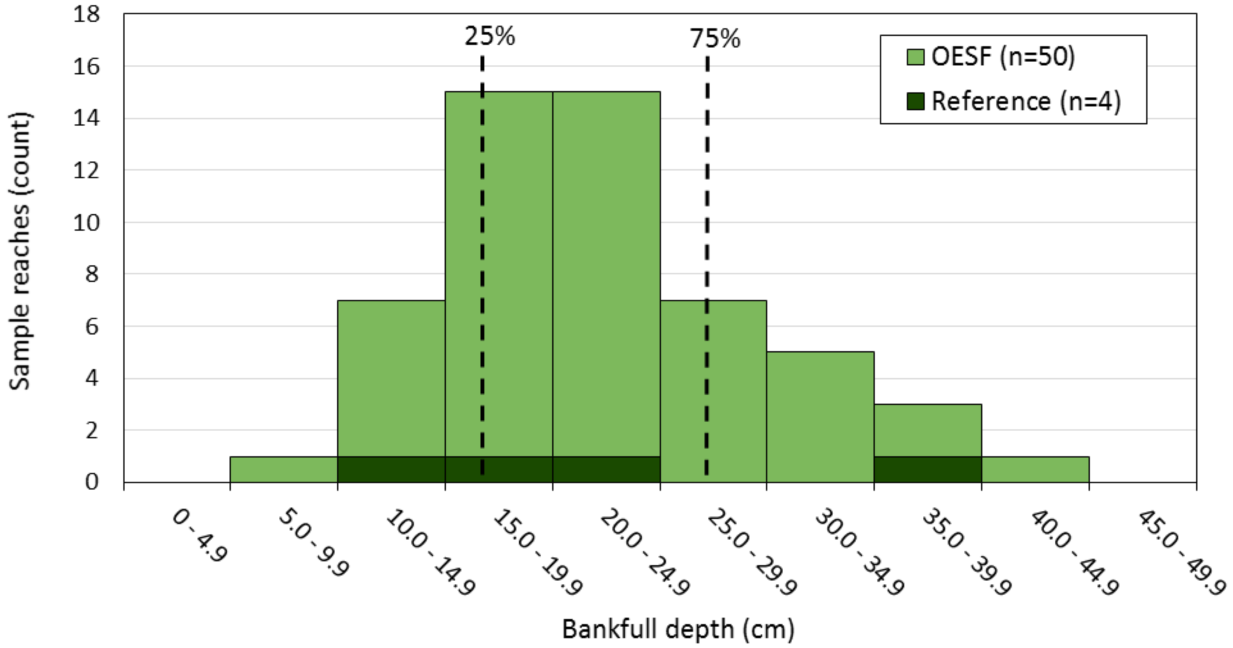


Figure 8. Distribution of mean bankfull depth (cm) for OESF and reference sample reaches.

Width: depth ratios ranged from 11 to 39 in the OESF (mean=24) (Figure 9). One of the reference reaches fell in the lower quartile of the OESF data (<20); two fell within the interquartile range (20-27), and the fourth fell in the upper quartile (>27).

Floodplain width ranged from 2.3 to 23.1 m (mean=8.7 m) for the OESF sample (Figure 10). The distribution of reaches was skewed to the right, a pattern attributed to several reaches having wide floodplains. One reference reach fell in the lower quartile of the OESF data (<6.1 m); two fell within the interquartile range (6.1 to 10.6 m), and the fourth fell in the upper quartile (>10.6 m).

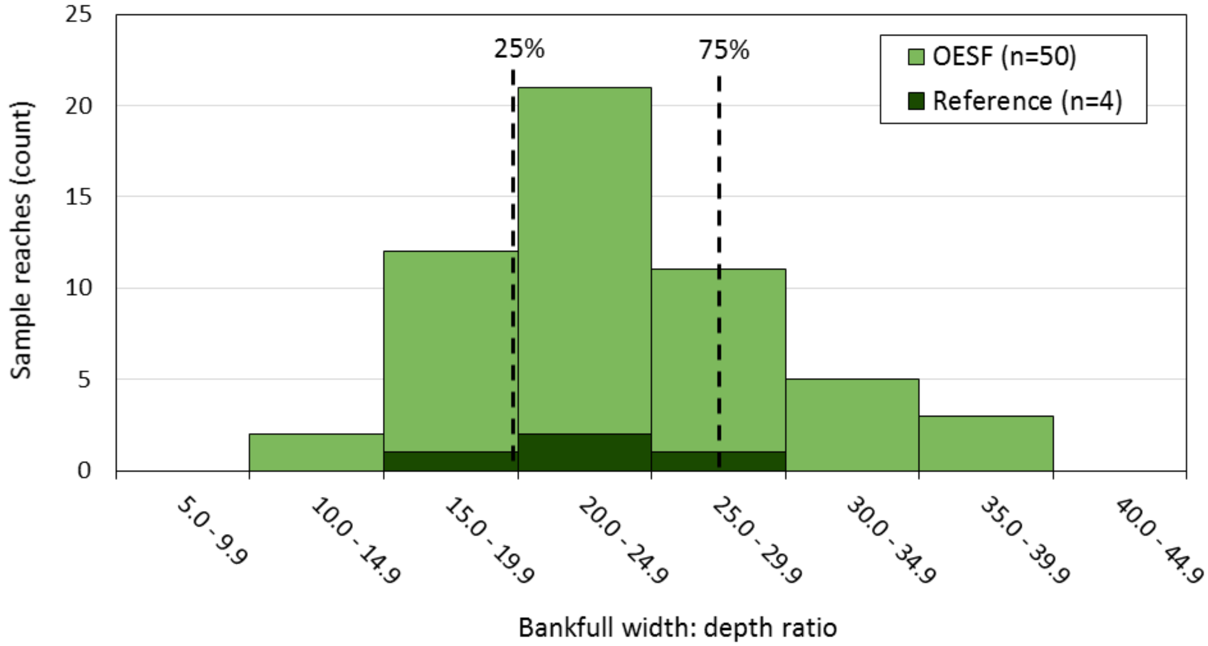


Figure 9. Distribution of bankfull width: depth ratio for OESF and reference sample reaches.

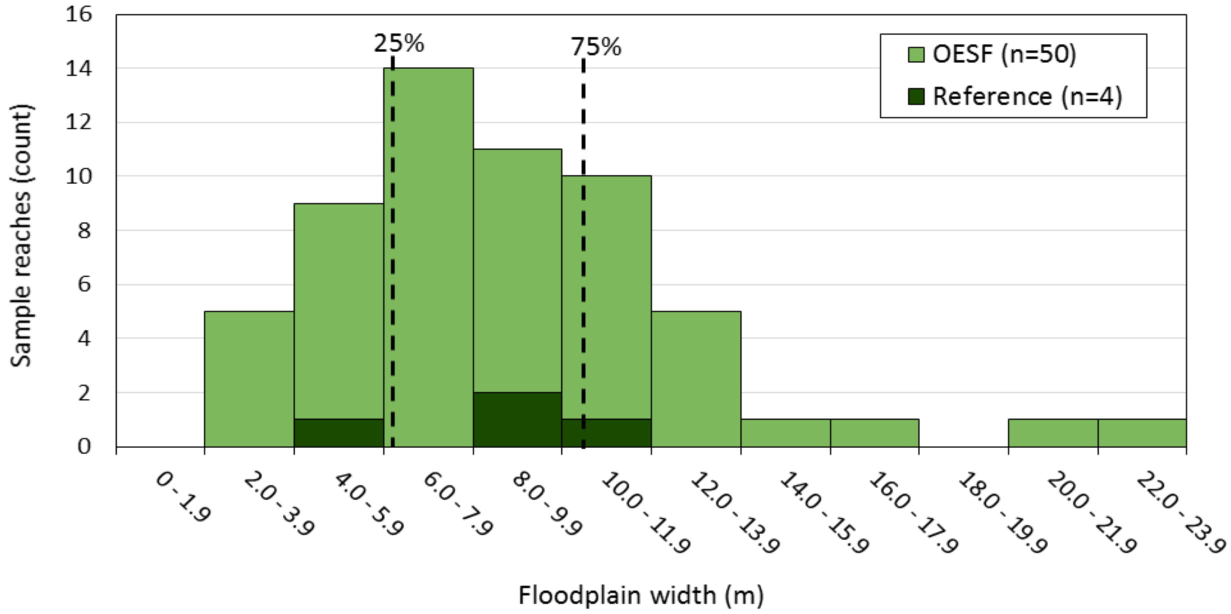


Figure 10. Distribution of floodplain widths (m) for OESF and reference sample reaches.

Channel confinement

Channel confinement is defined as the ratio of 100-year floodplain width to bankfull width. These measurements are taken at three cross-sections in each sample reach (A, C and F), and are averaged. Channels are then classified into 3 confinement classes: confined (floodplain width ≤ 2 bankfull widths), moderately confined (floodplain width > 2 bankfull widths and ≤ 4 bankfull widths), and unconfined (floodplain width > 4 bankfull widths).

For the 50 OESF sample reaches, 34 (68%) were classified as confined, and 16 (32%) were classified as moderately confined. None were unconfined. Three of the four reference reaches (75%) were classified as confined, and one (25%) was classified as unconfined (Appendix 2).

Channel sinuosity

Channel sinuosity is defined as the ratio of sample reach length measured along the thalweg (using a reel tape) to the straight-line distance between the beginning and the end of the sample reach (measured with a resource-grade GPS). Reach length along the thalweg has been measured for all sample reaches; beginning and end points have been measured using GPS for 48 of the OESF sample reaches and 3 of the reference reaches.

Sinuosity ranged from 1.00 to 1.71 among the OESF sample reaches, with a mean of 1.14 (Figure 11). The distribution was strongly right-skewed, reflecting the predominantly confined and steep stream channels. Among the reference reaches, two fell within the interquartile range of the OESF distribution (1.11 to 1.17), and the third fell in the upper quartile (>1.17). See Appendix 2 for sinuosity values of individual reaches.

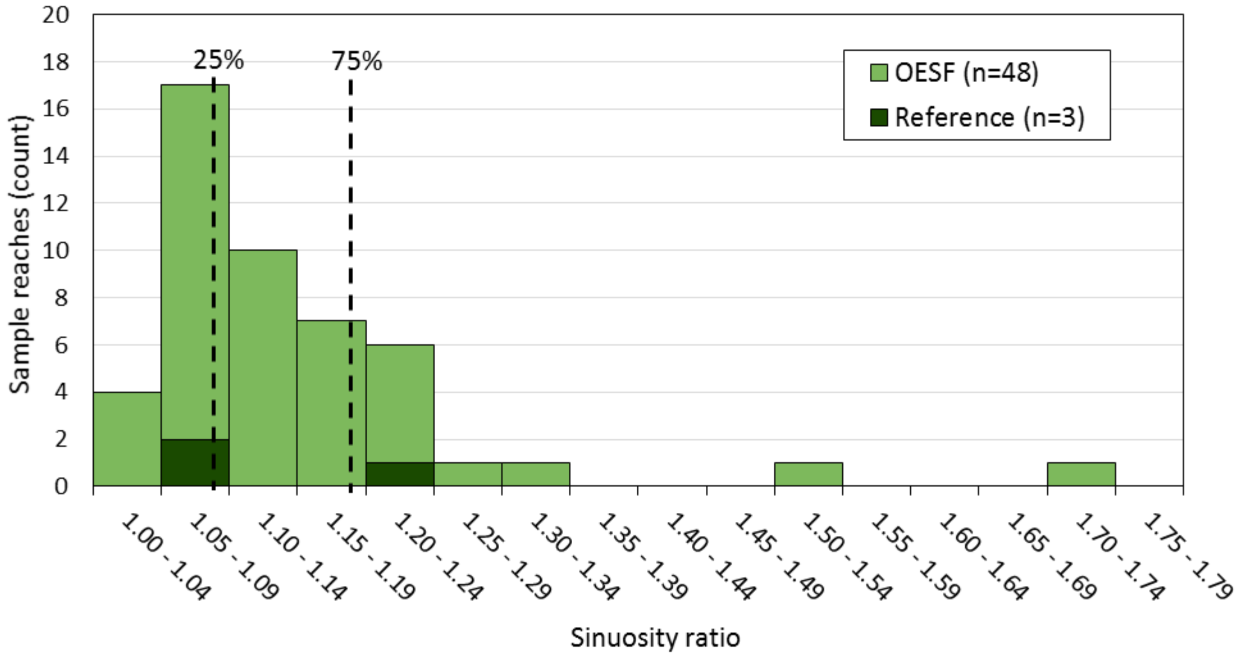


Figure 11. Distribution of sinuosity ratios for OESF and reference sample reaches.

Active Erosion

The measurement of active erosion is intended to measure bank stability. Stable banks prevent delivery of excess fine sediment (particles less than 2 mm diameter, such as sand, silt, and clay) to spawning and rearing habitat and maintain streamside vegetation, which provides shade cover and nutrients to the stream. Bank erosion also is a source of in-stream large wood and coarse sediment.

Active erosion, evidenced by exposed soil (watershed 157)

In each sample reach, actively eroding patches are measured on both stream banks. The percentage of stream bank length actively eroding is calculated by summing the lengths of actively eroding patches and dividing by the combined length of both sample reach banks.

For the OESF sample reaches, the portion of actively eroding stream bank ranged from 0 to 49 percent, with an average of 13 percent (Figure 12). The distribution was skewed to the right, as a result of a large number of reaches with little or no active erosion. All four of the reference reaches fell within the interquartile range of the OESF distribution, which was 2.1 to 21.8 percent.

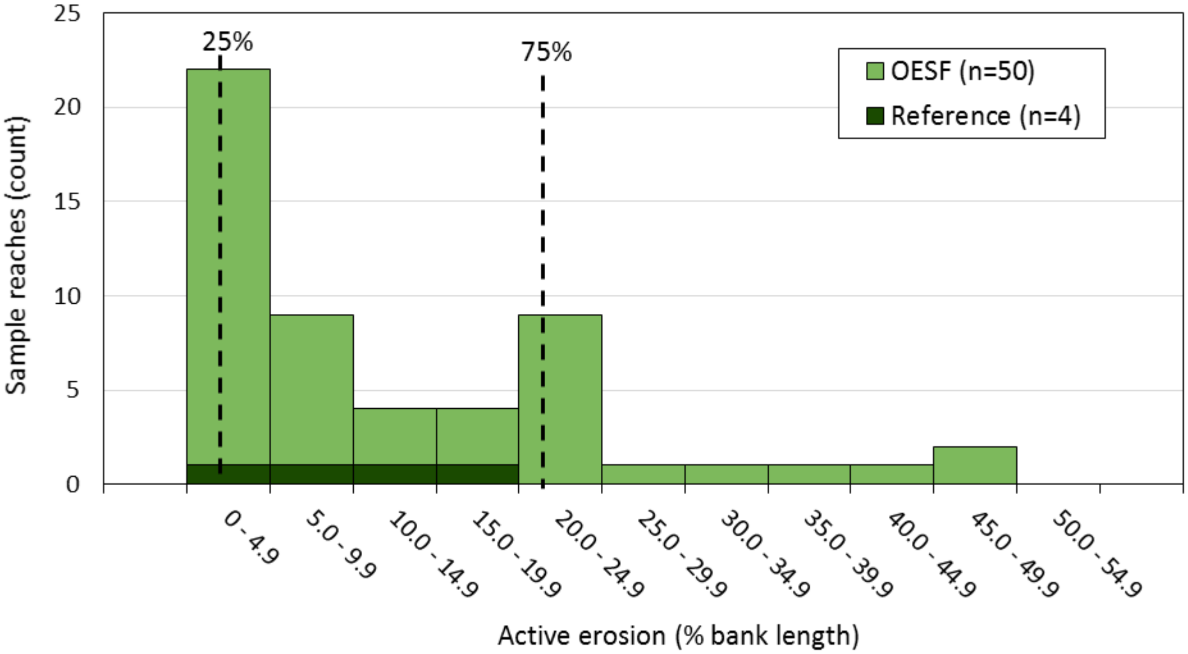


Figure 12. Active erosion, as a percentage of the combined length of both stream banks, for OESF and reference sample reaches.

Active erosion is inherently difficult to quantify owing to the difficulty in defining what constitutes an erosion patch and safety issues when measuring eroding slopes in the field (e.g., climbing an eroding slope to measure the height of the erosion patch). The quality control analysis (Devine and Minkova 2016) reported low sampling consistency within—and especially between—field crews. The report recommended improvements but recognized that these will only partially reduce the overall variability. Thus, it also recommended accepting a large margin of error for any inference applied around this metric in future analyses.

Discussion

Most of the channel morphology metrics presented above are used to stratify watersheds for further analyses, for example classifying the stream size using average bankfull width or grouping streams in low, medium, and high gradient classes to assess pool availability (see the sections below for these and other examples). Channel morphology metrics are also used to predict the relative values and rates of change of other habitat metrics, for example availability and stability of gravel in low, medium, and high gradient streams. Some of the channel morphology metrics are used for direct assessment of discharge variability or stream energy; for example, width: depth ratio can be used to assess a channel's sediment transport capacity, among other measures.

Channel Substrate

Channel substrate refers to the mineral and organic material forming the bottom of a stream. Channel substrate influences the hydraulic roughness and consequently the range of water velocities in a stream channel. It controls species composition of macroinvertebrate, periphyton, and fish assemblages in streams (Cummins 1974). Substrate size, composition, and stability can be limiting factors in anadromous salmonid spawning and rearing habitats (Bain 1999; Kondolf 2000); for example, different species require different sizes and amounts of gravel to build a nest, or redd. One of the mechanisms of substrate influence is through the size range of interstices that provide living space and cover for macroinvertebrates, amphibians, and fish (Hicks et al. 1991; Roni et al. 2006).

Disturbances, including historic, i.e., pre-HCP, and contemporary timber harvest and road management, affect channel substrate in two main ways: 1) directly, by delivery of coarse sediment which is variously important in spawning habitat (Buffington et al. 2004) and/or fine sediment (particles <2 mm) which fills spaces in larger-sized substrates, thereby eliminating critical habitat and reducing the flow of oxygen to invertebrates and to developing salmon eggs and juveniles (Cederholm and Salo 1979; Jensen et al. 2009; Kondolf 2000), and 2) indirectly, by affecting the magnitude of stream flow which may lead to channel bed scouring, or by delivery of wood to the stream, which may trap sediment (Bisson et al. 1987; Poff et al. 1997).

Twenty-one random substrate particles are sampled at 20 equally spaced intervals across each of the 6 cross sections for a total of 126 particles measured in each sample reach (Figure 3). The size class of each substrate particle is determined using a gravel size template or gravelometer and later classified as one of six substrate types (Table 4). For particles 45 mm and larger, the fraction of particle volume that is embedded in sand or finer sediments on the stream bed is visually estimated in classes of 10%.

Summary statistics are calculated for each sample reach, including median particle size class (D$_{50}$), percent fines, and percent boulders. Percent fines is calculated as the percentage of particle samples in a reach that are 2 mm or smaller. Percent boulders is calculated as the percentage of particle samples in a reach that are in the boulder size class (250 – 3999 mm). Numerous other metrics can be calculated from the substrate data; these will be presented later when the substrate data are analyzed in relation to other habitat attributes and to watershed-wide stressors.

Table 4. Classification of substrate types by size.

Substrate type	Particle size (mm)
Fines (sand, silt, clay)	≤ 2
Fine gravel	> 2 to 16
Coarse gravel	> 16 to 64
Cobbles	> 64 to 250
Boulders	> 250 to 3999
Bedrock	≥ 4000

D$_{50}$

For the OESF sample reaches, D$_{50}$ values ranged from the 8-11-mm diameter class to the 129-180-mm class (median = 45-mm class) (Figure 13). Among the reference reaches, one fell into the lower quartile of the OESF distribution (<32 mm), one fell into the interquartile range (33-64 mm), and two fell into the upper quartile (>64 mm).

Because the substrate varies naturally in streams of different slopes (high gradient streams tend to have coarser substrate than the low gradient streams), we compared the four reference reaches to OESF reaches of similar gradient (Figure 14). As expected, D$_{50}$ values increased with increasing gradient. In all three cases, the reference reaches were within the range of distribution of the OESF sample reaches.

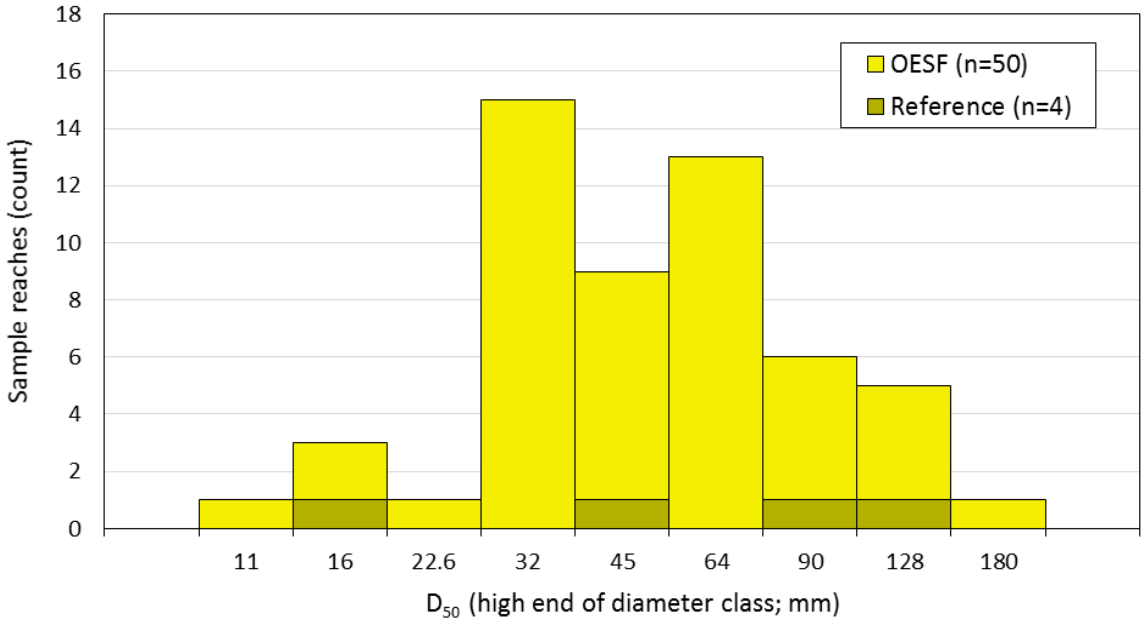


Figure 13. Distribution of D$_{50}$ (median particle size) for OESF and reference sample reaches. Quartile ranges are not shown because data were collected by size class.

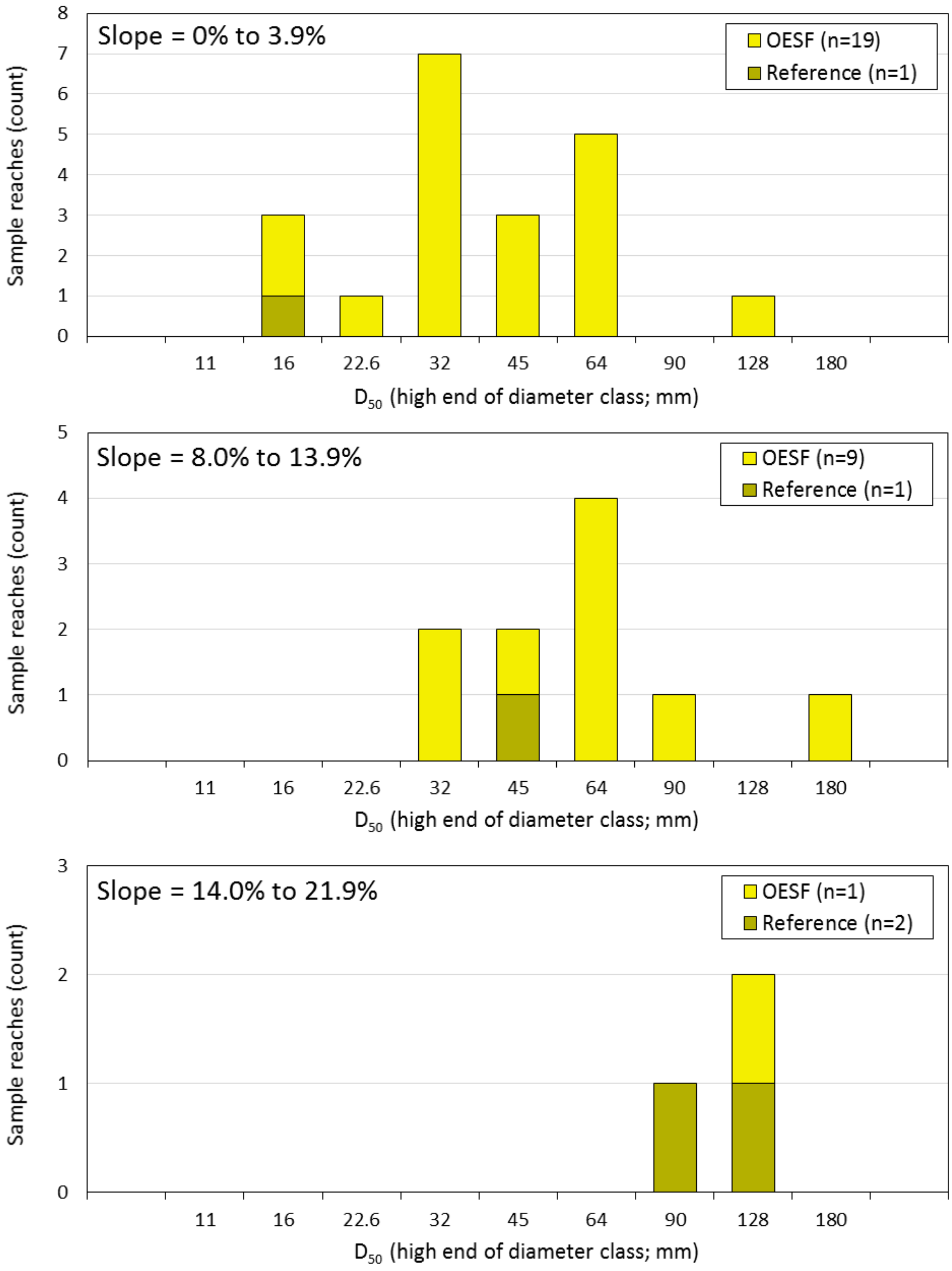


Figure 14. Distribution of D_{50} (i.e., median particle size) for OESF and reference sample reaches classified in three groups according to the slope of the sample reach.

Percent Fines and Boulders

Percent fines ranged from 0 to 25 percent (mean = 8.1%) for the OESF sample reaches (Figure 15). Two of the references reaches were in the lower quartile of the OESF distribution (<3.8%), and two were in the upper quartile (>11.7%).

Percent boulders ranged from 0 to 34 percent (mean = 9.3%) for the OESF reaches (Figure 16), though the distribution was strongly skewed to the right, indicating a large proportion of reaches with few or no boulders. Among the reference reaches, one fell into the lower quartile of the OESF distribution (<0.2%), two fell into the interquartile range (0.2 to 15.5%), and one fell into the upper quartile (>15.5%).

Using a gravelometer to measure the size of substrate particles

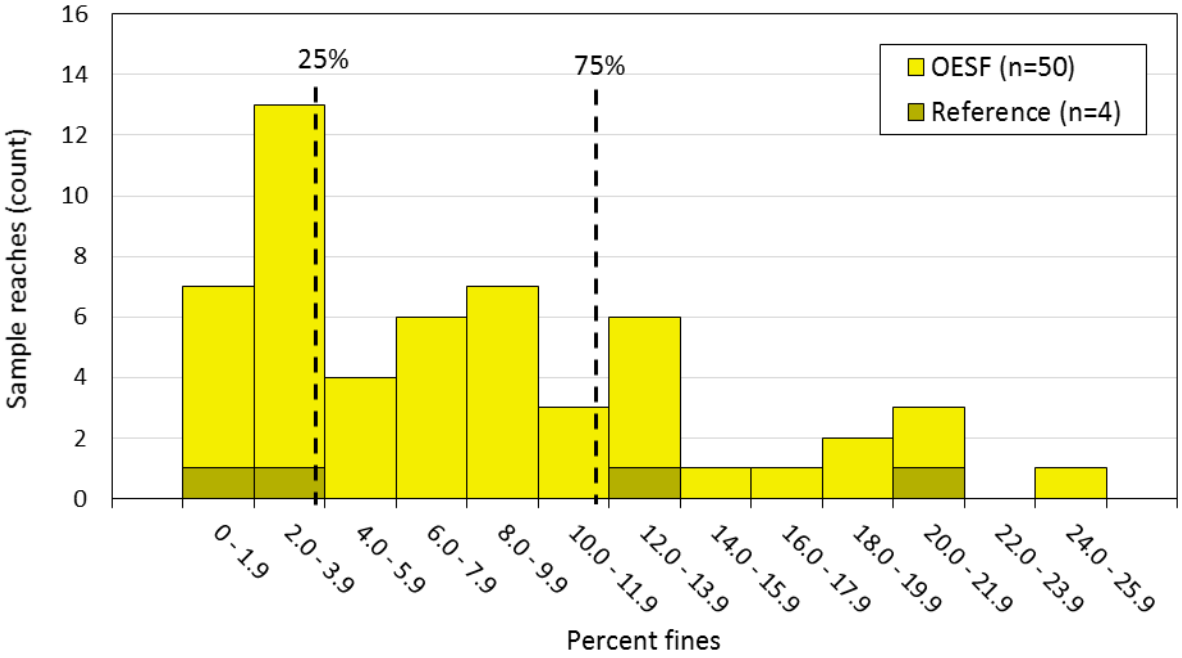


Figure 15. Distribution of percent fines for OESF and reference sample reaches.

Embeddedness

Embeddedness ranged from 14 to 62% (mean = 31%) for the OESF sample reaches (Figure 17). Based on the OESF distribution, two of the reference reaches were in the lower quartile (<24%) and two were in the interquartile range (24-35%).

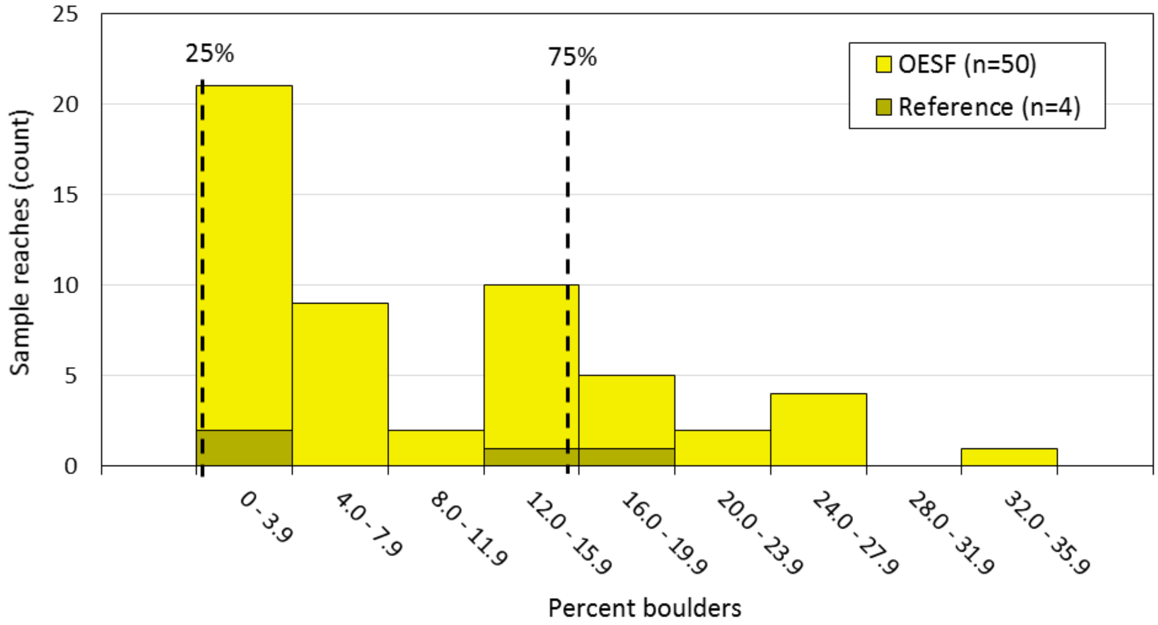


Figure 16. Distribution of percent boulders for OESF and reference sample reaches.

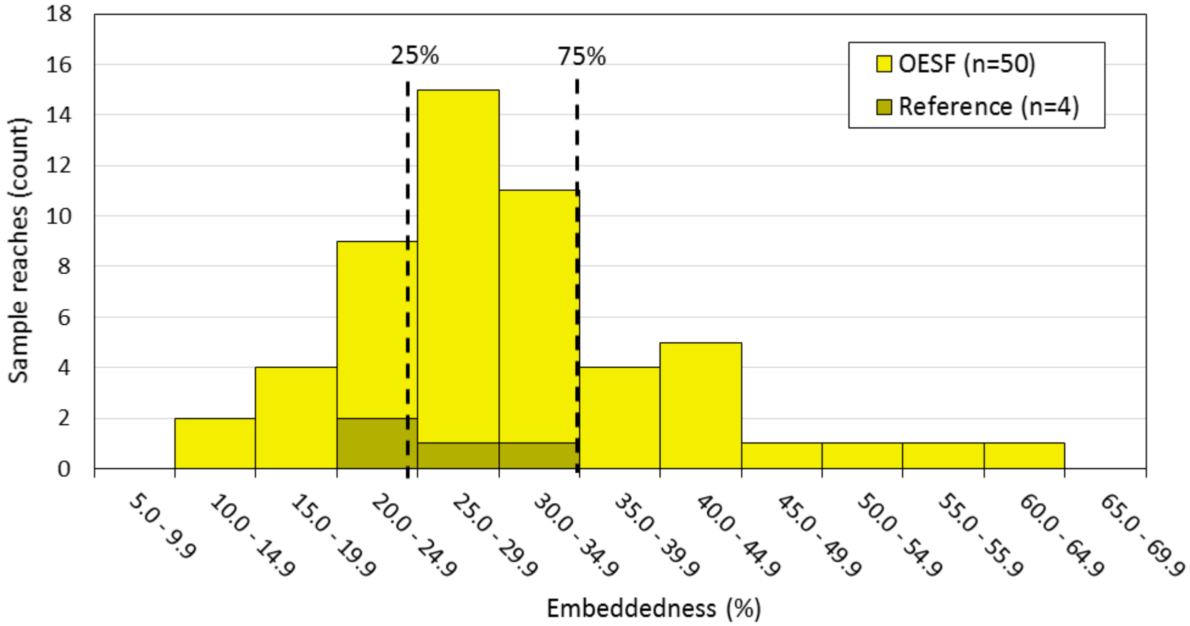


Figure 17. Distribution of mean particle embeddedness values for OESF and reference sample reaches.

Discussion

The quality control analysis (Devine and Minkova 2016) found high variability in the substrate metrics, with the variance analysis showing that improvements in protocols and training can only partially reduce the overall variability. This is consistent with findings from other studies (Roper et al. 2010). The implications of this metric's inherent variability are: 1) it may be difficult to detect trends in substrate particle size, and 2) it is challenging to draw definitive conclusions from comparisons with other studies and with regulatory thresholds.

With these limitations in mind, we looked at reported values for percent fines in other regional studies and regulatory documents. It is not possible to directly compare the percent fines in our study to the fine sediment thresholds in the Forest Practices Watershed Analysis Manual (WADNR 2011) because their definition of fines is <0.85 mm (Schuett-Hames et al. 1999a) and ours is <2.0 mm. Thus, applying the Forest Practices guidelines to the percent fines data from our OESF sample reaches will yield conservative results (i.e., our habitat quality is likely better than its classification according to the manual because our values include a broader range of particle size). Despite this limitation, 38 of the 50 OESF reaches and two of the four reference reaches fall in the manual's "good" habitat quality category (<12% fines); 6 OESF reaches and one reference reach fall in the "fair" habitat quality category (12-17% fines), and 6 OESF reaches and one reference reach fall in the "poor" habitat quality category (>17% fines).

Percent fines for the 50 OESF sample reaches averaged 8.1%, a value comparable to what has been reported in unmanaged forests. For example, a study in the Olympic National Park reported 6.37 ±2.61 percent fines, where fines were defined as particles <0.85 mm, rather than <2.0 mm as in our study (Cederholm and Reid 1987).

The target threshold recommended to the Forest Practices Timber, Fish, and Wildlife (TFW) Agreement by Peterson et al. (1992) was no more than 11% of substrate distribution in fines. This value was recommended for a broad range of stream sizes but is applicable to streams with <3% gradient and 5 to 30 m in width. Fourteen of the 50 OESF sample reaches exceeded this threshold, though it is important to remember that the threshold is based on fines <0.85 mm rather than <2.0 mm.

Meta-analysis of impacts of fine sediment on egg-to-fry survival of Pacific salmon (Jensen et al. 2009) shows that the threshold for egg survival of Chinook salmon and steelhead is 50% fines for fines <4.8 mm. Although their definition of fines includes a broader size range, we believe that all of our sample reaches would remain below their 50% threshold.

Ultimately, the size distribution of substrate, and specifically the D_{50} value, will be assessed in the context of the spawning and rearing numbers of the salmonids inhabiting streams within the OESF. Fish monitoring in the 50 monitored OESF streams started in 2015 (refer to the sub-section *Riparian Validation Monitoring* in the *Progress Report* of this document for more details).

In-Stream Large Wood

In-stream large wood, also known as large woody debris (LWD), is defined as pieces with a midpoint diameter of at least 10 cm and a length of at least 2 m. In-stream large wood is an important habitat component for fish and other aquatic organisms. Large wood pieces trap and retain sediment, change the shape and steepness of streams, change water velocity, release nutrients slowly as they decompose, and provide cover from predators (Bisson et al. 1987; Cummins 1974).

Forest management within the riparian area affects in-stream large wood by controlling the amount, species composition and size of trees available for recruitment from the stream buffers.

Our in-stream large wood survey protocols employ a slightly modified Level II procedure described by Schuett-Hames et al. (1999b). To be included in this survey, a piece of wood must be dead, have a diameter of at least 10 cm for at least 2 m of its length, and have at least 10 cm of its length within or directly above the bankfull channel. Several wood characteristics are measured or estimated in the field: number of pieces of large wood in each sample reach; piece diameter, length, species category (deciduous, conifer or unknown), and decay class; piece orientation relevant to the channel; if a piece is pool forming and storing sediment; and number and size of woody debris (log) jams. Individual piece volume is calculated from diameter and length measurements. Cumulative values (e.g., total pieces of wood per sample reach) are expressed on a 100-m basis, owing to the fact that sample reach length varies among reaches.

In-stream large wood plays a key role in creating habitat in streams.

Wood Piece Density

The density of individual pieces of large wood (not including pieces that are part of log jams) ranged from 8 to 60 pieces per 100 m (mean = 29 pieces per 100 m) in the OESF reaches (Figure 18a). Based on the distribution of the OESF reaches, all four of the reference reaches fell into the interquartile range (19 to 37 pieces). When pieces of wood in log jams were included in the count of large wood pieces, the number of pieces per sample reach ranged from 8 to 159 per 100 m (mean = 58 pieces per 100 m) (Figure 18b). Based on the distribution of the OESF reaches, one of the reference reaches fell into the lower quartile (≤35 pieces) and three fell into the upper quartile (>71 pieces).

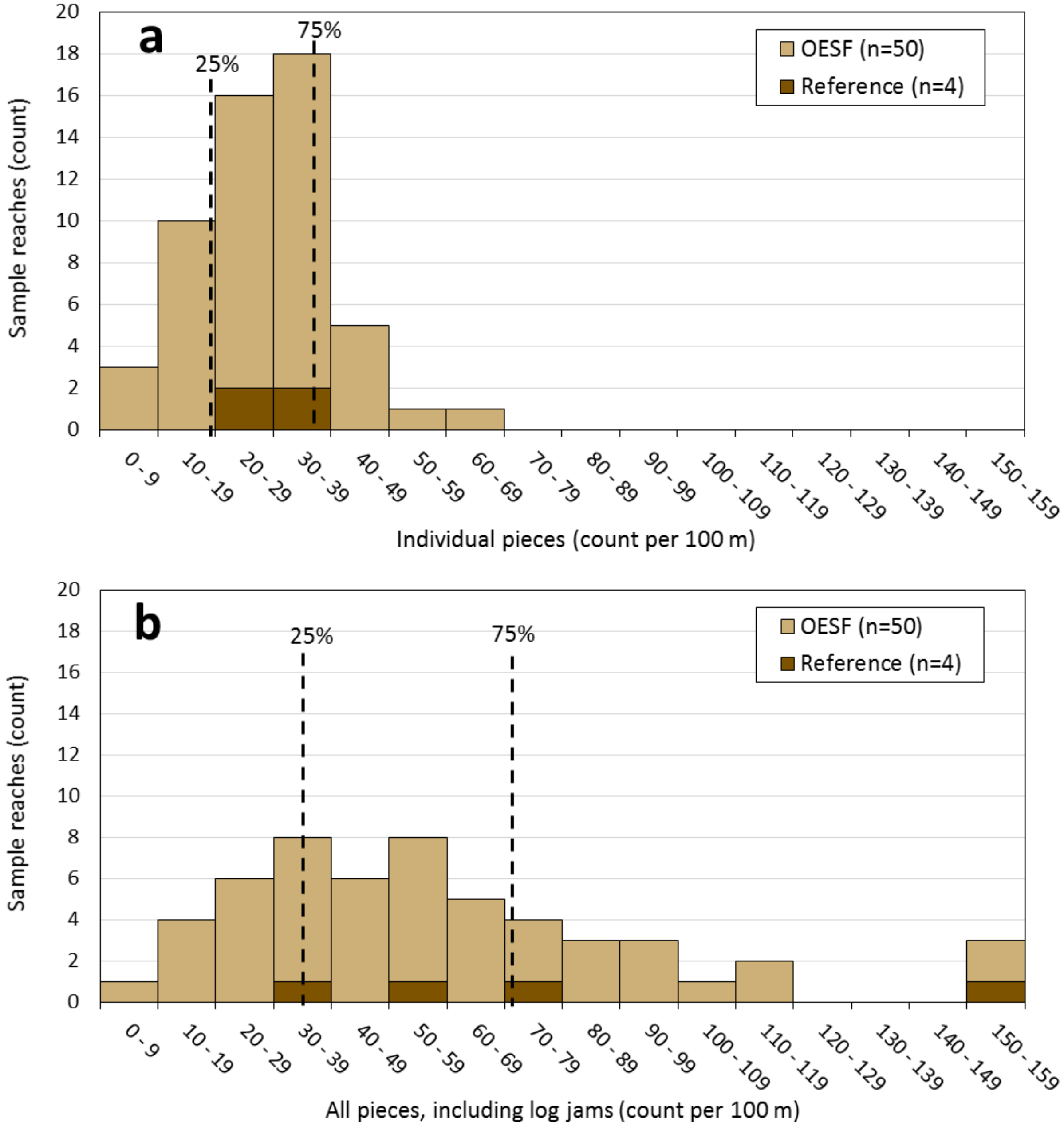


Figure 18. Distribution of in-stream large wood piece density for OESF and reference sample reaches, not including pieces in log jams (a), and for all pieces, including pieces in log jams (b).

Mean Piece Diameter

Mean piece diameter in the 50 OESF sample reaches ranged from 17 to 54 cm, with a mean of 34 cm (Figure 19). Three of the four reference reaches fell into the lower quartile (<30 cm) of the OESF distribution, and the fourth fell within the interquartile range (30 to 38 cm).

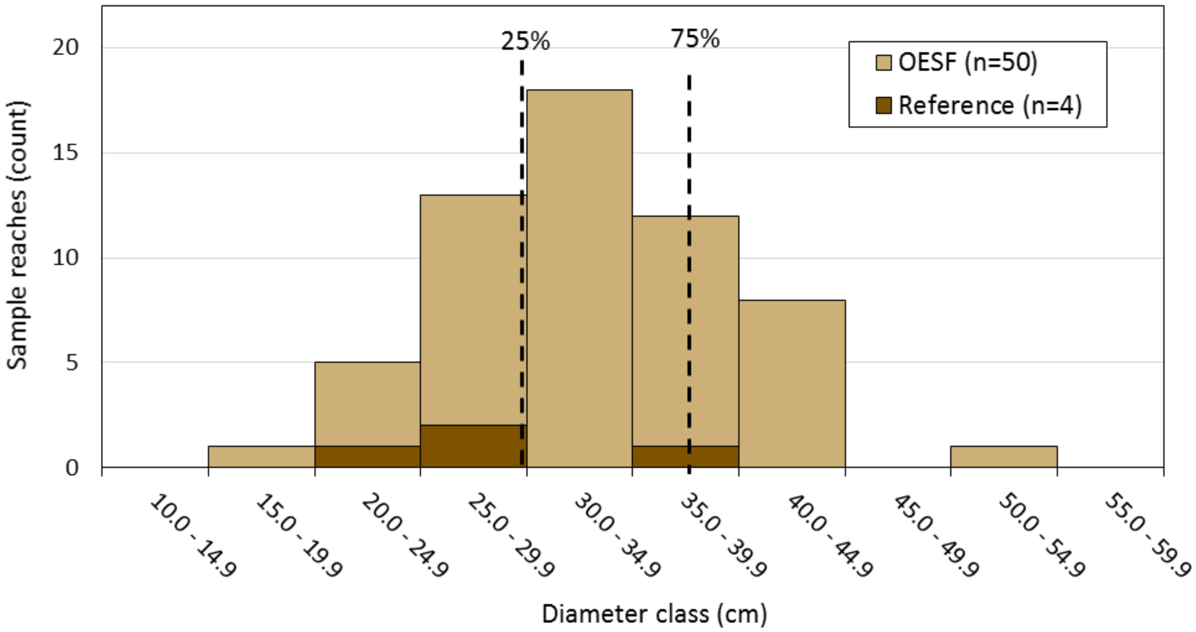


Figure 19. Distribution of the mean diameter of in-stream large wood pieces per sample reach for OESF and reference sample reaches (not including pieces in log jams).

Cumulative Volume

The cumulative volume of individual pieces per 100 m of sample reach ranged from 1.4 to 69.6 m^3 in the OESF (mean = 24.7 m^3) (Figure 20). Among the reference reaches, one fell into the lower quartile (<11.3 m^3); two fell within the interquartile range (11.3 to 31.8 m^3), and one fell into the upper quartile (>31.8 m^3).

Log jam (watershed 196).

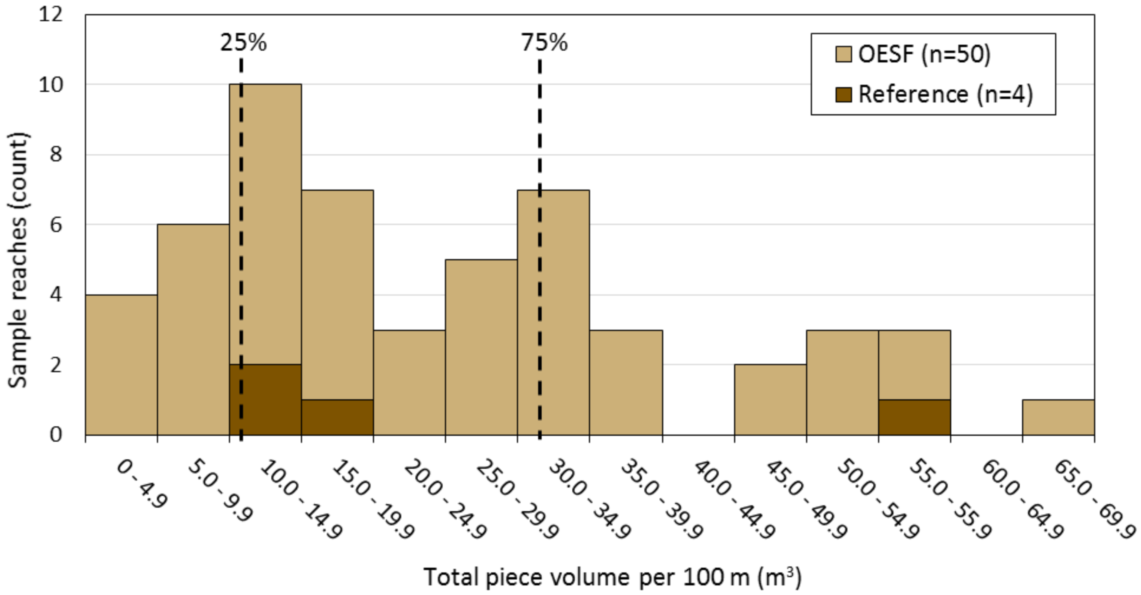


Figure 20. Distribution of the cumulative volume of all in-stream large wood pieces per 100 m for OESF and reference sample reaches (not including pieces in log jams).

Log Jams

Twenty of the reaches sampled (19 OESF; 1 reference) had no log jams. The OESF reaches had a maximum of 3.6 jams per 100 m, and the references reaches had a maximum of 2.9 jams per 100 m (Figure 21). The number of pieces of wood per jam in the OESF ranged from 11 to 135 (median of 23 pieces; mean of 31 pieces). Reference reach jams ranged from 12 to 55 pieces per jam.

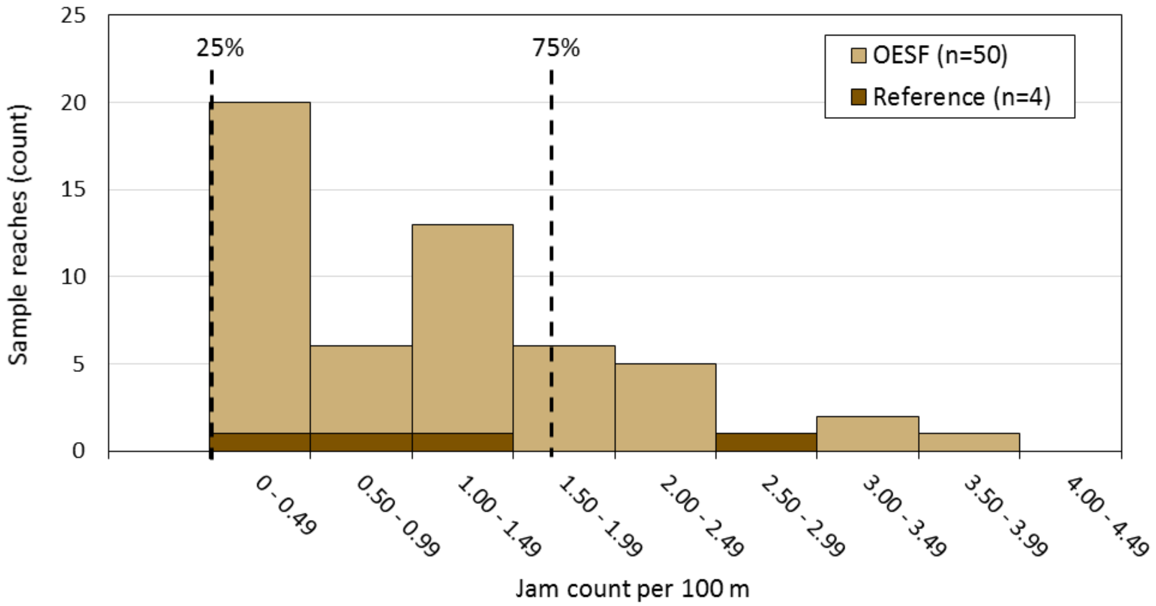


Figure 21. Distribution of the number of log jams per 100 m for OESF and reference sample reaches. Thirty-eight percent of the OESF sample reaches had no log jams.

Pool Forming Function

Instream large wood can contribute to forming a pool by redirecting the stream flow, causing scour, or by blocking it, causing a dammed pool. Qualifying pools have to meet minimum surface area requirements which are based on the stream's mean bankfull width.

The number of pool-forming pieces per 100 m of sample reach in the OESF ranged from 0 to 14 with a mean of 2.7 (Figure 22). Thirteen of the OESF reaches had no pool-forming pieces. Two of the reference reaches had no pool-forming pieces, and thus fell into the lower quartile. The other two reference reaches fell within the inner quartile range.

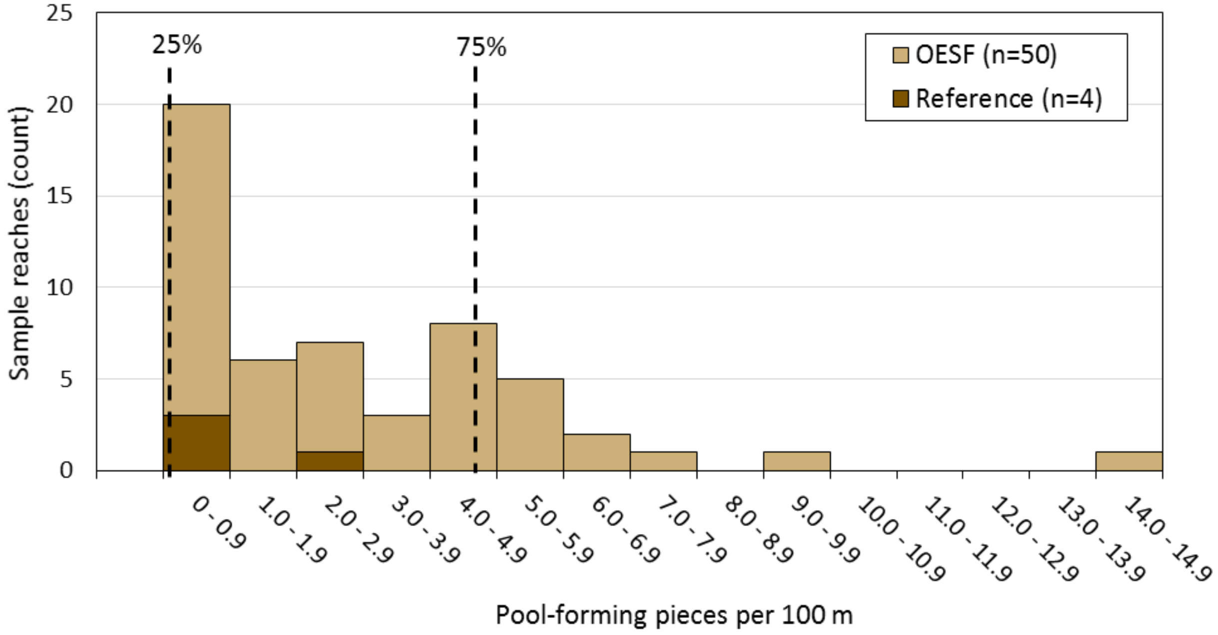


Figure 22. Number of pool-forming wood pieces per 100 m for OESF and reference sample reaches.

Decay Class

The distribution of in-stream large wood pieces by decay class and diameter class showed the greatest number of pieces in the 10-19-cm diameter class, with a general decline in number of pieces with increasing diameter (Figures 23 and 24). This pattern occurred for both the OESF and the reference sample reaches. Among the diameter classes, the proportion of pieces in a more advanced state of decay (i.e., classes 4 and 5) generally increased with increasing diameter.

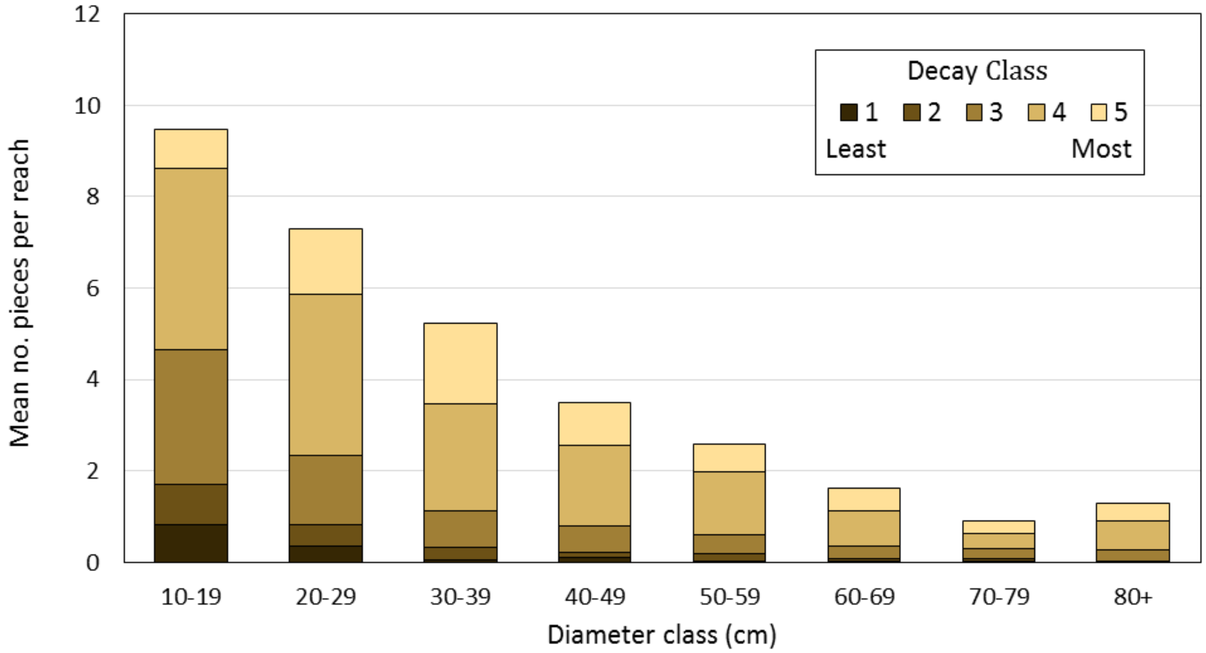


Figure 23. Mean number of pieces of large wood per sample reach, by decay and diameter class, for the 50 OESF sample reaches.

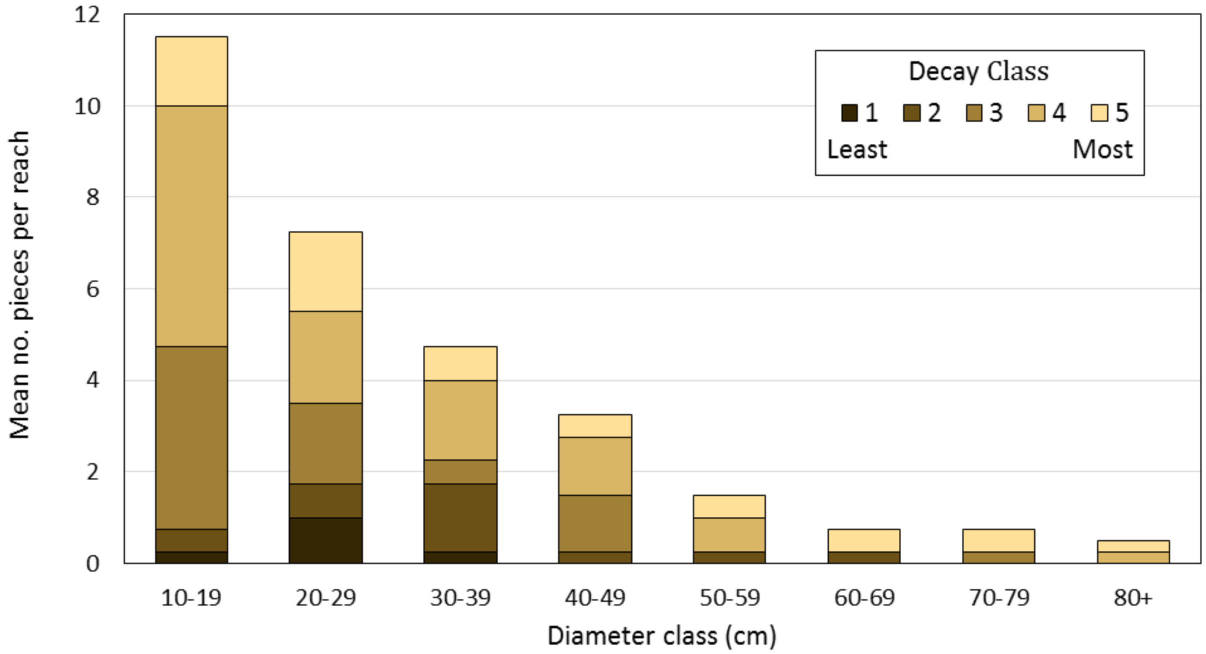


Figure 24. Mean number of pieces of large wood per reach, by decay and diameter class, for the four reference reaches.

Discussion

A comparison of the amount in-stream large wood pieces in our study to the habitat thresholds in the Forest Practices Watershed Analysis Manual (WADNR 2011) for streams less than 20 m wide shows that 28 sample reaches in the OESF and 3 reference reaches had large wood in the “good” habitat quality category. Sixteen OESF reaches and one reference had large wood in the “fair” habitat quality category, and 6 OESF reaches had large wood in the “poor” habitat quality category.

In-stream large wood has been studied extensively in western Washington; here, the status of large wood in OESF streams is compared to several of the most relevant studies. The frequency of in-stream large wood in the 50 OESF sample reaches (58.4 pieces per 100 m) (Figure 18b) compares favorably with results reported for unmanaged streams in western Washington. Bilby and Ward (1991) reported a relationship between stream width and frequency of large wood pieces in old-growth forests in southwestern Washington; applying that relationship to the widths of our OESF sample reaches yields a mean of 59.5 pieces per 100 m, indicating that their streams in old-growth forest had only a slightly higher piece frequency than the 58.4 pieces per 100 m that we found. For managed forests, Peterson et al. (1992) suggested a target large wood frequency of 2.38 large wood pieces per meter of channel width for streams 5 meters in width (the approximate mean of the OESF sample reaches); the OESF sample reaches however already exceed this value with a mean of 2.86 pieces. The OESF sample reaches also exceed the large wood piece counts reported for unmanaged western Washington forests by Fox and Bolton (2007) and Ralph et al. (1994).

In addition to the frequency of pieces, the volume of in-stream large wood is a key variable in determining its influence on stream habitat (Bilby and Ward 1991). Although the Forest Practices Watershed Analysis Manual (WADNR 2011) does not contain guidelines for large wood volume, other studies have reported large wood volume for unmanaged streams in western Washington that can be used in evaluating large wood in the OESF. Peterson et al. (1992) reviewed several studies and recommended using, as target conditions, large wood volumes reported for old-growth stands by Bilby and Ward (1989). Based on those target conditions, 38 of the 50 OESF sample reaches had large wood mean piece volume indices that met the target values (2 of the 4 reference reaches met the large wood mean piece volume targets). The volume index calculations from our study are based on mean volume of individual large wood pieces; means don’t incorporate pieces in log jams because we did not measure dimensions of those pieces. However, if we assume that pieces in jams have the same mean volume per piece as the individual large wood pieces within the same reach, the total estimated large wood volume per 100 m is 36.9 m^3 for the 50 OESF sample reaches. This value is somewhat lower than the median value of 51 m^3 found in unmanaged western Washington watersheds by Fox and Bolton (2007).

Detecting change in large wood metrics over time is challenging owing to high variability in large wood frequency and volume among streams (Peterson et al. 1992) and to low precision of some large wood metrics, as identified in our quality control analysis (Devine and Minkova 2016). To improve the precision of our monitoring, we recommended specific protocol and training changes and implemented these modifications prior to the 2016 field season.

Habitat Units

Channel units, also called habitat types or habitat units, are relatively homogenous, localized areas of the channel that differ from adjacent areas in depth, velocity and substrate. They exert a powerful influence on the distribution and abundance of aquatic plants and animals by governing the characteristics of water flow and the capacity of streams to store sediment and transform organic matter (Bisson et al. 2006).

Forest management may affect the type, frequency, and dimensions of channel units (Ralph et al. 1994; Woodsmith and Buffington 1996). Given the climate projections for increased summer temperatures and decreased summer precipitation on the Olympic Peninsula (Halofsky et al. 2011), the importance of deep pools as refugia for fish may increase.

Habitat units are identified using the classification system described in Bisson et al. (2006) with an abbreviated two-tier classification for slow water units (scour and dammed pools) and the addition of backwater pools. The habitat units are classified using mostly qualitative criteria and therefore the observer error typically is higher compared to purely quantitative measurements (Kaufmann et al. 1999). To reduce the subjectivity and to speed up the classification, the field crews use a field guide developed in-house (Minkova and Vorwerk 2015). Owing to differences in reach length, all counts of habitat units are standardized by adjusting to a 100-m basis.

While classifying and measuring the length and width of habitat units, the field crew also measures the maximum depth and tail-crest depth for each pool, which allows calculation of residual pool depth (the difference between the maximum pool depth and the tail-crest outlet depth). Residual pool depth is a quantitative measure less subject to observer error than other measures of stream dimensions and is independent of streamflow at the time of measurement (Lisle 1987).

Measuring pool width.

Habitat Units per 100 m

The number of habitat units per 100 m ranged from 7 to 25 (mean=14) for the OESF sample reaches (Figure 25). Based on the distribution of the OESF sample reaches, one of the four reference reaches fell into the lower quartile (>11 units per 100 m), and the remaining three reference reaches fell within the interquartile range (11 to 17 units per 100 m).

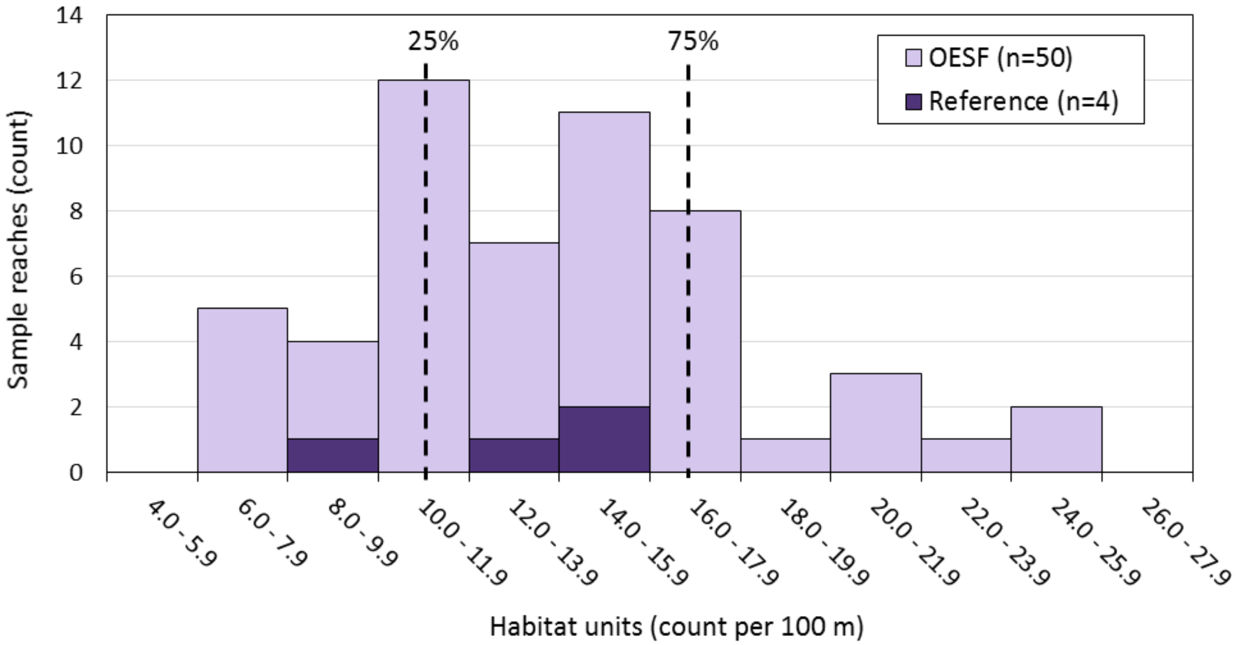


Figure 25. Number of habitat units per 100 meters of reach length for OESF and reference sample reaches.

Pool Area

The availability of pools is an important measure of fish habitat, and therefore their presence is assessed separately from the other types of habitat units. For the OESF sample reaches, the proportion of pool surface area (dammed, scour, or backwater pools), relative to the total surface area of the sample reach, had a broad range, from 0 to 77% (mean = 31%; standard deviation = 17%). (Figure 26). Among the reference reaches, three fell into the lower quartile of the OESF distribution (≤20% of surface area in pools), and the other one fell into the upper quartile (>39% of surface area in pools).

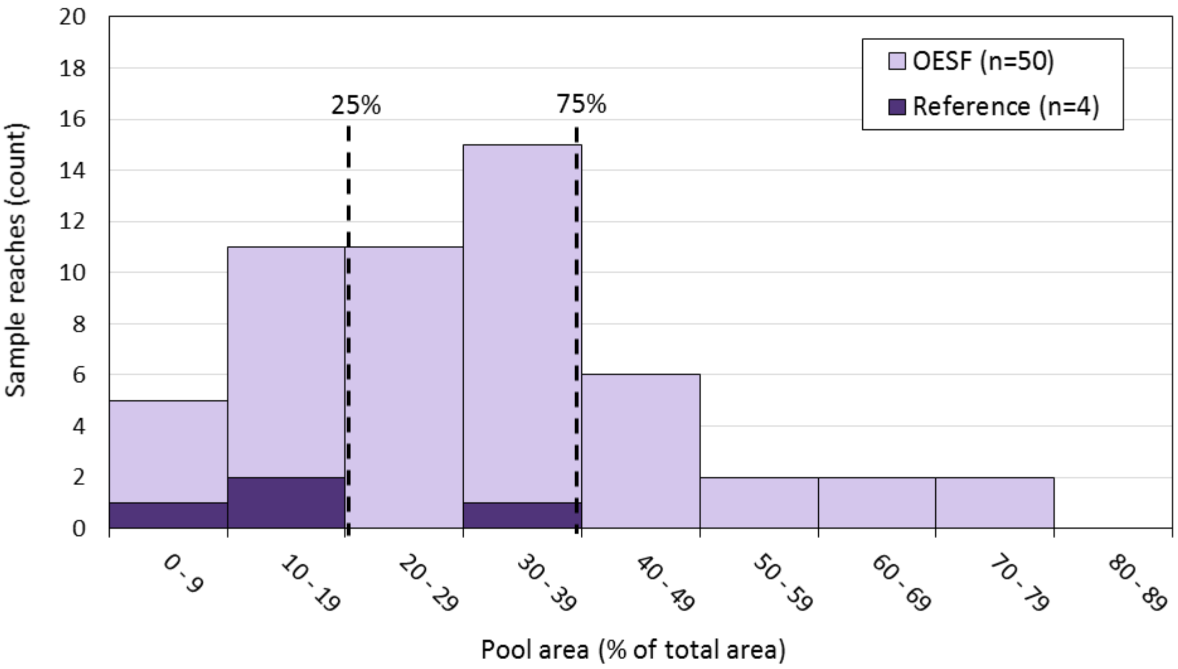


Figure 26. Pool surface area, as a percentage of total sample reach surface area, for OESF and reference sample reaches.

Because pool frequency typically differs by channel type, the percentage of pool area was examined separately for the three major channel types observed among the sample reaches: pool-riffle, step-pool, and cascade. For the pool-riffle type, the OESF sample reaches averaged 45% pools, and the single reference reach had 39% pools (Figure 27). For the step-pool type, the OESF sample reaches averaged 27% pools (Figure 27). For the cascade type, the OESF sample reaches averaged 19% pools, and the three reference reaches averaged 11% pools (Figure 27). The single sample reach of the braided type (in watershed 796) was the only reach to have no pools at all.

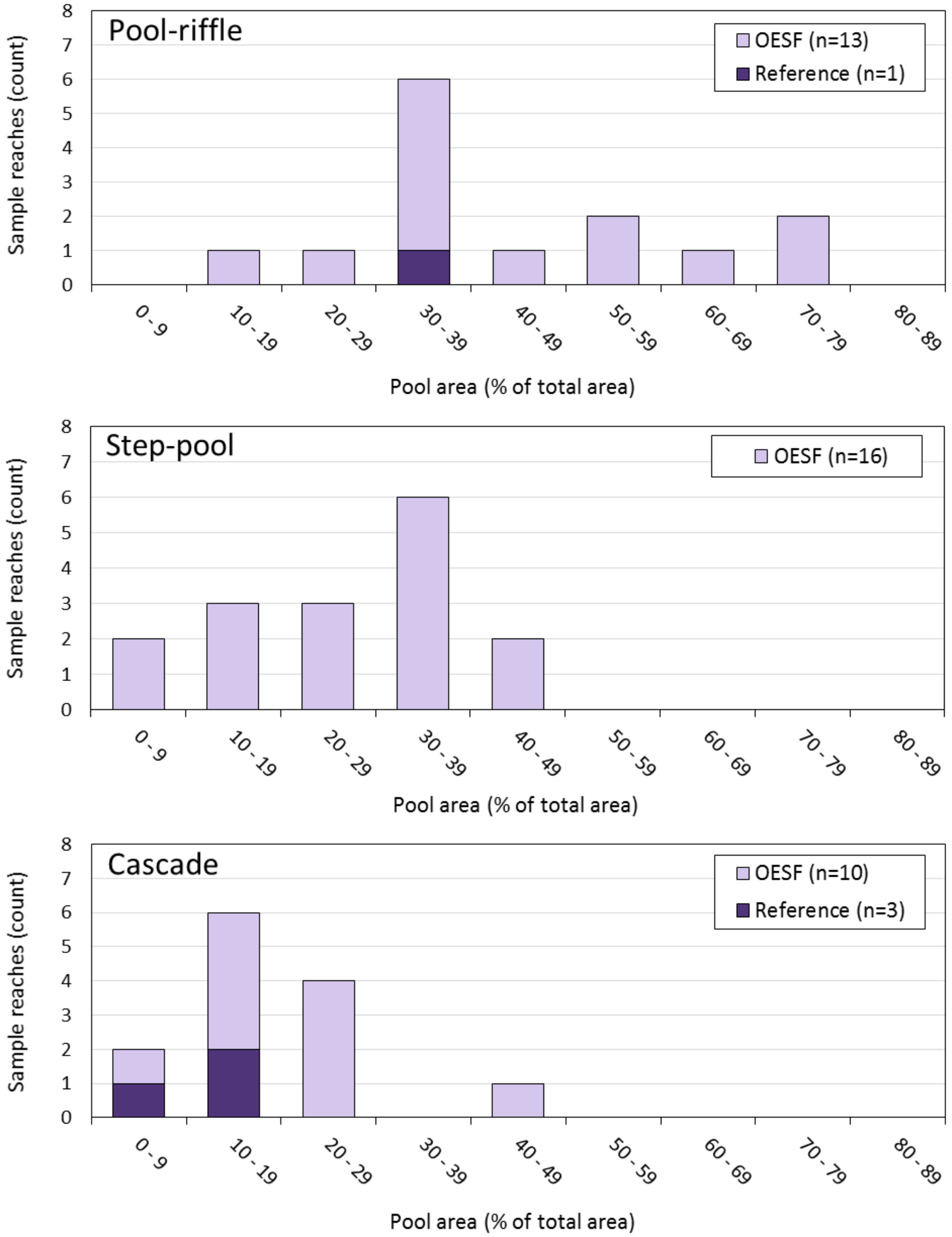


Figure 27. Pool surface area, as a percentage of total sample reach surface area, shown separately for pool-riffle, step-pool, and cascade channel types (10 sample reaches have not yet had channel type identified; one sample reach is not shown because it was the braided type and had no pools).

Residual Pool Depth

The mean residual pool depth for OESF sample reaches ranged from 16 to 71 cm, with a mean of 35 cm and a standard deviation of 13 cm (Figure 28). Among the reference reaches, three fell within the interquartile range of the OESF sample reaches (25 to 44 cm), and the fourth fell in the upper quartile (>44 cm).

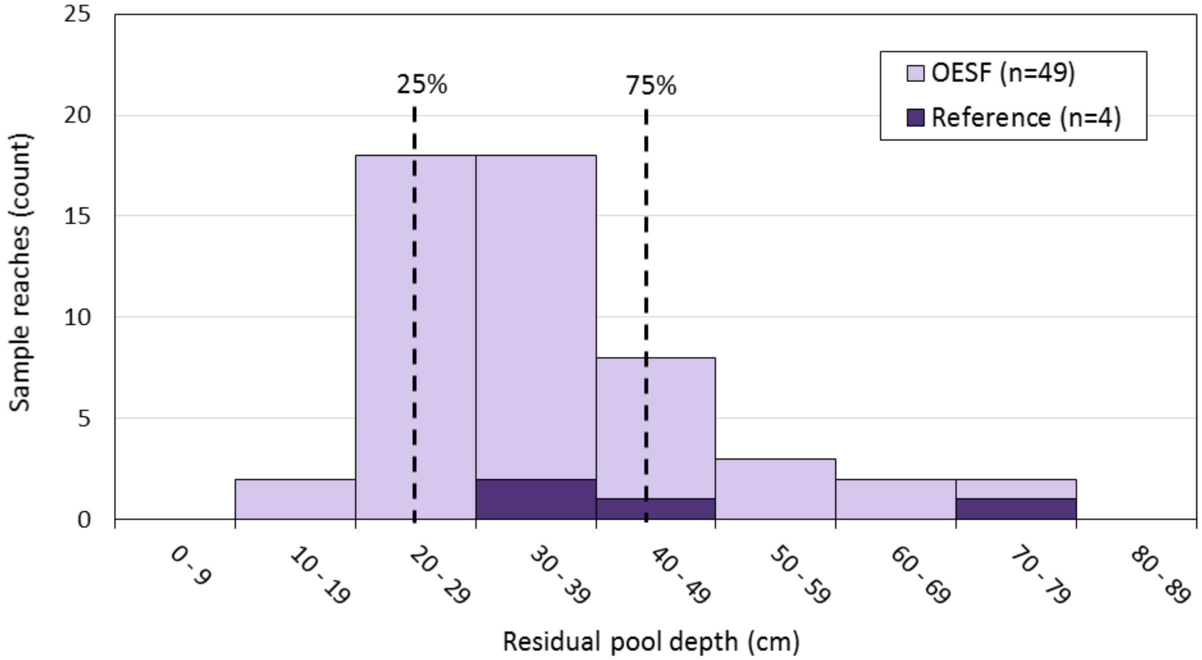


Figure 28. Distribution of mean residual pool depth values for OESF and reference sample reaches that contained pools.

Discussion

Results on pool frequency, surface area, and depth were compared with Forest Practices guidelines and with values reported for unmanaged watersheds in other studies.

Pool frequency and the percentage of stream surface area comprised by pools are habitat parameters in the Forest Practices Watershed Analysis Manual (WADNR 2011). An excerpt of the manual indicating the habitat thresholds for these metrics is presented in Table 5. The pool frequency for the 50 OESF sample reaches indicated “fair” habitat quality (28 sample reaches) or “poor” habitat quality (22 sample reaches), according to the manual’s guidelines. Among the reference reaches in the Olympic National Park, one reference reach indicated “fair” habitat quality, and three of the reference reaches indicated “poor” habitat quality.

The percentage of stream surface area in pools for the 50 OESF sample reaches indicated “good” habitat quality for 13 reaches, “fair” habitat quality for 17 reaches, and “poor” habitat quality for 20 reaches, based on the manual’s guidelines (Table 5). Percentage of stream surface area indicated “poor” habitat quality for all four of the ONP reference reaches. We suggest those regulatory standards were not designed with knowledge of the physical and biological conditions of managed and unmanaged Type 3 watersheds in the OESF.

In unmanaged watersheds in Washington, the percentage of stream area occupied by pools was reported as 51% in a study of streams ranging from 3 to 19 m in bankfull width and from 1 to 18% gradient (Peterson et al. 1992). For streams with a gradient of less than 3%, Peterson et al. (1992) recommended a target of 50% of the surface area comprised by pools. Sixteen OESF sample reaches and one reference reach have a gradient less than 3%; of those, 62% of the OESF reaches and the single reference reach have less than 50% surface area in pools.

Residual pool depth in unmanaged streams in western WA had a mean of 0.36 m (Ralph et al. 1994). This value is nearly identical to the 0.35 m mean residual pool depth for the 50 OESF sample reaches.

Table 5. Excerpts from the Forest Practices Watershed Analysis Manual Appendix Table F-2 (WADNR 2011).

Habitat Parameter	Channel Type	Life Phase Influenced	Habitat Quality		
			Poor	**Fair**	**Good**
Percent Pool	<2%; <15 m wide	Summer/winter rearing habitat	<40%	40 – 55%	>55%
	2-5%; <15 m wide	Summer/winter rearing habitat	<30%	30 – 40%	>40%
	>5%; <15 m wide	Summer/winter rearing habitat	<20%	20 – 30%	>30%
Pool Frequency	<2%; <15 m wide	Summer/winter rearing habitat	>4 channel widths per pool	2 – 4 channel widths per pool	<2 channel widths per pool
	2-5%; <15 m wide	Summer/winter rearing habitat	>4 channel widths per pool	2 – 4 channel widths per pool	<2 channel widths per pool
	>5%; <15 m wide	Summer/winter rearing habitat	>4 channel widths per pool	2 – 4 channel widths per pool	<2 channel widths per pool

Stream Shade

Stream shade refers to the extent to which incoming sunlight is blocked on its way to the stream channel (WADNR 2016a). It is one of the primary factors influencing stream temperature (Brown 1969), which in turn affects aquatic organisms directly or through changes in the amount of oxygen and nutrients that support aquatic life.

Forest management that reduces (or eliminates) riparian vegetation decreases stream shade which likely translates into increased stream temperature. In the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016a), changes in the amount of shade are used to infer changes in stream temperature, following a modeled relationship in the published literature.

Stream shade is measured using hemispherical canopy photos taken with a digital camera through a fish-eye lens. The photos are taken in the center of the stream at each cross section for a total of six photos per sample reach (Figure 3). The software Hemispher (Schleppi 2016) is used to calculate canopy closure (percent covered sky in the photo image). Canopy closure is then averaged across the six cross sections in each sample reach.

Percent Canopy Closure

Of the 50 OESF sample reaches, shade was assessed in 43 reaches between 2013 and 2015. Data presented here are based on the most recent set of photos in each sample reach (Table 6). None of the reference reaches have yet been photographed.

For 42 of the 43 reaches sampled, canopy closure was within a relatively narrow range, from 89 to 95 percent closure (i.e., 5 to 11 percent open sky) (Figure 29). One sample reach (690), had a lower canopy closure of 83.4 percent. Variation in canopy closure within sample reaches was generally low (Figure 30). In this canopy closure assessment, 26 of the 43 reaches sampled had a standard deviation of less than 1 percentage point, and 39 of the 43 reaches had a standard deviation of less than 2 percentage points.

Table 6. The year in which the most recent hemispherical photos were taken at each sample reach.

Year	Sample reach
2013	145, 157
2014	328, 443, 542, 550, 567, 568, 582, 621, 625, 637, 653, 690, 694, 730, 737, 760, 767, 796, 797, 804, 844
2015	158, 165, 196, 433, 488, 544, 545, 584, 597, 642, 687, 716, 717, 718, 724, 763, 769, 773, 776, 790

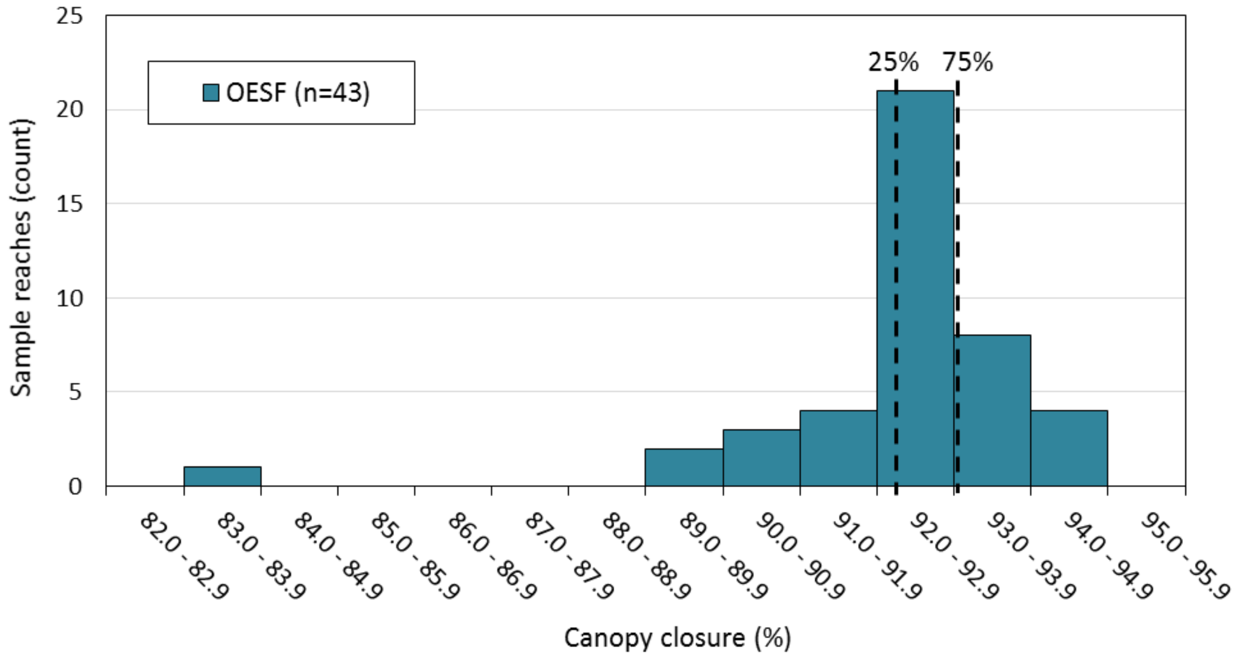


Figure 29. Mean canopy closure, assessed as the mean of six hemispherical photographs per sample reach (2013-2015), for 43 OESF sample reaches.

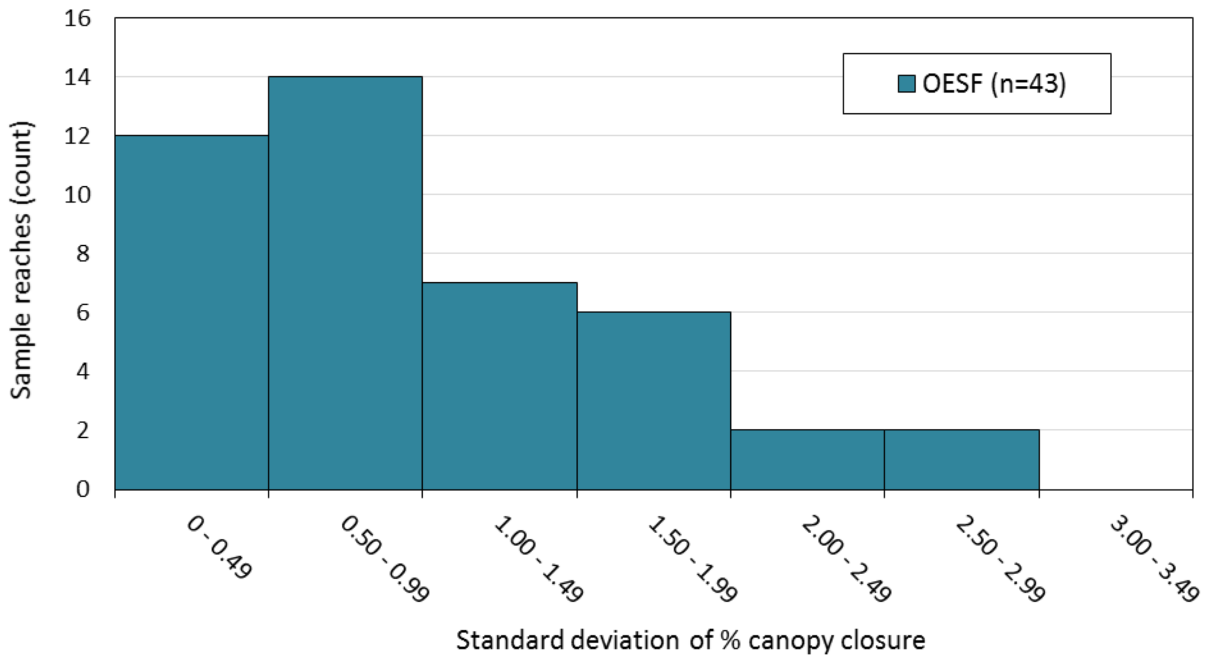


Figure 30. The standard deviation of canopy closure measurements for each sample reach, assessed using six hemispherical photographs per sample reach (2013-2015), for 43 OESF sample reaches.

Discussion

We suggest two potential explanations of the high canopy closure across the OESF sample reaches and the uniformity of canopy closure within a sample reach. First, the riparian forests along the majority of our sample reaches have relatively dense canopies, as expected for stands originating after intensive harvest 30-40 years ago. The analysis of the riparian vegetation overstory in the *Riparian Vegetation* section (further below) showed a mean basal area of 55 m^2/ha (240 ft^2/ac) (standard deviation = 16 m^2/ha or 70 ft^2/acre) and a mean relative density (Curtis 1982) of 61. Operational records of past management activities in the buffers as well as shade and riparian vegetation data from the reference reaches and from four additional OESF watersheds for which the sample reaches are within the ONP (to be analyzed in late 2016), will help further assess this hypothesis.

The second, likely additive contributor to stream shade, is the topography. For the sample reaches located in steep confined valleys, the local topography contributes to the portion of the sky that is obstructed. At this point of our analysis, we have not distinguished between topographic and vegetation shading.

Stream Temperature

Stream temperature is a key indicator for determining the health of a stream system. Temperature changes can affect the productivity, mortality, and life histories of all aquatic life forms. Forest management affects stream temperature through various mechanisms. The most direct and well documented pathway is by removing riparian vegetation, decreasing riparian shade, and allowing solar radiation to reach and warm the water. Other, less direct mechanisms include effects of riparian and upland forest harvesting on stream morphology, hydrology, sedimentation, and riparian microclimate (see review in Moore et al. 2005).

Paired stream and air temperature loggers (Onset Tidbit® v2 thermistors) were installed in each sample reach in September 2012. The purpose of the air temperature loggers is to assist in identifying periods when the stream temperature logger may become dewatered as a result of low flow or disturbance (Figure 31). All loggers record temperature data throughout the year at an interval of 60 minutes, and the data are downloaded at least once per year.

Multiple temperature metrics can be calculated from the long-term time series data. The seven-day average daily maximum temperature (7-DADmax) is reported here because it is used by the Environmental Protection Agency (EPA) and Washington State Department of Ecology (WADOE) to set water temperature criteria for various aquatic life-use categories (per WAC 173-201A-200 in WADOE 2016) and is commonly reported in other stream temperature studies.

Two WADOE aquatic-life use categories are applicable to the sample reaches in this project (Table 7). The categories are designated based on the presence of, or the intent to provide protection for, the key uses listed in the table. The spatial designation is based on actual or modeled fish presence. The temperatures represent the regulatory maximum threshold for the time period specified.

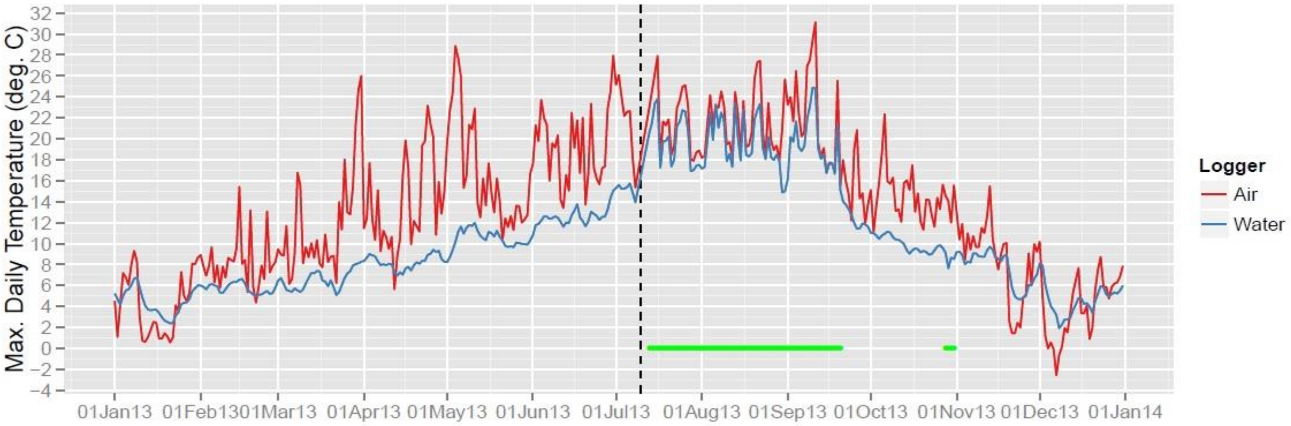


Figure 31. Example of a year-long temperature data record from watershed 694. Green lines indicate periods of dewatering. Data points from these periods are excluded from the analyses.

Table 7. Stream temperature thresholds (WADOE 2016) for the sample reaches in this project.

Aquatic Life Temperature Criteria			
Category	**Highest 7-DADmax (°C)**	**Time Period**	**Monitoring Watersheds**
Core summer salmonid habitat	16	June 15–September 15	145, 157, 158, 165, 196, 328, 433, 443, 488, 542, 544, 545, 550, 567, 568, 582, 584, 597, 605, 637, 642, 653, 658, 688, 690, 717, 718, 724, 730, 760, 763, 767, 769, 773, 776, 790, 796, 797, 804, 820, 844, Bogachiel, Queets
Char spawning and rearing	12	All year	619, 621, 625, 639, 687, 694, 716, 737, 750, Hoh, South Fork Hoh

WADOE (2016) recognizes that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria. In these cases, human actions, considered cumulatively, may not cause the 7-DADmax temperature of that water body to increase by more than 0.3 °C (0.54°F).

Seven-Day Average Daily Maximum Temperature (7-DADmax)

The 12 °C 7-DADmax char spawning and rearing habitat criterion applies to nine sample reaches in the OESF and two reference reaches (Figure 32). During three years of monitoring, only one sample reach did not exceed the 12-degree threshold in one of the years.

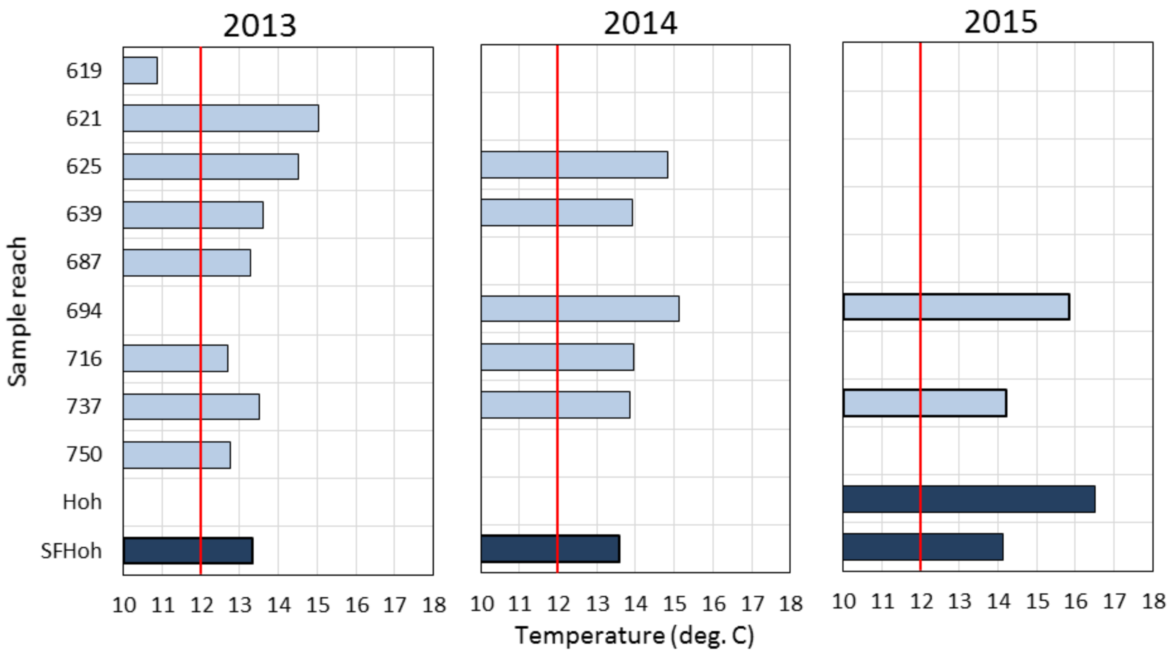


Figure 32. The 7-DADmax stream temperature for sample reaches with a 12 °C char spawning and rearing habitat criterion. Data are shown only for sample reaches where acceptable data existed for at least 80% of the summer time period. Darker color bars represent reference reaches.

The 16 °C 7-DADmax core summer salmonid habitat criterion applies to 41 sample reaches in the OESF and two reference reaches (Figure 33). None of the sample reaches exceeded 16 °C in 2013. In 2014, five reaches exceeded 16 °C, but only two of those five also exceeded the WADOE-approved 0.3-degree margin of error (i.e., 7-DADmax greater than 16.3 °C). Of those two reaches, one was in the OESF and one was a reference reach. In 2015, nine reaches exceeded 16 °C, seven of which also exceeded the 0.3-degree margin of error (five of the seven were OESF reaches and two were reference reaches).

Summer Diel Temperature Range

Summer (1 June through 31 August) diel stream temperature range (maximum minus minimum temperature in a 24-hour period) varied from 0.2 to 2.6 °C among sample reaches during 2013 to 2015 (Figure 34). In 2014, the two sample reaches that exceeded the 16.3 °C 7-DADmax threshold averaged a diel range of 2.2 °C, whereas the remaining sample reaches averaged 1.0 °C. In 2015, the seven sample reaches that exceeded the 16.3 °C 7-DADmax threshold averaged a diel range of 1.7 °C, and the remaining sample reaches averaged 1.1 °C. This suggests a relationship between summer diel range and warm stream temperatures.

Figure 33. The 7-DADmax stream temperature for sample reaches with a 16 °C core summer (15 June – 15 September) salmonid habitat criterion. Data are shown only for sample reaches where acceptable data existed for at least 80% of the summer time period. Darker color bars represent reference reaches.

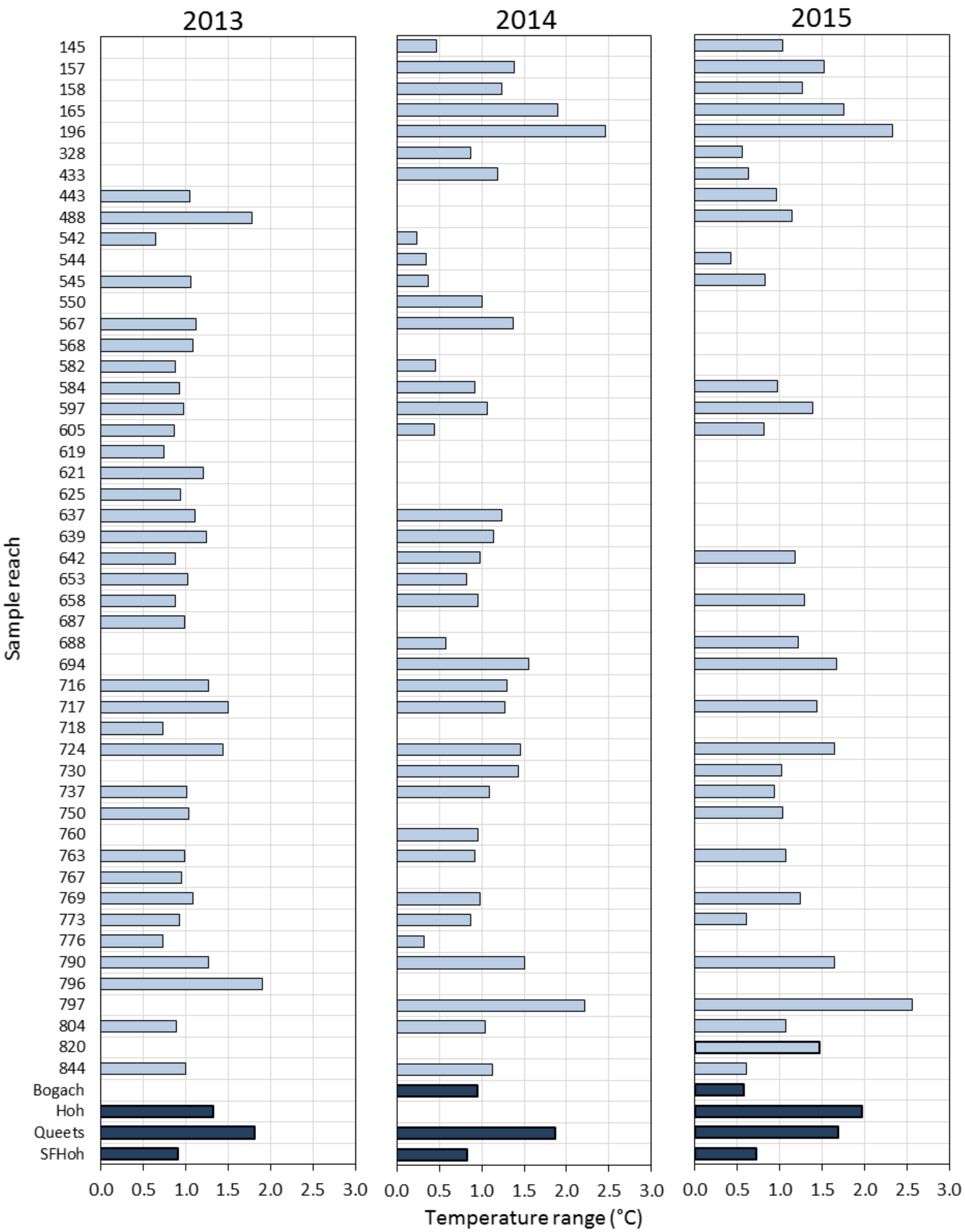


Figure 34. Mean diel stream temperature range for the months of June through August. Data are shown only for sample reaches where acceptable data existed for at least 80% of the June-August time period. Darker color bars represent reference reaches.

Average Monthly Temperature

In addition to the 7-DADmax and summer diel range, we also examined overall seasonal and yearly temperature patterns for the entire monitoring period. When stream temperature was averaged across all OESF sample reaches, inter-annual differences became apparent (Figure 35). For most months, temperatures increased from 2013 to 2014 and again from 2014 to 2015. Stream temperatures in reference reaches (not included in Figure 35) followed very similar seasonal and annual patterns.

Air temperature across the OESF sample reaches showed an inter-annual pattern similar to that of stream temperature (Figure 36). Mean summer air temperature (1 June through 31 August) increased during the three-year period (2013 to 2015) from 13.8 to 14.3 to 15.1 °C, respectively.

Summer air temperature measured at a weather station in Forks (NOAA, http://www.ncdc.noaa.gov/cdo-web/datasets/GHCNDMS/stations/GHCND:USC00452914/detail) showed inter-annual increases from 15.6 to 16.1 to 17.2 °C for 2013 to 2015. These increases were nearly identical in magnitude to the air temperature increases at the OESF sample reaches. These similar inter-annual trends in air and stream temperatures demonstrate the link between regional air temperature and local stream temperatures.

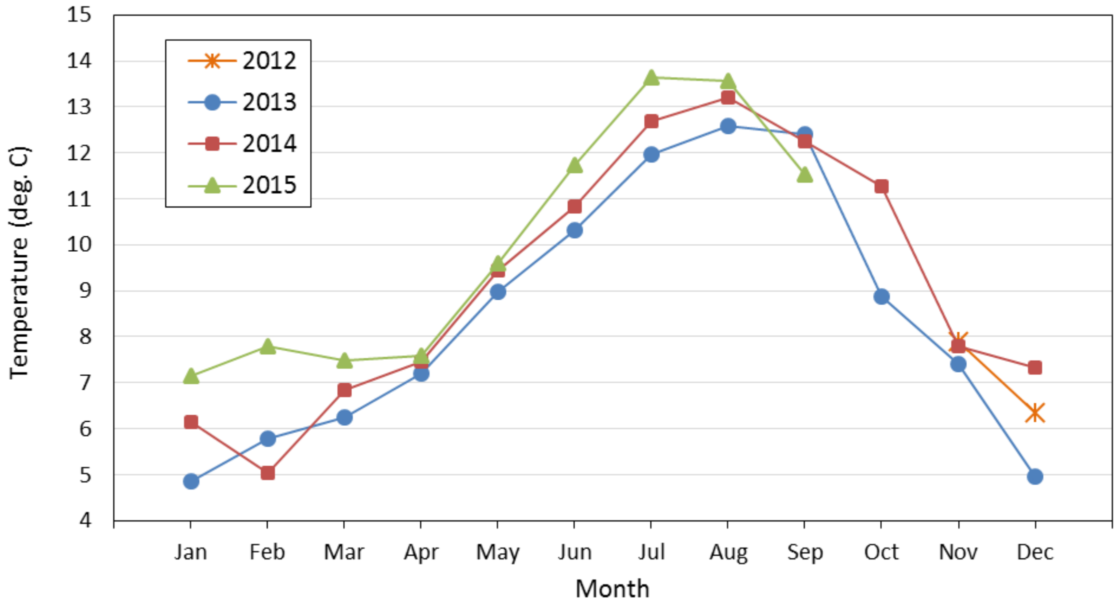


Figure 35. Mean water temperature of all OESF sample reaches, by month, from November 2012 through September 2015.

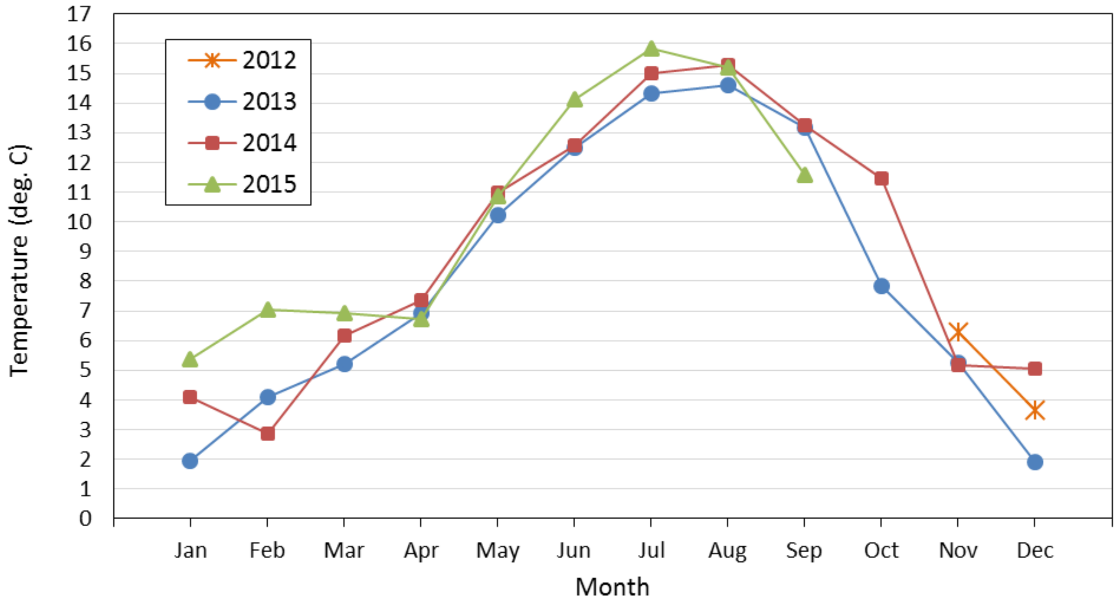


Figure 36. Mean air temperature, measured near each sample reach and averaged across all OESF sample reaches, by month, from November 2012 through September 2015.

Discussion

The metrics 7-DADmax and mean diel range were reported previously for state lands in the OESF. In 2004, WADNR measured water temperature in 49 streams located on tributaries of Clearwater River, Hoh River and South Fork Hoh River using Onset® data loggers (Pollock et al. 2004). The streams had similar size and gradient to the population in our study. Twenty-four of the monitored streams (49%) exceeded the WADOE 7-DADmax threshold of 16 °C. No air temperature data were reported. The authors found that stream temperatures in watersheds harvested in the previous 40 years were often (but not always) higher and more variable than those in unharvested watersheds. The considerably smaller proportion of streams exceeding the same threshold in our study (8% averaged across three years of monitoring) indicates improvement of stream temperature conditions since 2004.

The finding that the two reference reaches and all but one OESF sample reach, to which the WADOE threshold of 12 °C 7-DADmax applies, exceeded the threshold during the three years of monitoring is indicative of two potential problems: 1) the designation of these streams as char (i.e., bull trout) spawning and rearing habitat may not be accurate and/or 2) this temperature threshold may be unrealistically low for the monitored streams. The fish monitoring, initiated by WADNR in 2015 (refer to the sub-section *Riparian Validation Monitoring* in the *Progress Report* section of this document) and a review of local studies on bull trout habitat associations will help us identify the reason.

Further analyses of stream temperature will include more metrics (e.g., minimum winter temperatures), assessment of the relationship between stream temperature and other habitat indicators such as shade and stream flow, as well as spatial and temporal analyses of temperature regimes. All analyses of potential management effects on stream temperatures will account for the influence of inter-annual air temperature variation and will consider other factors known to affect stream temperature, such as stream morphology, ground water influences, and watershed forest condition (Brofoske et al. 1997).

Stream Discharge

Stream discharge, or stream flow, is the volume of water that moves over a designated point during a fixed period of time. Stream flow quantity and timing are critical components of water supply, water quality and the ecological integrity of river systems (Poff et al. 1997). Stream discharge is an important determinant of aquatic habitat conditions because it affects channel morphology, concentrations of chemical elements such as nutrients and dissolved oxygen, and distribution of habitat elements such as in-stream large wood. The life histories of many aquatic species are dependent on stream flow regimes.

Forest harvesting activities, including tree removal and associated roads, generally increase the fraction of precipitation that is available to become streamflow, increase rates of snowmelt, and modify the runoff pathways by which water flows to the stream channel (Moore and Wondzell 2005). Harvesting may potentially decrease the magnitude of hyporheic exchange flow through increases in fine sediment and clogging of bed materials and through changes in channel morphology. In small headwater catchments, forest harvesting generally increases annual runoff and peak flows and reduces the severity of low flows (Moore and Wondzel 2005). Ground-based equipment used for harvesting can cause compaction of the soil surface resulting in decreased hydraulic conductivity and soil infiltration capacity (Startsev and McNabb 2000).

In the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016), WADNR used the indicator peak flow (periods of maximum discharge). Changes in this indicator were assessed by measuring the proportion of hydrologically mature forest in a watershed.

For this project, stream flow is measured through permanent gage stations consisting of pressure transducers that continuously record water level every 15 minutes and a staff gage. The stations were installed in 14 OESF sample reaches in 2013. In addition to the permanent installations, stream discharge is measured in the field repeatedly throughout the year in the 14 reaches. The channel cross-section at the gage station and the elevation of the gage station are surveyed at least once per year because changes in channel morphology and instrument drift affect the hydrology monitoring results (Kenney 2010). Refer to Minkova and Vorwerk (2014) for details on the spatial allocation of the gage stations and to the stream discharge field protocol (LovellFord et al. *in prep*) for detailed field procedures.

The manually recorded discharge measurements are combined with simultaneous water level readings from the pressure transducers to build a stage-discharge rating curve using methods described in Rantz (1982) and Gore (1996). Rating curves are least-squares regression plots of stage height by discharge, depicting the relationship between water level and streamflow that is specific to each sample reach. Continuous discharge over time (i.e., a hydrograph) is then calculated using the rating curve in conjunction with the continuous water level data. Refer to Devine and LovellFord (*in prep*) for details on hydrology data management and analyses.

The results and discussion from the initial analyses of the hydrology dataset for the period October 2013-June 2015 are presented below. These results include the development of watershed-specific rating curves but do not include hydrographs, which are still in a preliminary form. Refer to the 2015 Hydrology Status Report (Korenowsky and Devine 2016) for details on methods and watershed-specific results and recommendations.

Progress

Time series plots were created for each watershed showing the measurements from the recording gage, staff gage measurements, and the difference between the staff gage and recording gage measurements at the time of the staff gage reading (see Figure 37 for an example).

For each watershed: the recording gages' data and the staff gages' readings were examined for relative frequency of observations at different stage values, the gages' cross section profile was assessed for changes over the analysis period, and the stage values from the recording gage were plotted against discharge measurements taken at the same time (see Figure 38 for an example).

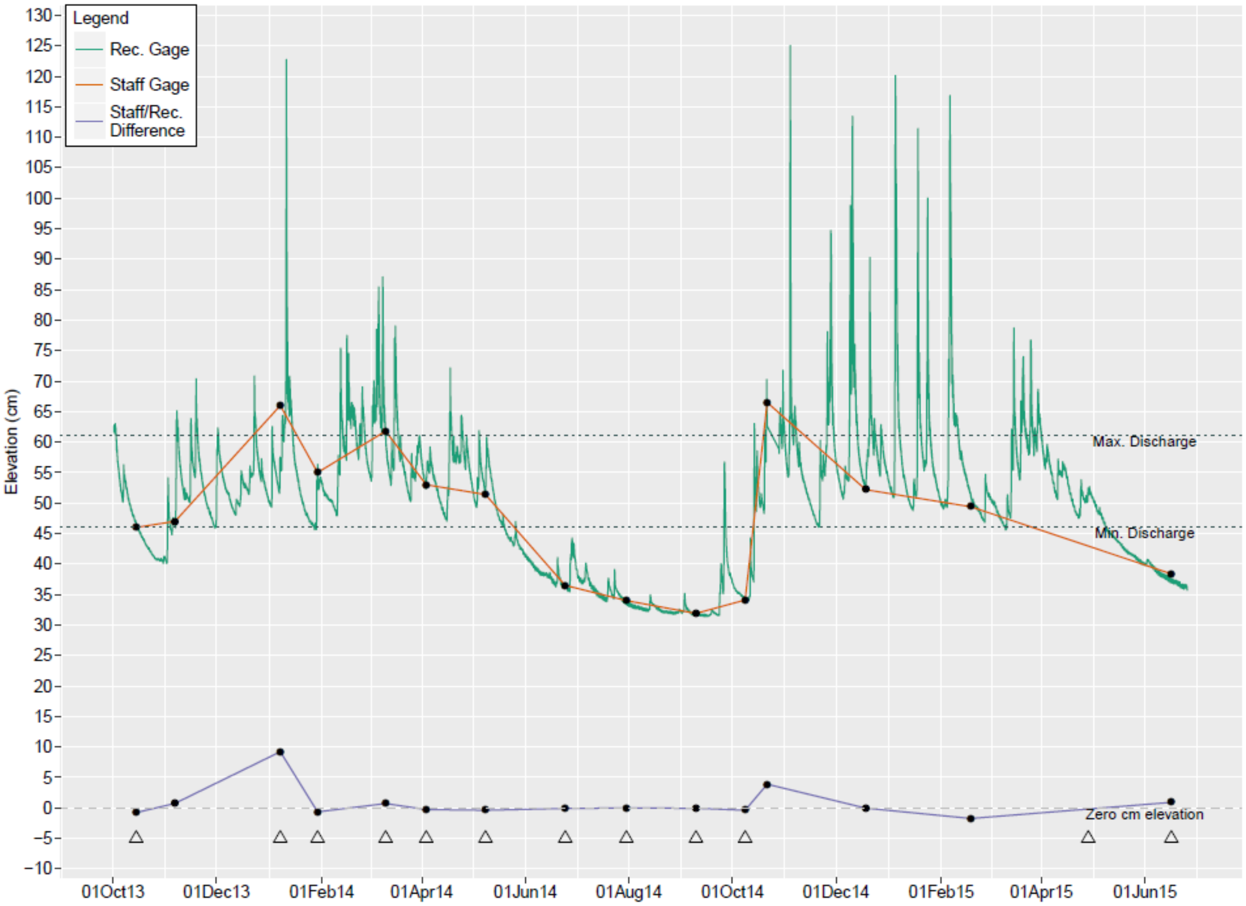


Figure 37. Stage data time series for Watershed 165 (triangles indicate discharge measurement dates)

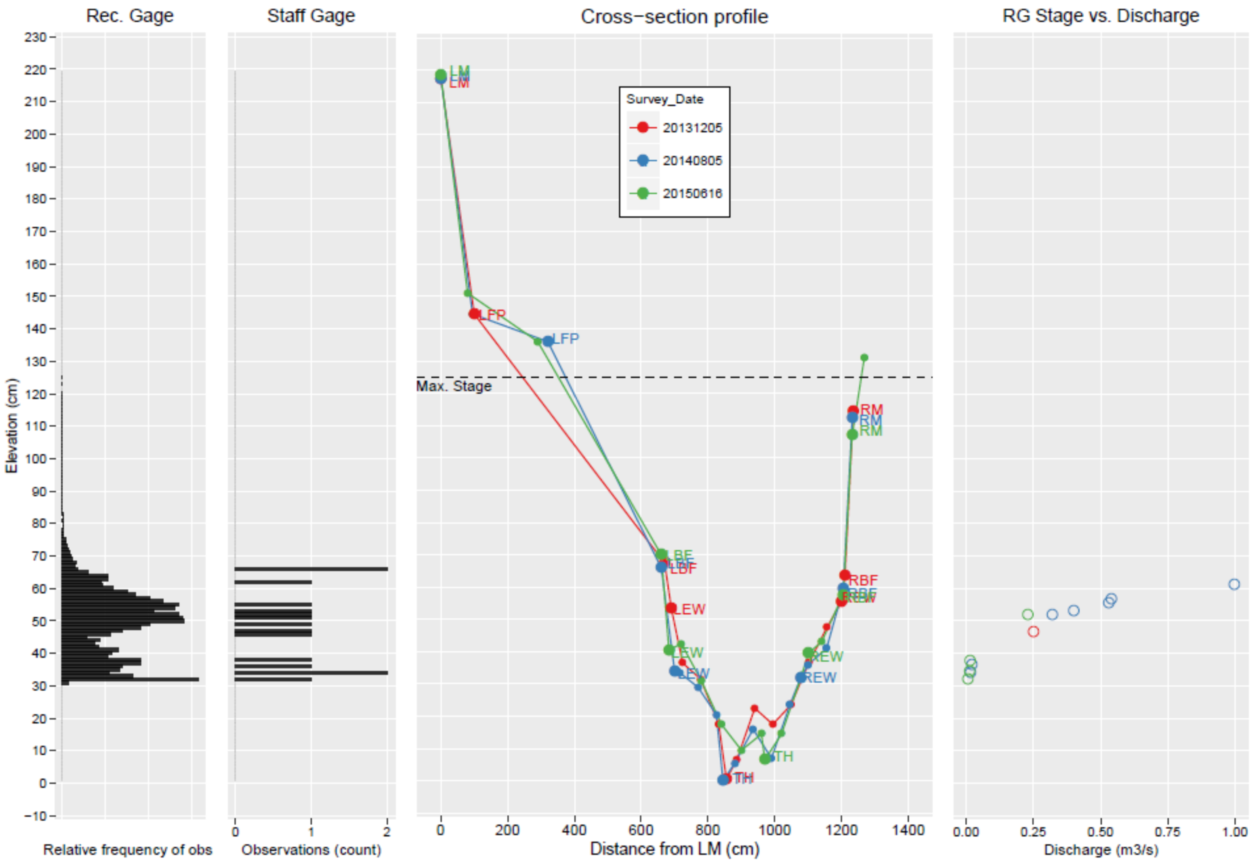


Figure 38. Gage data histograms, cross−section profile, and stage−discharge data for Watershed 165.

A preliminary set of stage-discharge rating curves was then created for each watershed using all data collected through July 2015. In many cases, the preliminary curves did not accurately describe the stage-discharge relationship for the entire dataset because the stage-discharge relationship was not constant throughout the data collection period (usually due to changes in the channel morphology) or was not constant across the full range of stage values). In these cases, multiple curves were developed for the same watershed. In all situations, we only fit stage-discharge curves where there were sufficient data present to create a “reliable” model, defined here as one in which R^2 >0.95 and n >4. Since the rating curves will be utilized in creating watershed-specific hydrographs for the monitored watersheds, an assessment of the rating curves’ capacity to accurately predict discharge is essential.

Reliable rating curves are currently available for the entire range of observed discharges in two watersheds: 165 and 737. Reliable rating curves are available for a subset of the monitoring period in eight watersheds: 145, 328, 544, 694, 717, 724, 769, and 790. One or more reliable rating curves are available for one or more subsets of stage heights in two watersheds: 196 and 584. Reliable rating curves couldn’t be created with the available data in two of the monitored watersheds (433 and 642) because of large changes in channel geometry near the gage station.

Hydrographs for the streams with reliable rating curves are under development and will be completed in 2016. Relevant monitoring metrics are currently being discussed and will be calculated later.

Discussion

Many of the hydrology monitoring stations experienced channel shifts, due to either aggradation or erosion. These shifts likely occurred during high-flow events and are expected to continue. As a result, a reliable rating curve(s) cannot be developed and a hydrograph cannot be maintained in some watersheds over time. The impact of channel shifts on the rating curves is exacerbated by the small size of the monitored streams, where even minor changes in channel geometry affect a large portion of the cross-section. It is likely that several gages located in the most dynamic channels will be discontinued because of our inability to maintain reliable rating curves with a reasonable amount of effort.

A limited number of discharge readings occurred during high flows, which limits the range of our stage-discharge rating curves. Rating curves are only accurate within the range of measured discharges from which they are built, and thus the range of discharge values that we are able to predict is relatively small. The flow in the monitored streams is highly dependent on precipitation, falling mainly as rainfall in the winter. Streams have a very rapid time-to-peak (Figure 37), which makes it difficult to collect field data across many watersheds during the narrow window of time when flows peak. After storm events, the high flows in some of our sample reaches last for only a few hours. In addition, because the method of stream discharge measurement that is utilized in this project involves wading in the stream, there is an increased safety risk to measure discharge during over-bankfull flows and during rapid storm surges. In the future, extra effort should be made to collect data during high flows, where it can be done safely.

Our stage-discharge dataset thus far has a relatively small number of data points, as this long-term hydrologic monitoring is still in its early stages. This reduces our confidence in the produced rating curves. However, we expect that the predictive capabilities of the rating curves will improve as more data are collected. Even with the issues to be resolved, we are gaining valuable knowledge about flow dynamics and affecting factors.

Riparian Microclimate

Many riparian-associated plant and animal species require moist, cool, relatively stable conditions for their reproduction and survival. Streams are known to influence microclimate conditions in the surrounding forest, with near-stream air and soil temperatures being cooler and air humidity being higher than in the upland forest (see review in Moore et al. 2005). The effect gradually dissipates further from the stream, a phenomenon known as microclimate gradient.

Removing and altering vegetation, such as harvesting timber on or near riparian areas can influence microclimate conditions, and those harvest effects may continue in the unharvested riparian area (Kluber et al. 2009). The two influences are conceptually depicted in Figure 39. Microclimate is relatively sensitive to changes in the forest canopy; a number of studies quantify the lengths of the microclimate gradient (Brofoske et al. 1997) and the distances of the warming effects from harvest (Chen et al. 1995). Ovaska et al. (2016) described the short term effects of forest harvesting on gastropods.

In the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016), the changes in daytime air temperature, soil temperature and relative humidity within a microclimate gradient were modeled as a result of nearby timber harvests.

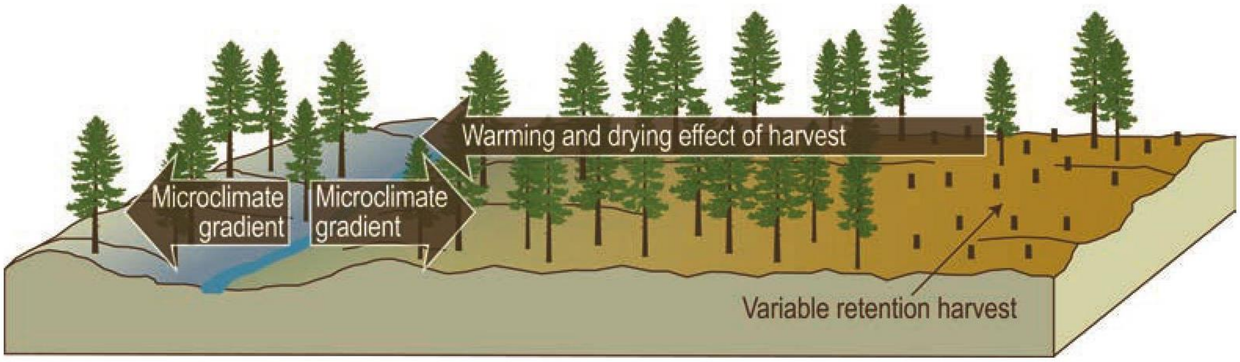


Figure 39. Riparian microclimate gradient and effects of harvests on it (from OESF Forest Land Plan Environmental Impact Statement (WADNR 2016)).

Air temperature and humidity have been monitored in ten watersheds in the OESF since Fall 2013 using two sampling transects installed on opposite banks of the sample reach. The transects are perpendicular to the reach, and each extends 60 meters from the stream's 100-year floodplain into the adjacent riparian forest (Figure 3). Each transect consists of five data loggers (2-channel HOBO® Pro v2, Onset Computer Corp.) recording air temperature and relative humidity every two hours throughout the year. Microclimate data are downloaded at least once per year. Data are subjected to quality control to ensure removal of erroneous values resulting from animal or physical damage to the data loggers or housings.

Air moisture data are presented here as vapor pressure deficit (VPD) rather than relative humidity because VPD measures the "drying power" of the air and therefore has a more direct biological relevance than relative humidity. Furthermore, a single VPD value represents a single value of drying power, whereas a single relative humidity value can represent a range of drying power values, depending on the air temperature. As a frame of reference, VPD is typically 0 kPa (i.e., the air is saturated with water vapor) at night and in winter but reaches 1 to 2 kPa during the afternoon of a warm summer day.

Temperature and Vapor Pressure Deficit

The gradient in mean daytime (i.e., between sunrise and sunset) air temperature along the transects varied by month, though there was significant variation among the 20 transects, as shown by the large standard deviations (Figure 40a). The clearest spatial trend occurred for the month of July, in which temperatures increased from the station nearest the stream to the distal end if the transect.

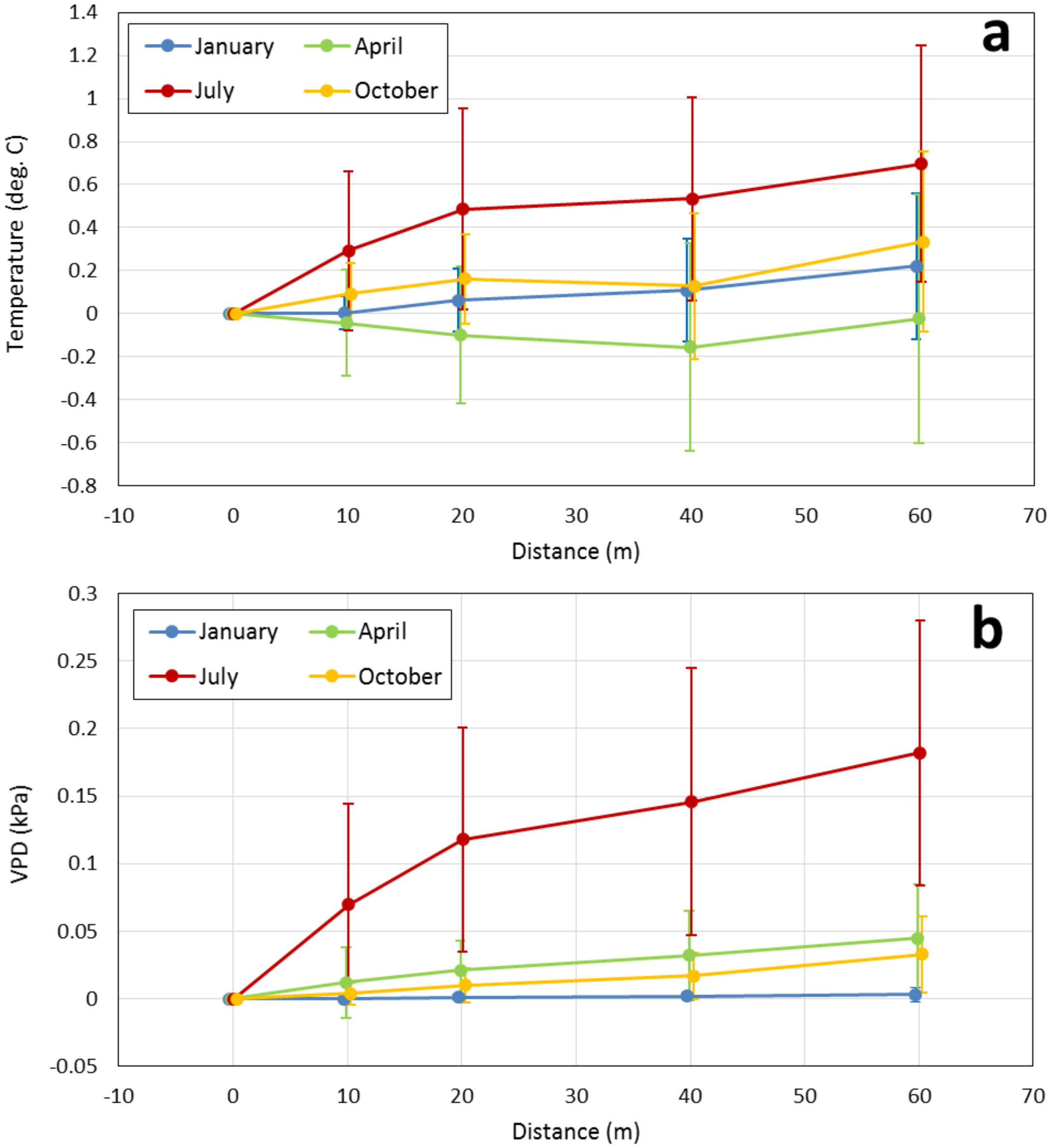


Figure 40. Mean differences in daytime temperature (a) and daytime vapor pressure deficit (VPD) (b), relative to the 0-m transect station, for twenty 60-m transects in ten watersheds on the OESF. Error bars show one standard deviation. Data are from 2013, 2014 and 2015.

The gradient in mean daytime VPD along the transects also varied by month (Figure 40b). As with air temperature, there was significant variation among the 20 transects. The clearest trend in VPD again occurred for the month of July, with VPD increasing at greater distances from the stream.

Patterns in air temperature and VPD at individual transects indicate that factors other than distance from stream are affecting microclimate. This is evident when examining the data from multiple transects, collected on the same day. For example, in Figure 41a, afternoon air temperatures are generally warmer at increasing distances from the stream. But for other transects, different patterns are evident. For the transect in Figure 41b, the warmest temperature occurs at the station nearest the stream, and the 40- and 60-m stations show a brief increase in temperature from 16:00 to 18:00. VPD—shown for the same two transects as temperature on the same day (Figure 42)—also shows patterns that cannot simply be explained by distance from stream.

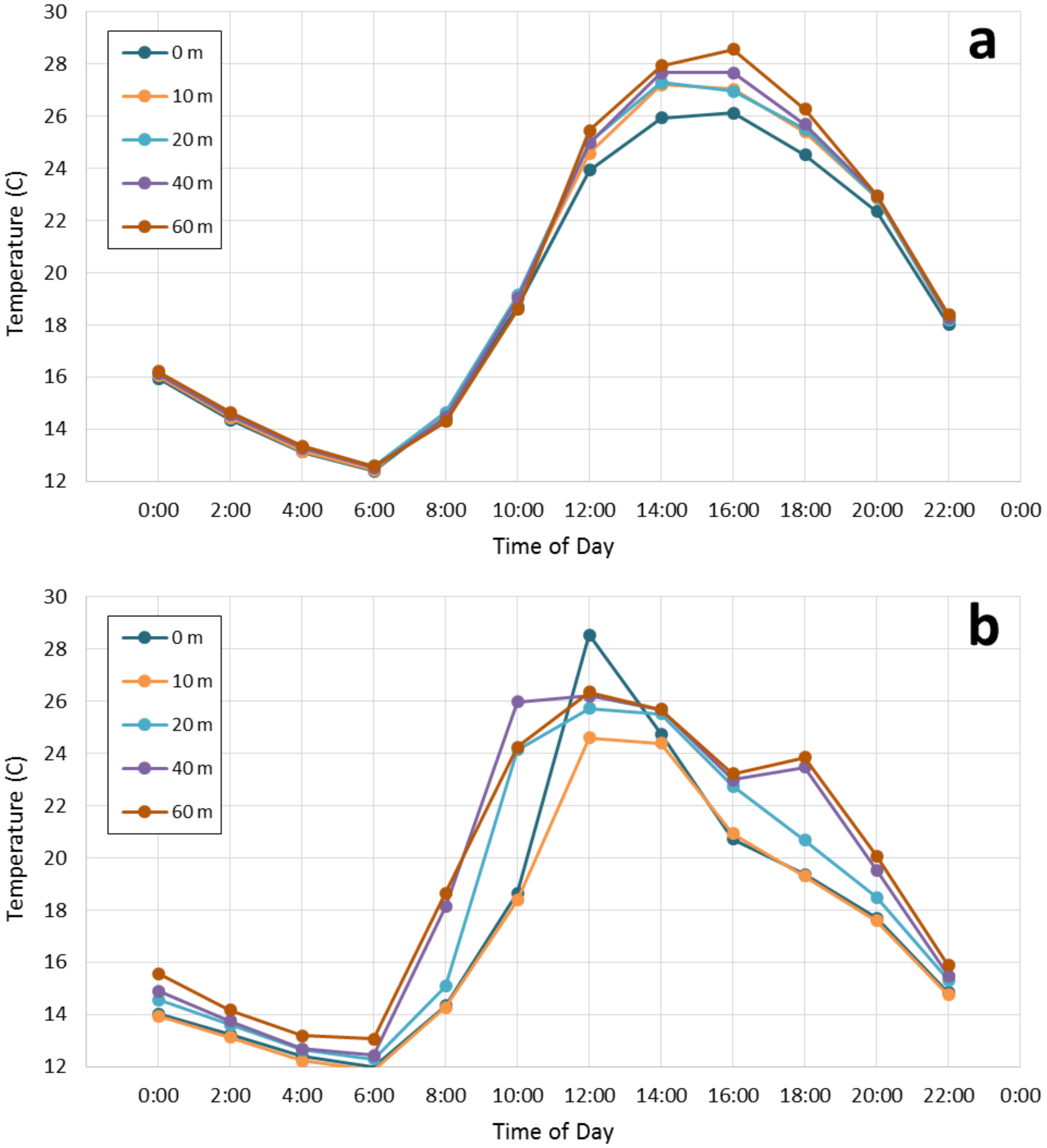


Figure 41. Temperature on 2 July 2015, a warm, clear day, for microclimate stations on transects in watersheds 642 (transect D) (a) and 145 (transect A) (b).

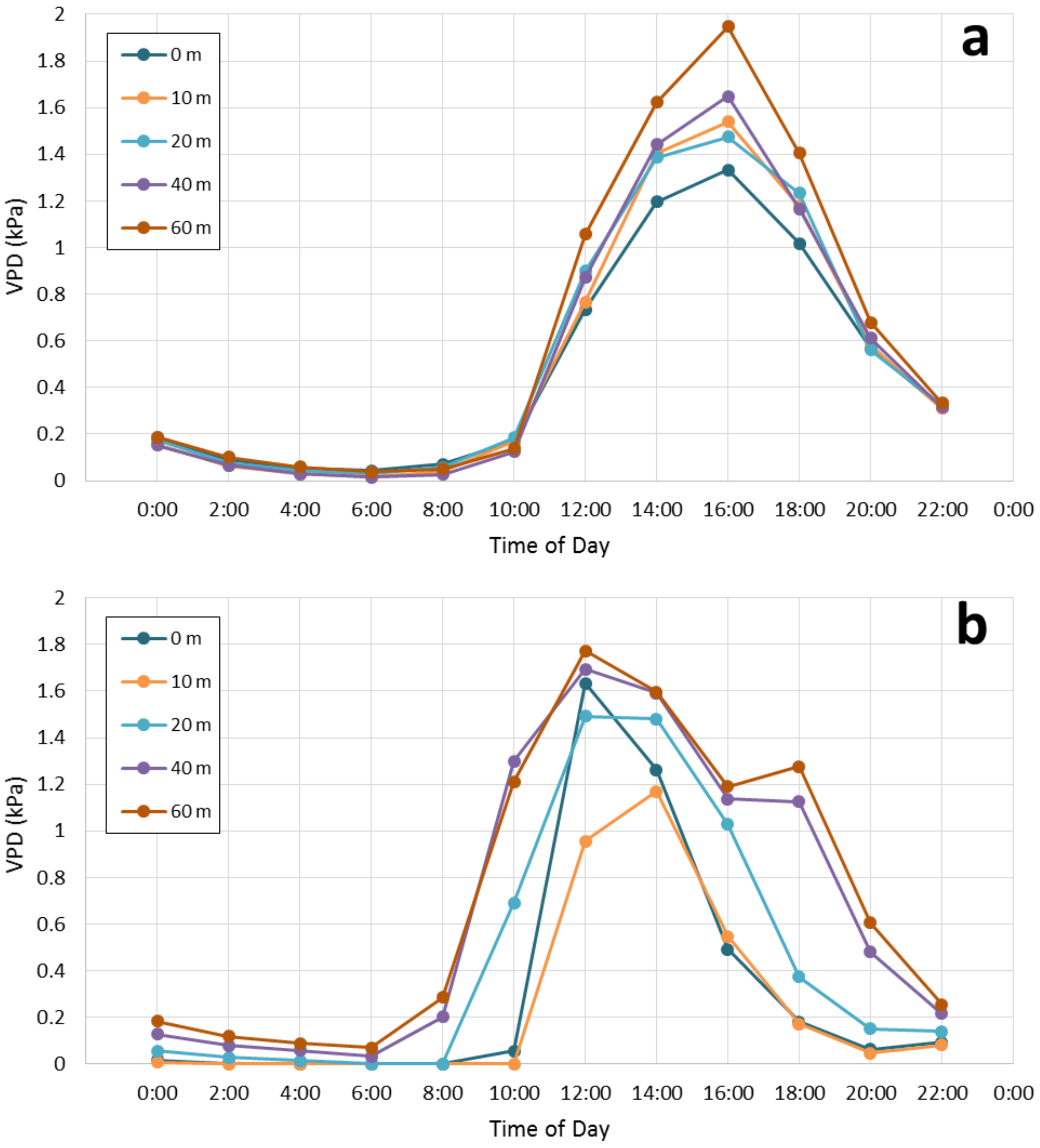


Figure 42. Vapor pressure deficit (VPD) on 2 July 2015, a warm, clear day, for microclimate stations on transects in watersheds 642 (transect D) (a) and 145 (transect A) (b).

Discussion

In order to explain temporal and spatial variations in microclimate metrics, predictive microclimate models will be created using factors such as riparian vegetation, topography, aspect, and elevation.

Given that WADNR's primary concern is the type and extent of riparian management, our future analyses will focus the relationship between microclimate and riparian vegetation. Past scientific reviews of riparian functions in the Pacific Northwest identified microclimate as the function requiring furthest extent of riparian buffers (FEMAT 1993). This resulted in leaving riparian buffers two tree-heights in width on fish bearing streams on federal lands. A recently published review of scientific research on the effects of forest management on riparian microclimate (Reeves et al. 2016) suggests that riparian buffers with widths of one tree-height on fish bearing streams are adequate to substantially reduce potential impacts from adjacent harvesting. This finding is in line with the buffers applied by WADNR to most of Type 3 streams in the OESF: 100-ft (30-m) wide interior-core buffers and, where necessary, additional 80-ft (24-m) wide wind buffers. However, under the OESF Forest Land Plan (WADNR 2016b), WADNR has the management flexibility to vary the width of the interior-core buffers depending on the overall watershed health (for a description of the integrated management approach, refer to the section *Study Area and Study Design*). Despite the sound ecological rationale behind this experimental approach, its effects on habitat are still untested. The ongoing microclimate monitoring will help reduce this uncertainty.

Riparian Vegetation

Stream-adjacent vegetation provides shade, strongly influences riparian microclimate, supplies large wood and leaf litter to streams, and stabilizes stream banks. Riparian forests support a large variety of life forms including riparian-obligate species such as Cope's giant salamander (*Dicamptodon copei)* and coastal tailed frog (*Ascaphus truei*).

Historic timber harvests in riparian zones influenced streams by reducing the recruitment rate and abundance of large wood, producing changes in channel morphology (Keller and Swanson 1979; Bisson et al. 1987), increasing fine sediment delivery to channels (Beschta 1978; Hartman et al. 1996), and influencing riparian zone hydrology through reduced transpiration and water table drawdown (Moore and Wondzel 2005). Prior to the adoption of the state lands HCP (WADNR 1997), WADNR riparian forest management included clearcuts, often extending to the banks of the stream, and replanting. Harvest in the OESF was most intensive between 1970 and 1990. Not all streamside forest was harvested and individual trees or tree patches were sometimes left in the clearcuts.

Large Sitka spruce in riparian area (watershed

Contemporary WADNR management in the OESF designates riparian management zones to protect stream habitat by minimizing the disturbance of unstable channel banks and maintaining forest cover in proximity to streams. The riparian management zone consists of: 1) an interior-core buffer which is adjacent to the stream and is intended to protect and aid restoration of riparian processes and functions, and 2) an exterior wind buffer applied when the probability of windthrow in the interior-core buffer is high. The exterior wind buffer is adjacent to the interior-core buffer and is intended to protect the integrity of the interior-core buffer from loss of riparian function. In addition, interior-core buffers are extended to incorporate potentially unstable slopes or landforms that could deliver in the stream network. Buffer size and configuration vary on a site-specific basis depending on the condition of the watershed in which the stream reaches are located, presence of unstable slopes, and risk of severe endemic windthrow. Implementation of this approach is described in detail in the OESF Forest Land Plan (WADNR 2016b).

In each watershed, riparian vegetation is sampled in two 0.18-ha (0.44-ac) rectangular fixed-area permanent plots located on opposite banks of the sample reach. Each plot extends 60 m (200 ft) away from the stream and is 30 m (100 ft) wide (Figure 4). The overstory vegetation is sampled (tree species, DBH, and whether each tree is alive or dead) for every tree ≥12.5 cm (5 in) DBH on the sample plots. Percent cover of forbs, ferns, low shrubs, and tall shrubs is visually estimated by species on five 4.0-m (13.1-ft) radius circular subplots within each rectangular overstory plot. Canopy cover dynamics are sampled through hemispherical canopy photos taken at 0-, 10-, 20-, 40- and 60-m (0-, 33-, 66-, 131-, and 200-ft) distances from the stream.

Species Composition

The predominant tree species, in terms of number of trees and basal area per acre, was western hemlock, followed by red alder, Sitka spruce, Douglas-fir, western redcedar, and Pacific silver fir (Table 8). In the understory, moss was the most prevalent plant, but among the vascular species, Oregon oxalis, salmonberry, and swordfern had the greatest mean cover (Table 9).

Table 8. Overall mean values for trees per hectare (acre) and basal area per hectare (acre) for overstory trees on 82 plots in 41 watersheds.

Common name	Scientific name	Trees/ha	Basal area (m^2/ha)	Trees/ac	Basal area (ft^2/ac)
Western hemlock	*Tsuga heterophylla*	289.8	30.46	117.3	132.7
Red alder	*Alnus rubra*	106.5	8.24	43.1	35.9
Sitka spruce	*Picea sitchensis*	63.0	8.33	25.5	36.3
Douglas-fir	*Pseudotsuga menziesii*	27.1	5.56	11.0	24.2
Western redcedar	*Thuja plicata*	6.5	1.66	2.6	7.2
Pacific silver fir	*Abies amabilis*	6.2	0.56	2.5	2.4
Bigleaf maple	*Acer macrophyllum*	0.8	0.02	0.3	0.1
Grand fir	*Abies grandis*	0.2	0.04	0.1	0.2
Bitter cherry	*Prunus emarginata*	0.2	0.01	0.1	0.0

Table 9. Mean cover (%) for the most common understory species observed on 4-m-diameter circular plots (n=410) in 41 watersheds.

Common name	Scientific name	Cover (%)
Moss spp.	-	24.7
Oregon oxalis	*Oxalis oregana*	17.9
Salmonberry	*Rubus spectabilis*	13.5
Swordfern	*Polystichum munitum*	9.4
Oval-leaf huckleberry	*Vaccinium ovalifolium*	4.8
Salal	*Gaultheria shallon*	4.4
Deerfern	*Blechnum spicant*	3.9
Piggyback plant	*Tolmiea menziesii*	3.4
Ladyfern	*Athyrium filix-femina*	1.8
Red huckleberry	*Vaccinium parvifolium*	1.5
Fool's huckleberry	*Menziesia ferruginea*	1.3
Stink currant	*Ribes bracteosum*	1.1
Vine maple	*Acer circinatum*	0.9
False lily-of-the-valley	*Maianthemum dilatatum*	0.9
Three-leaved foamflower	*Tiarella trifoliata*	0.8
Grass spp.	-	0.7
Cascara	*Rhamnus purshiana*	0.6
Skunk cabbage	*Lysichitum americanum*	0.6
Devil's club	*Oplopanax horridus*	0.5

Stand Conditions by Watershed

The number of trees per hectare ranged from 211 to 1,111 (85 to 450 trees/ac) (Figure 43). For conifer species, this value ranged from 147 to 986 trees/ha (60 to 399 trees/ac); for hardwood species, it ranged from 0 to 378 trees/ha (0 to 153 trees/ac). Basal area ranged from 25 to 85 m^2/ha (109 to 370 ft^2/ac) (Figure 43). For conifers this value ranged from 20 to 85 m^2/ha (87 to 370 ft^2/ac), and for hardwoods it ranged from 0 to 35 m^2/ha (0 to 153 ft^2/ac).

Stand Conditions by Plot

Values in Figure 43 are presented at the watershed level by combining data from the two plots per watershed, one on either side of the sample reach. Averaging the two plots is a logical approach when estimating the influence of overstory vegetation on the sample reach (e.g., shade and large wood). However, in some watersheds, there is a different management history on either side of the sample reach, and as a result the overstory vegetation is significantly different. For this reason we also summarize overstory vegetation at the plot level (n=82) (Table 10).

Relative density on the 82 plots ranged from 24 to 95, with a mean of 61 (Figure 44). According to OESF riparian management procedures, buffers with relative density ≥35 maintain sufficient stream shade.

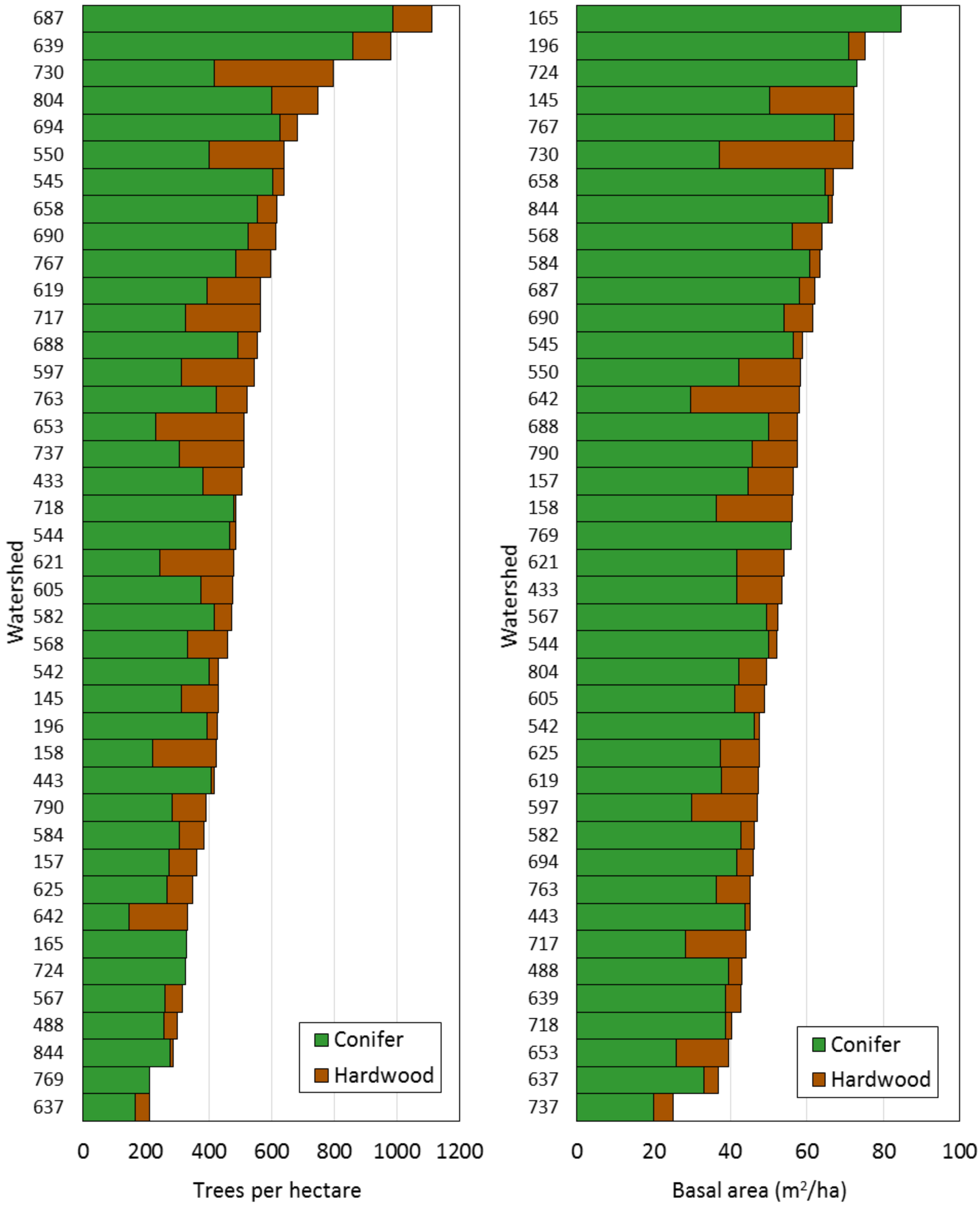


Figure 43. Trees per hectare (left) and basal area per hectare (right) in the riparian overstory sampling plots of the 41 watersheds sampled in the OESF.

Table 10. Plot-level means for riparian overstory stand conditions on 82 riparian vegetation plots (2 in each of 41 watersheds).

Metric	Metric units			English units		
	Overall mean	Standard deviation	Range of plot means	Overall mean	Standard deviation	Range of plot means
	trees/ha			*trees/ac*		
No. trees (all spp.)	500	224	156 – 1,322	202	91	63 – 535
No. trees (conifers)	393	209	78 – 1,083	159	85	32 – 438
No. trees (hardwoods)	108	122	0 – 533	44	49	0 – 216
	cm			*in*		
Tree diameter (all spp.)	38	10	17 – 69	15	4	7 – 28
Tree diameter (conifers)	41	11	20 – 65	16	4	8 – 26
Tree diameter (hardwood)	32	11	15 – 85	13	4	6 – 33
	m^2/ha			*ft^2/ac*		
Basal area (all spp.)	55	16	16 – 97	240	70	70 – 422
Basal area (conifer)	47	19	7 – 96	205	83	30 – 418
Basal area (hardwood)	8	10	0 – 46	35	44	0 – 200
	%					
Percentage hardwood (based on tree count)	21	21	0 – 83	21	21	0 – 83
Percentage basal area hardwood	16	19	0 – 66	16	19	0 – 66

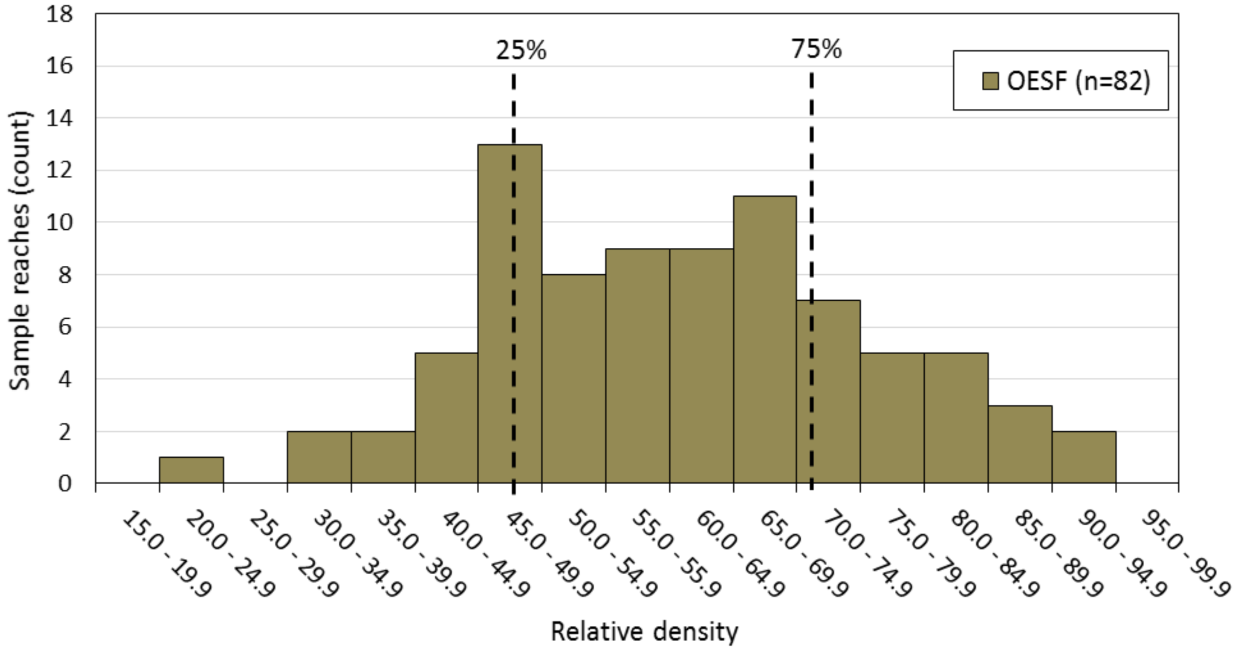


Figure 44. Distribution of overstory relative density values for 82 plots located in 41 OESF watersheds.

Discussion

In general, the forest along the sample reaches consisted of well-stocked stands dominated by conifers. The hardwood component, which was 21% of the stems and 16% of the basal area, was comprised mainly of red alder. Red alder in many of the riparian areas is showing signs of natural age-related senescence, with branches and tops dying. The variation in forest conditions across the sample plots, evident in Figures 43 and 44, reflects the diverse disturbance history of the OESF and the influences of the streams.

A feasibility study was conducted in 2015 to assess the use of aerial photo interpretation to characterize the harvest history on both sides of the 50 OESF sample reaches and the reference reaches (e.g., for the 50 OESF reaches, both banks were analyzed for a total of 100 sample reach banks). Preliminary results indicate that 17% of the sample reach banks had never been harvested within 100 m of the stream. Eight percent of the sample reach banks had patches of 10- to 20-m wide buffers over at least 50% of the reach length. The remaining 75% of sample reach banks were previously clear-cut harvested. In the future, these characterizations will be further validated using remotely sensed inventories. Data from the permanent vegetation plots in this study will be used to validate the remote sensing inventory data and allow documentation of stand dynamics including understory development, recruitment of future overstory trees, and down wood recruitment.

After riparian vegetation data collection is completed in 2016, spatial patterns in overstory and understory vegetation (e.g., distance from stream) in the sample plots will be analyzed. A number of ecological relationships, such the influence of forest condition on riparian microclimate, will be investigated at that point.

Future analysis using the recently available LiDAR-derived forest inventory data will provide information on past harvest activity in each monitored watershed, within the riparian zone and in upland areas. This will allow assessment of the influence of watershed-wide disturbances and forest succession on stream habitat conditions.

Watershed-level Summaries

The habitat conditions in streams depend on the geophysical and ecological features of their watersheds (e.g., topography, geology, and plant associations), the ecological processes that operate throughout the watersheds (e.g., hillslope erosion and forest succession), as well as natural disturbance events (e.g., wind throw) and management activities (e.g., timber harvest and road construction) (FEMAT 1993, Naiman 1992).

In order to interpret the habitat data collected at our sample reaches, we need to know the watersheds' geophysical characteristics, land use designations, land cover, and past and ongoing management activities and natural disturbances. A brief characterization of each watershed is presented in a tabular format in Appendix 3. The following graphical summaries and explanations clarify and provide additional detail to the appendix table. The purpose is to give an initial picture of the monitored watersheds; analyses of the watershed-wide conditions and their influence on stream and riparian habitat at the reach level will follow at a later stage of the project.

The information below comes from remote sensing data and operational records. The data sources are described in Appendix 4.

Land use allocation

The integrated management approach in the OESF doesn't imply that every acre of land must contribute equally to both revenue projection and ecological values (WADNR 2016b). Some areas have been deferred (removed from active management) permanently, such as Natural Resources Conservation Areas and Natural Area Preserves. Other areas have been deferred per WADNR policies (e.g., old-growth forests) or per current management guidance (e.g., marbled murrelet habitat). Yet other areas, such as riparian and unstable slopes, although not deferred, are subject to management only after certain field or office assessments.

Figure 45 illustrates the proportion of each monitored watershed that is currently deferred per various WADNR policies, procedures, and management guidance. The major land designations in the deferral category include marbled murrelet habitat, spotted owl habitat, old-growth forest, wetlands, research plots, and Natural Resources Conservation Areas and Natural Area Preserves. Riparian areas and modeled unstable slopes are not included in the deferral category. Parts of such areas can be managed after geological assessment and/or review of allotted riparian acres per procedure PR-14-004-160 (WADNR 2016b).

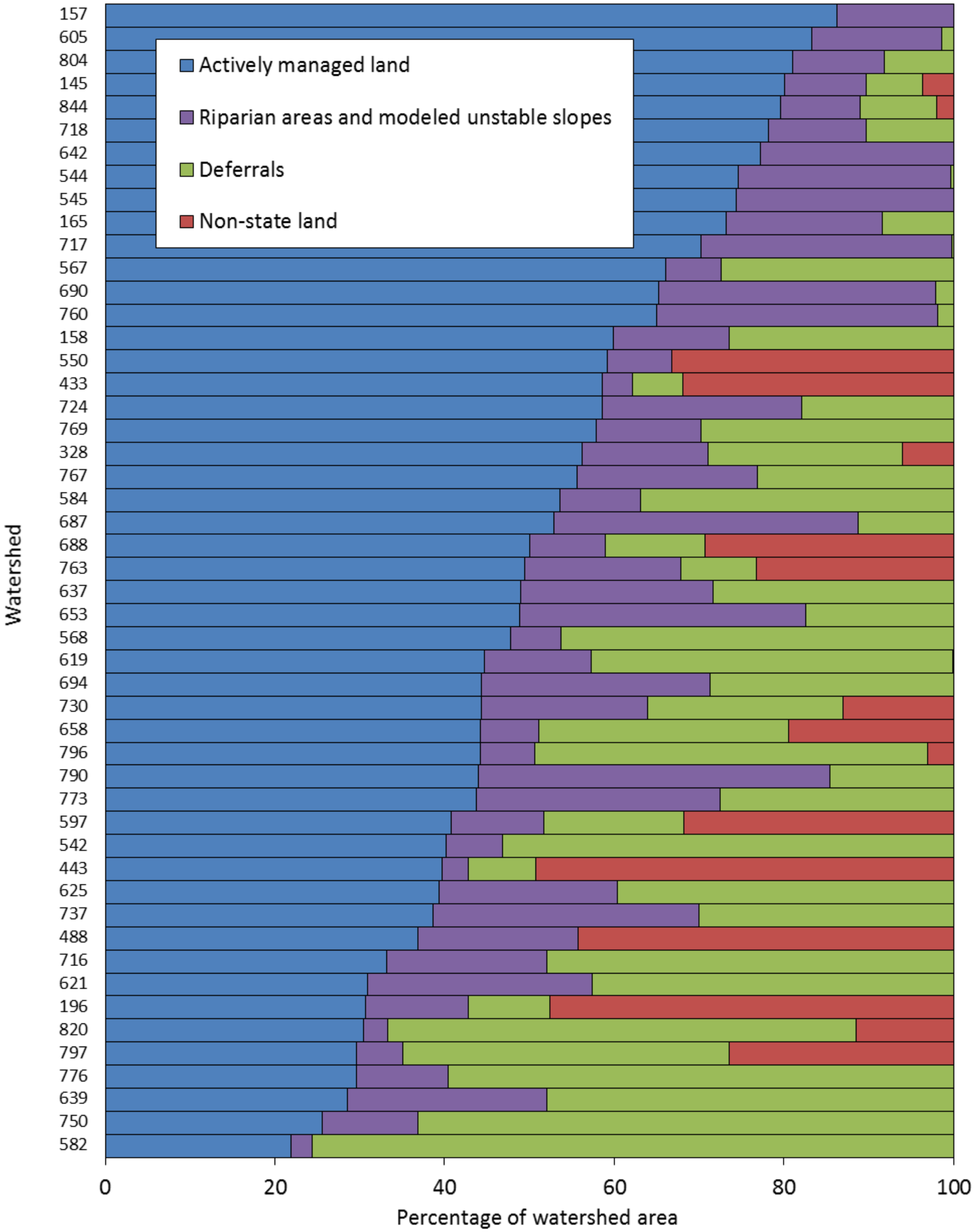


Figure 45. Allocation of WADNR land in the monitoring watersheds to actively managed land, riparian areas and modeled unstable slopes, deferrals (any type), and non-state land.

Planned timber harvest

The primary harvest methods used in the OESF are variable retention harvest (a type of regeneration, or stand-replacement harvest in which key structural elements of the existing stand are maintained while the commercial forest stand cohort is re-initiated) and variable density thinning (a non-uniform commercial thinning which is usually used to accelerate stand development).

Figure 46 shows the proportion of monitoring watersheds projected to be harvested under each method for the decade 2011-2021 (WADNR 2016a). This projection was produced by a forest estate model for the purpose of environmental impact analysis for the OESF Forest Land Plan. It is not the exact harvest schedule that will be implemented on the ground but rather an optimal model solution for balancing multiple objectives across the landscape. The foresters use the model output as a starting point for selecting areas to harvest. As they verify the actual, on-the-ground conditions, they may adjust the harvest units and methods, and therefore the numbers reported in these figure are expected to change.

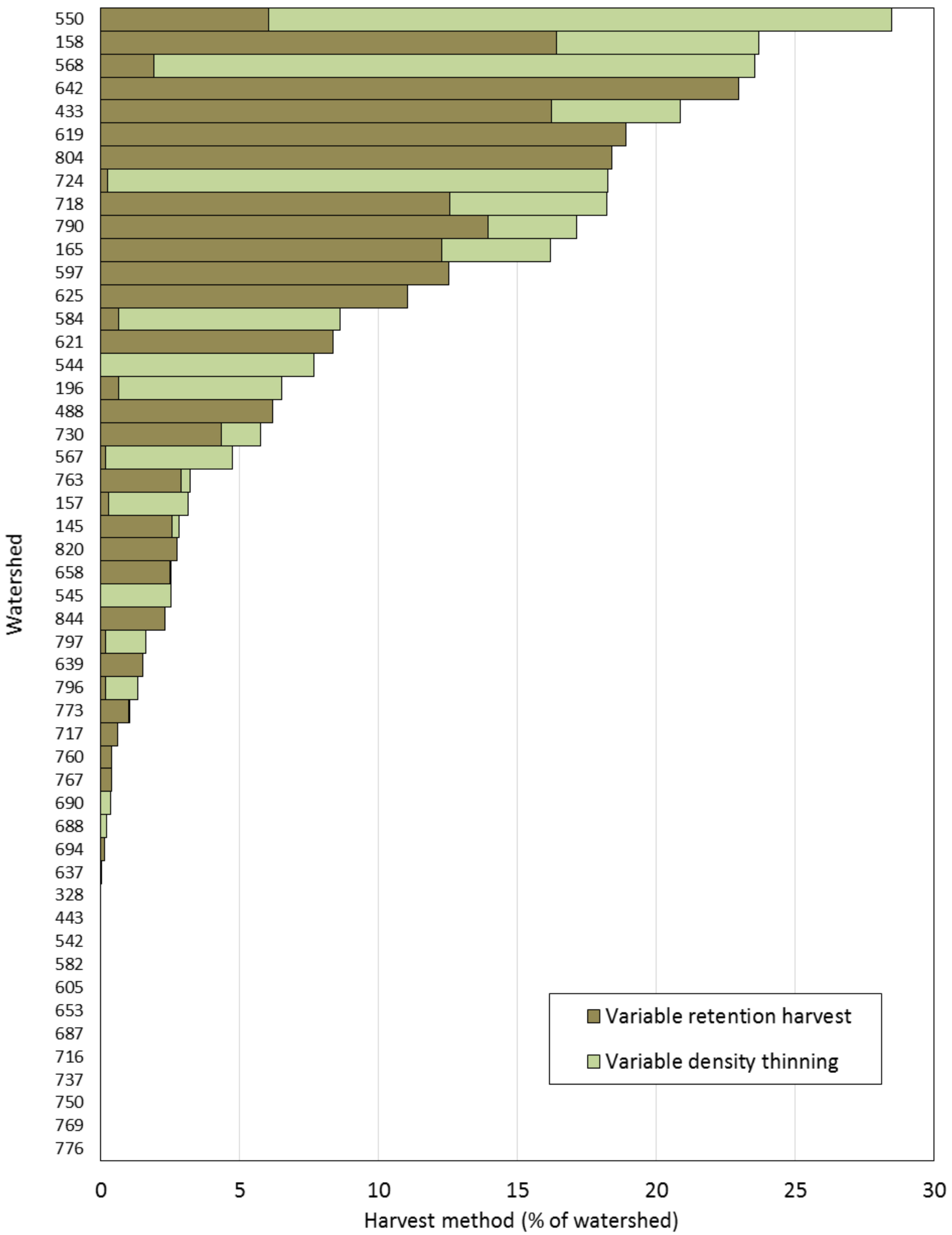


Figure 46. Decadal forest harvest, as a percentage of WADNR land in each monitoring watershed, modeled for the period 2011-2021.

Density and location of roads

Road building, management, and use are substantial elements of forest management in the OESF. As evident from Figure 47, WADNR maintains a dense network of roads in most of the monitored watersheds. The type of road surface, the proximity of the roads to streams, the number of stream crossings, and the intensity and timing of road use (primarily to haul timber) were used as indicators of potential environmental impacts in the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016a). The same variables will likely be used in future analyses, for example for interpreting percent fines and substrate embeddedness in the sample reaches.

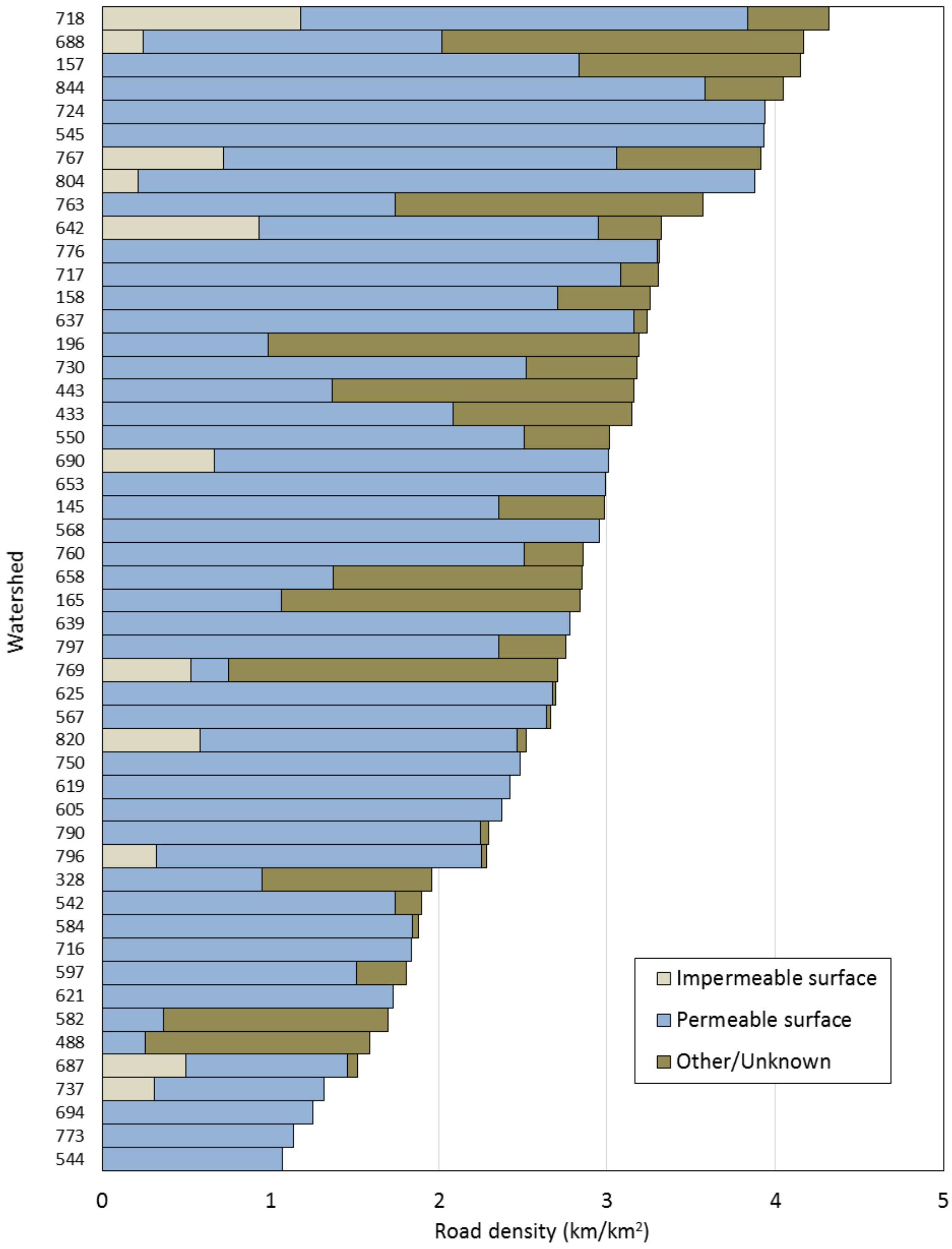


Figure 47. Road density in each monitoring watershed, by surface type.

Figure 48 shows the density of roads within three riparian zones based on distance from stream (0-20, 20-40, and 40-60 m). These zones were used in the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016a).

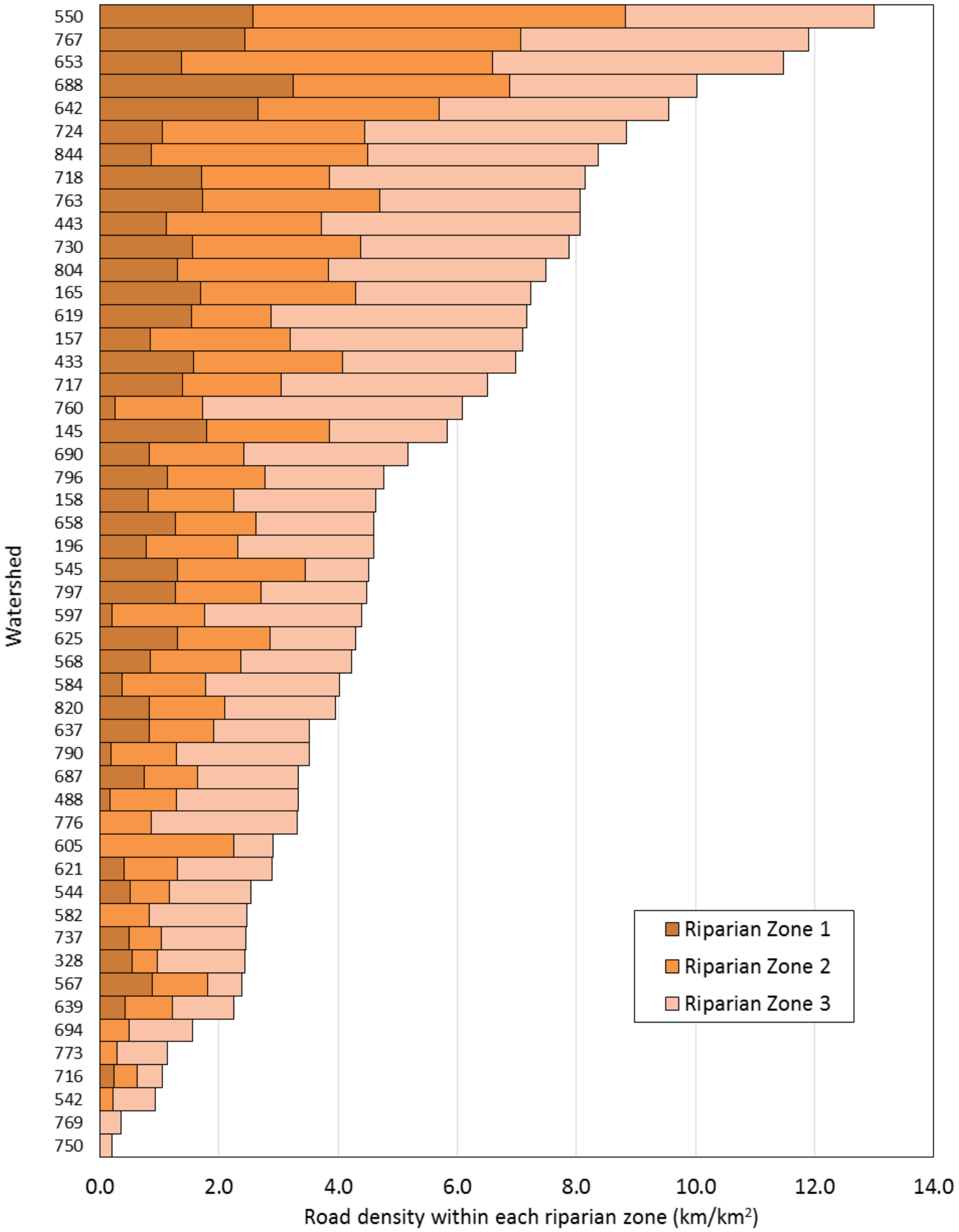


Figure 48. Road density in three zones, based on distance from stream: Zone 1 (less than 20 m from a stream), Zone 2 (20 to 40 m from a stream), and Zone 3 (40 to 60 m from a stream).

Extent and density of stream network

The sample reach in each monitoring watershed is located on a Type 3 stream at the watershed outlet (Figure 2). The extent of the currently mapped stream network above each sample reach is summarized in Figure 49. Type 4 streams are non-fish bearing streams that have a defined channel with a minimum 2-ft width and a gradient of 20 percent or greater. Type 5 streams are non-fish bearing streams that are less than 2 ft wide and may be headwaters of streams, seeps or wet areas.

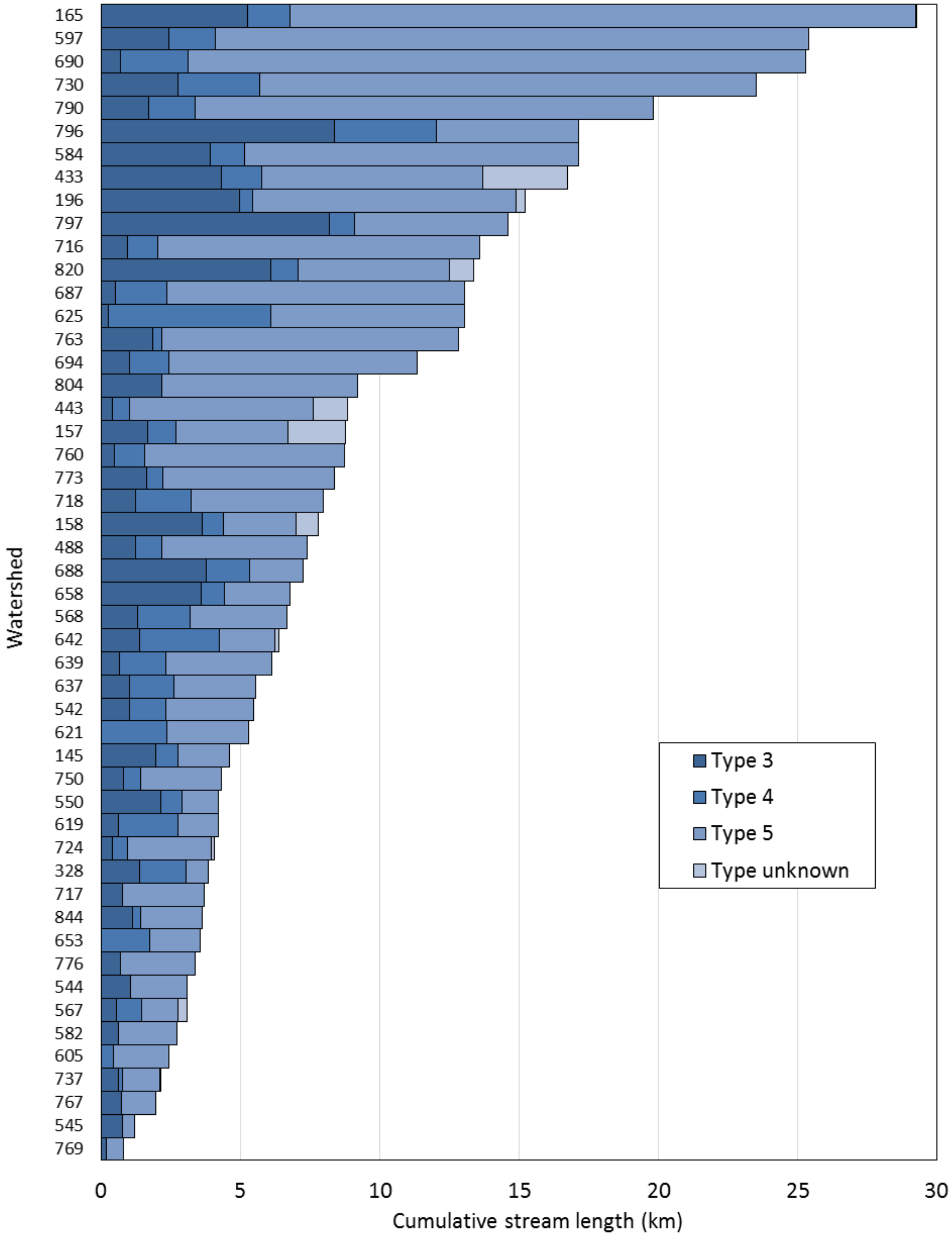


Figure 49. Cumulative stream length, by type, in each monitoring watershed.

The density of the stream network, illustrated on Figure 50, ranges from 1.0 to 8.5 km/km^2 across the 50 monitoring watersheds, with mean of 4.6 km/km^2. WADNR has identified problems with the corporate data source for this summary, with streams being mistyped or missing. Most of the unmapped streams are Type 4 (S. Horton, pers. communication). The agency is developing a new, more accurate GIS stream coverage (called Synthetic Stream Model) which uses LiDAR data. Once completed, it will be used in this project.

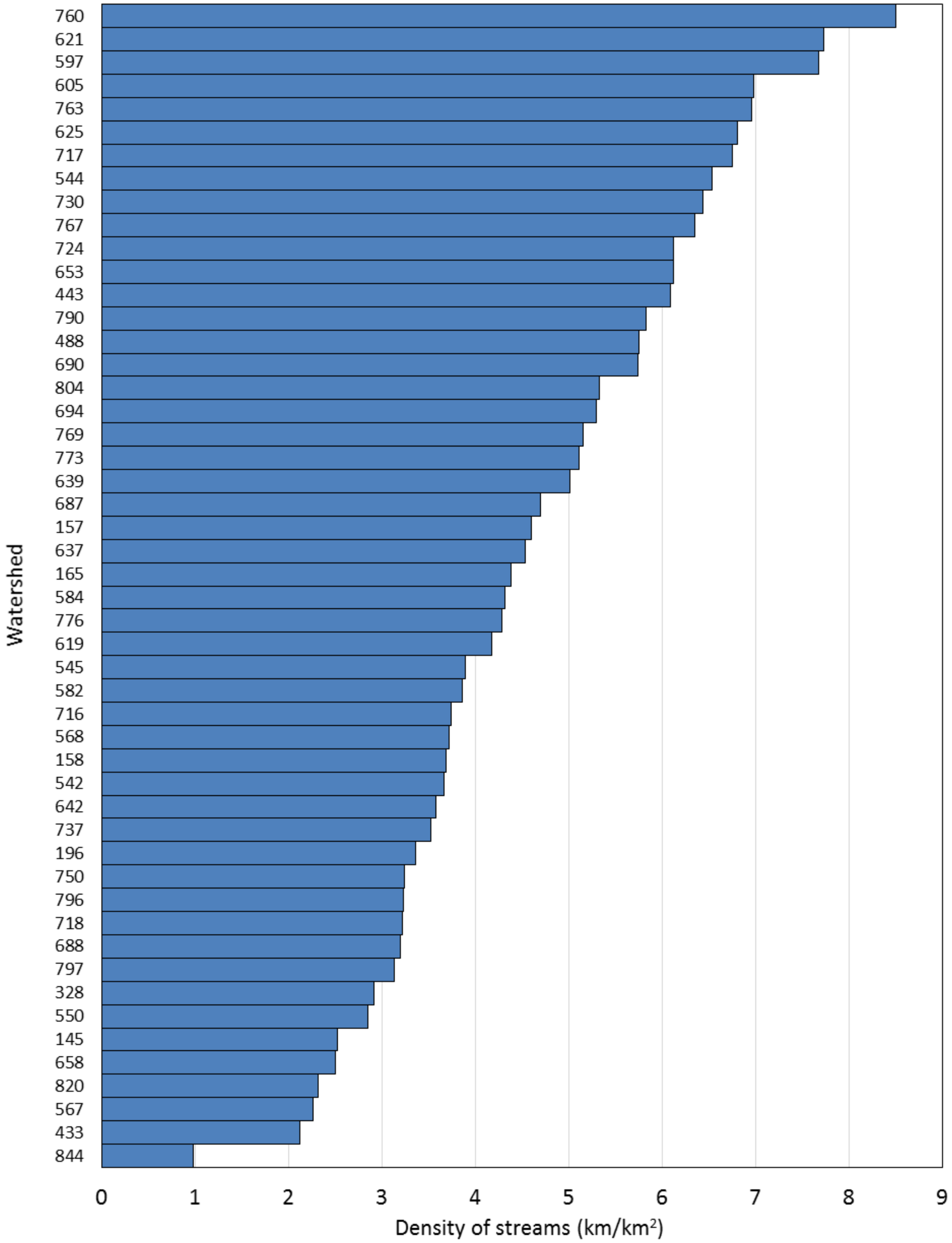


Figure 50. Stream density (all types) in each monitoring watershed.

Hydrologic maturity

Forested stands are identified as hydrologically mature when they meet the criteria for age 25 years or greater and relative density (RD) 25 or greater (WADNR 2016a). The proportion of hydrologically mature stands per Type 3 watershed was used in the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016a) to assess the potential impacts of peak flows. We will likely include this watershed-level characteristic as a covariate in the analysis of the hydrology monitoring data.

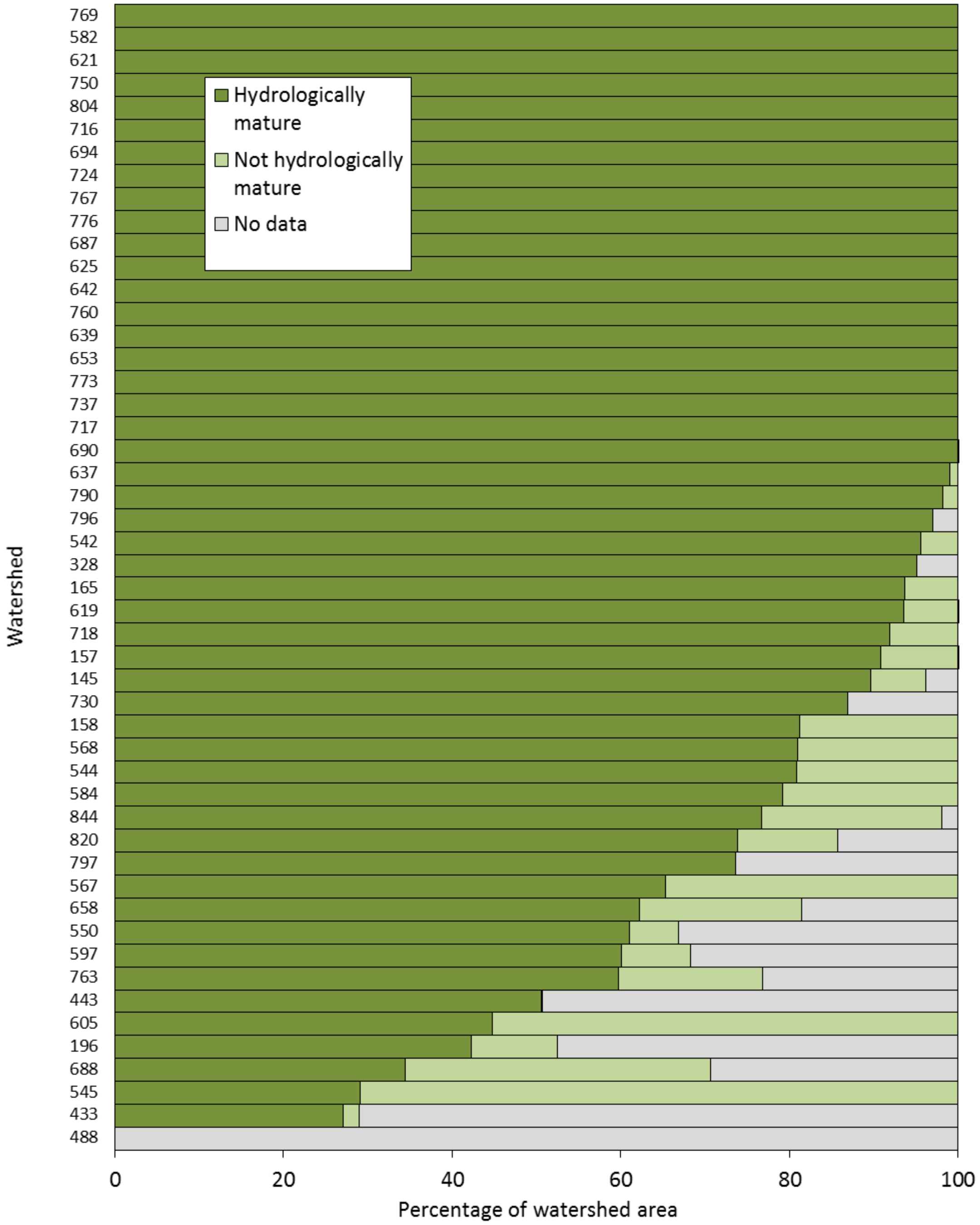


Figure 51. Percentage of WADNR land in hydrologically mature forest cover in each monitoring watershed. The category "No data" includes non-state lands and state lands without inventory data.

Conclusions

The results reported here document the current status of aquatic and riparian habitat in 50 Type 3 watersheds, selected to be representative of the Type 3 watersheds across the OESF, and the habitat status of four Type 3 watersheds in the Olympic National Park (reference sites), selected to have biophysical conditions similar to the OESF sites and to be reasonably accessible.

The main challenge in answering the question “How good is salmonid habitat in the sampled watersheds?” is the lack of robust numerical standards, habitat thresholds, or desired future conditions against which to compare these results. Riparian conservation objectives for the OESF are to maintain and restore the physical integrity of stream channels, flow regimes, sediment regimes and composition, function, and structure of aquatic, riparian, and wetland systems in the context of conserving “habitat complexity as afforded by natural disturbance regimes on the western Olympic Peninsula” (WADNR 1997, p. IV.107). In the absence of specific numerical targets for each of our metrics, our assessment of habitat status used three complementary comparisons to assess the OESF sample reaches: 1) reference reaches 2) regional studies in unmanaged forests, and 3) the habitat thresholds described in the Forest Practices Watershed Analysis Manual (WADNR 2011) and in Washington Department of Ecology Water Quality Standards (WADOE 2016).

For all reported metrics of stream physical habitat, the values for the OESF sample reaches encompass those of the four reference reaches in the Olympic National Park. While this is an encouraging sign, we do not know how well the four reference reaches represent unmanaged reaches.

The comparison of the OESF sample reaches to results of regional studies quantifying stream habitat in unmanaged forests was done using six metrics: percent fines, frequency of in-stream large wood, volume of in-stream large wood, pool frequency, and residual pool depth. All metrics for the OESF sample reaches showed values comparable to the regional studies.

The comparison of the OESF sample reaches to the thresholds for habitat quality described in the Forest Practices Watershed Analysis Manual (WADNR 2011) was done using five metrics: percent fines, frequency of in-stream large wood, pool frequency, and the percentage of stream surface area. The proportion of the OESF sample reaches in the “good”, “fair” or “poor” habitat quality category varied by metric. When OESF sample reaches fell in the “poor” habitat quality category, they were always accompanied by one or more of the reference reaches. The fact that even the unmanaged reference reaches fell in the “poor” habitat quality category underscores the challenge of creating a set of threshold values to apply across a diverse range of stream sizes and types and a large geographic area (i.e., western Washington).

The analyzed stream temperature metric 7-DADmax was below the 16°C WADOE (2016) thresholds in all OESF sample reaches in 2013, and in 97% of the OESF sample reaches in 2014, and in 80% of the OESF sample reaches in 2015. The increasing trend over time was consistent with summer air temperatures and was also observed in the stream temperatures of the reference reaches.

All these comparative analyses suggest two conclusions about the current status of in-stream habitat quality in the OESF sample reaches: 1) the 50 sample reaches represent a broad range of habitat conditions, and 2) overall, the sample reaches appear to have relatively good habitat quality.

The study plan for this project (Minkova et al. 2012) hypothesized that the current habitat conditions across the OESF were within a relatively narrow range and occurred towards the degraded end of the habitat quality spectrum (the brown distribution in Figure 52). The expectation was that, over time, the distribution would widen and shift towards improved conditions, i.e., towards the historic range of variability (the yellow distribution in Figure 52). However, the distributions presented in the results section of this report resemble more the latter distribution, a broader range of habitat conditions than expected. Questions remain whether habitat is continuing to improve; this should be answered through long-term monitoring.

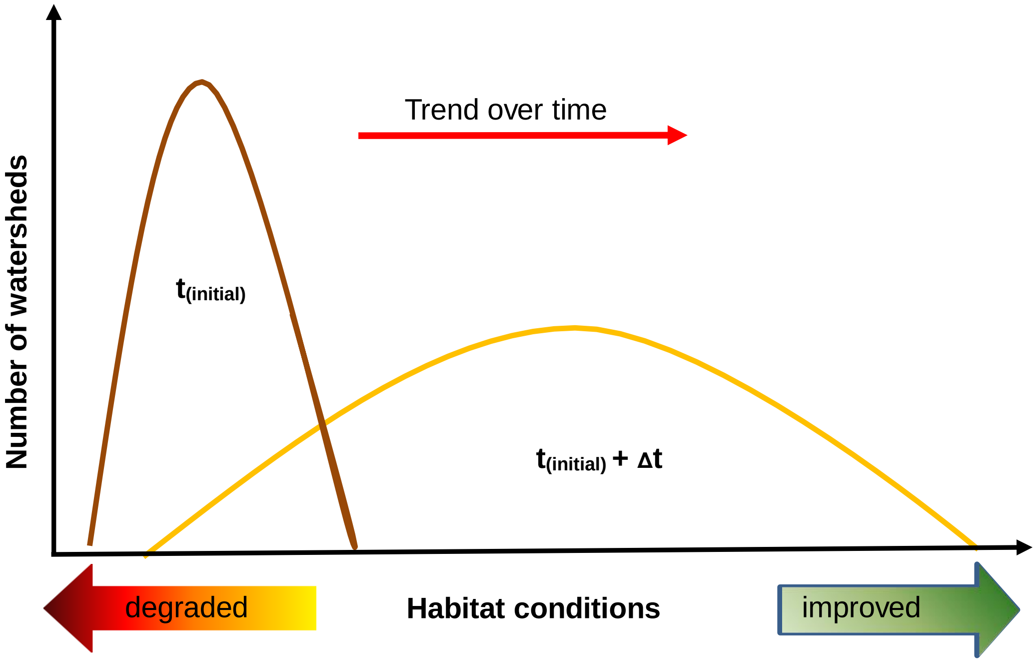


Figure 52. Conceptual model of the expected change in the range of habitat conditions across the monitored watersheds, as presented in the project study plan (Minkova et al. 2012). Brown – hypothesized current distribution of habitat conditions; yellow – expected future distribution of habitat conditions.

At the beginning of this status report, we discussed several inherent challenges when interpreting the habitat status results, such as uncertainties of how well the four reference reaches represent unmanaged systems and whether the existing regulatory standards for stream habitat are accurate for this area. Following are several additional considerations pertinent to our conclusions:

Because our sample consists of Type 3 watersheds selected to be representative of the OESF, our scope of inference is limited to Type 3 watersheds across the OESF. Therefore, although the streams of the Type 3 watersheds influence the larger streams in the OESF, we cannot directly apply our findings to larger water courses. These larger streams may retain indications of historic management disturbances longer than the Type 3 streams because, as a result of their low gradient, they increasingly function as deposition (response) and not transport reaches (Montgomery and Buffington 1993).

The ultimate indicator for habitat quality will be the habitat use and population dynamics of fish. The goal of the state lands HCP riparian conservation strategy (WADNR 1997) is to provide habitat that supports viable salmonid populations. Riparian validation monitoring (i.e., monitoring fish response to habitat change), which started in 2015, is expected to provide this information. The first project report is expected in 2017.

Climate change brings into question our ability to define the historic range of variability and/or the validity of using it as a conservation target. This may affect our comparisons with thresholds that were based on an historic range of variability. Examples of this include stream flow return periods (the time interval at which an event, such as channel-forming flow, can be expected to occur once, on average) and summer maximum stream temperature thresholds. Continuing to monitor reference sites will help with this potentially moving target and with parsing out climate trends and natural disturbances from management effects.

With repeated monitoring visits, we will be able to compare the distribution of habitat conditions across the OESF at different points in time and draw conclusions as to whether conditions are maintained, improving, or degrading. More information about this future trend analysis is presented in the following section.

Detecting Post-HCP Habitat Change over Time

A key question at this stage of the project is: How soon will WADNR be able to detect changes in aquatic and riparian habitat conditions across the OESF?

The short answer is: It will take at least 5-10 years before we are able to report any reliable trends and the time will depend on the variance of the habitat metrics (temporal, spatial, measurement error, etc.). For less variable metrics, we can detect and report trends sooner than for more variable ones. Overall, the reliability of the reported trends will increase with more years of monitoring. Below, we discuss the complexities involved and present an analytical approach we will use to estimate how soon we can expect to detect trends.

Slow rate of environmental recovery

We expect that the overall rate of habitat recovery in the monitored watersheds during the next several years will be slow because it is happening approximately two to four decades after the intensive and extensive timber harvesting that took place in the OESF in the 1960s-1980s. We now hypothesize that the initial fast-paced recovery of riparian and aquatic habitat, following the adoption of the HCP conservation measures in 1997, has already taken place in these watersheds. The timber harvest and road management practices currently implemented under the state lands HCP are thought to have a relatively small ecological footprint because of their extent and the implemented conservation measures. WADNR has been harvesting only about 0.5% of the OESF (about 1,400 ac) per year since the adoption of the HCP (source: WADNR Planning and Tracking

Database) and the harvest practices include leave areas such as riparian buffers and unstable slopes, leave trees, maintenance of watershed hydrologic maturity, and thinnings. In short, the rate of environmental recovery in the monitored watersheds is expected to have slowed, which increases the time that it will take to detect small changes (Bisson et al. 1997, Larsen et al. 2004, Roni et al. 2005).

The effect of environmental variability

The variability of the habitat attributes over space and time has a major effect on detecting trends. In habitat monitoring programs designed similarly to ours, the variance of each of the monitored habitat metrics can be divided into components attributed to: site (i.e., spatial variance), year (i.e., temporal variance), the site-year interaction, and residual variance (i.e., unexplained variance including measurement error) (Larsen et al. 2004). Because we currently have completed only one measurement at each sample reach, we can only calculate spatial and residual variance at this point. The 2015 quality control analysis (Devine and Minkova 2016) quantified these variance components using a sample of 5 of the 50 OESF sample reaches. Temporal variance can be calculated once we have repeated our measurements in each sample reach.

To demonstrate the influence of spatial variability on the time to detect change, we conducted a power analysis and presented the results for several of our metrics as a relationship between mean annual change and the length of time it would take to detect a trend at that rate of change (Figure 53). The example shows that it will take less time to detect a trend in stream shade than in the size of the channel substrate because stream shade had a smaller variance.

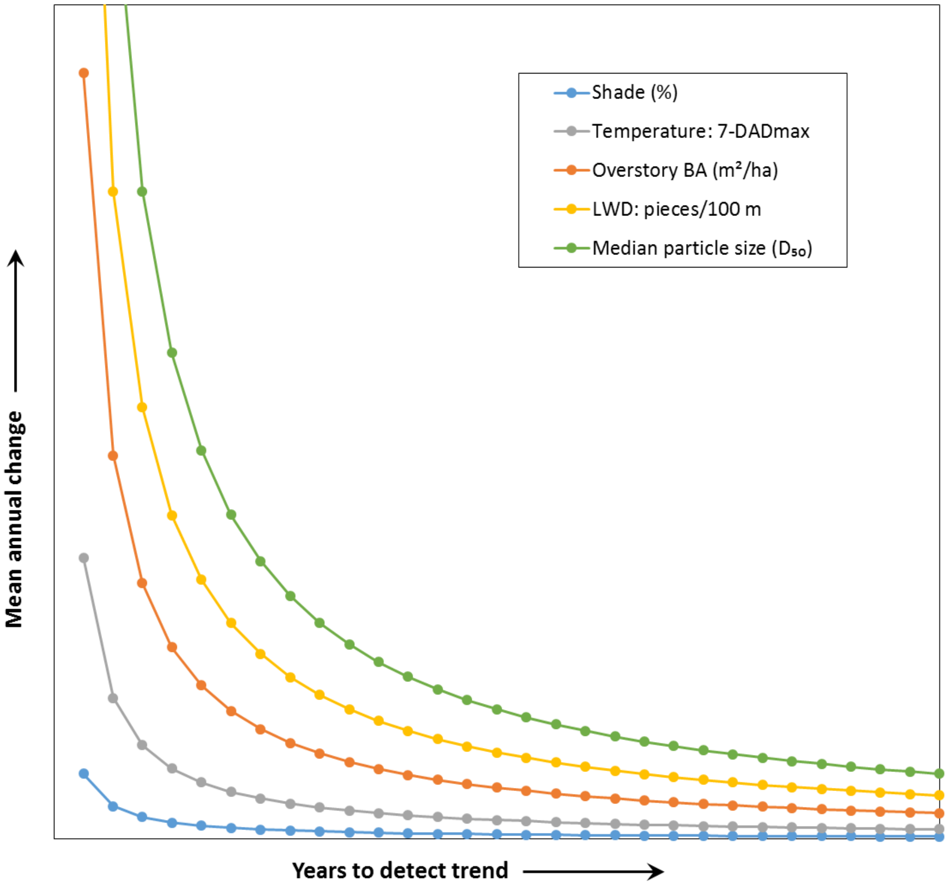


Figure 53. Hypothetical relationships between mean annual rate of change and the length of time required to detect change for five metrics. Because we have not yet measured temporal variance in this study, spatial variance was used to create this illustrative example.

In an analysis of stream habitat data from Oregon and Washington in which sample size, statistical power, and significance level were identical to that in the present study, and all sources of variability (spatial, temporal, interaction, and residual) were accounted for, the number of years to detect a 1% mean annual change ranged from 13 for canopy cover to 27 for large wood (Larsen et al. 2004). Residual pool depth and fine sediment could be detected after 20 and 21 years, respectively. Assuming a 2% mean annual change, the same study found that the number of years to detect a trend ranged from 8 for canopy cover to 17 for large wood. However, the big assumption here is unidirectional change and constant inter-annual change. Localized disturbances such as landslides and wind throw, and large-scale disturbances such as catastrophic wind and fire, can have major effects on these projections.

Value of the Monitoring Data

- Despite the sound ecological rationale behind the integrated management approach, it is considered experimental because its effects on habitat are still untested. The habitat metrics from WADNR-managed and ONP reference watersheds presented in this report already lend confidence to the general applicability of the HCP riparian conservation strategy. Continuous habitat monitoring in these watersheds will further reduce the uncertainties.
- Many ecological relationships within the riparian and aquatic systems are reasonably well understood at a qualitative level but are not quantified. For example, the relationships between riparian vegetation and microclimate. The combination of geomorphology, hydrology, and ecology data collected in this study will allow us to quantify a number of ecological interactions. The results will help land management planning and implementation.
- Small catchments are poorly represented within the federal and state hydrology monitoring networks. Therefore the 14 gaged sites monitored in this project have broader significance.
- Long-term environmental monitoring is repeatedly identified by land managers and environmental regulators as high priority for tracking and understanding the effects of climate change. This study is well suited to do this. For example, stream temperature data, currently being fed into regional databases like the multi-agency NorWeST network, provide for higher precision of on-going climate modeling efforts.
- This riparian monitoring program provides valuable characterizations useful for corollary research by WADNR and other entities such as the PNW Research Station, U.S. Geological Survey, and the University of Washington, among others.

Next Steps

In addition of the ongoing tasks of field training, downloading data loggers, data management, and reporting, in 2016, the project team will focus on the following:

- Communicating habitat status data with interested parties: WADNR stakeholders, local land managers, research organizations, etc.
- Seeking collaboration with potential research partners to analyze available monitoring data, add new research and monitoring modules, and to better utilize the educational opportunities of this project.
- Second round of stream surveys in all 54 monitored sites;
- Finishing the riparian vegetation and stream shade sampling in the sites not sampled in 2014 and 2015;
- Field visits to the 14 gage sites to measure water velocity and water levels at various flows, focusing on high-discharge events;
- Developing hydrographs for the streams with reliable rating curves;
- Finalizing and publishing all field protocols;
- Identifying additional metrics for the time series data (stream temperature, hydrology and microclimate) using two main criteria: 1) metrics that are informative for our monitoring objectives, and 2) metrics comparable with those of other regional studies;
- Exploring available remote sensing data (LiDAR, aerial photos, satellite imagery) for characterization of habitat attributes at the sample reaches and in entire watersheds;
- Exploring available operational records and remote sensing data for characterization of management and natural disturbances in the monitored watersheds;
- Initial analyses of ecological relationships among various streams and watershed-level monitoring data.

Glossary of Terms

Adapted from Armantrout 1998 unless otherwise indicated.

Active channel – Short-term geomorphic feature, defined by the bank break that marks a change to permanent vegetation.

Bankfull depth – Depth of water measured from the surface to the channel bottom when the water surface is even with the top of the streambank.

Bankfull stage – Bankfull stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in stream bank slope, perennial vegetation limit, rock discoloration, and root exposure.

Bankfull width – Channel width between the tops of the most pronounced banks on either side of a stream reach.

Canopy – The continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth.

Channel confinement – The degree to which stream channel migration is limited in its lateral movement by valley walls or relic terraces. It is expressed as the ratio of the width of the floodplain to the channel's bankfull width.

D_{50} – Median particle size of a distribution.

Diameter at breast height (DBH) – The diameter of a tree, measured 1.37 m (4.5 ft) above the ground on the uphill side of the tree.

Diel – Pertaining to a 24-hour period or a regular occurrence in every 24-hour period.

Discharge – Rate at which a volume of water flows past a point per unit of time.

Fines – Particulate material less than 2 mm in diameter, including sand, silt, clay, and fine organic material.

100-year floodplain – Area adjoining a water body that becomes inundated during periods of overbank flooding that happens an average of once every 100 years.

Gaging station – Particular location on a stream, canal, lake, or reservoir where systematic measurements of streamflow or quantity of water are made.

Geographic information system (GIS) – A computer system that stores and manipulates spatial data, and can produce a variety of maps and analyses.

Habitat attribute– Single element of the habitat or area (such as stream temperature or pools) where an organism lives or occurs (synonymous with *habitat component).*

Habitat metric– Quantitative characteristics that describes the biological, chemical, and physical components of ecosystem (for example mean daily stream temperature or residual pool depth) (synonymous with *habitat parameter and habitat variable*). A variety of metrics can be derived from original measurements.

In-stream large wood (large woody debris) – Wood in the active channel with pieces larger than 10 cm in diameter and 2 m in length.

Log jam or *jam* – Wholly or partially submerged accumulation of woody debris from winds, water currents, or logging activities that partially or completely blocks a stream channel and obstructs streamflow.

Monitored Watersheds – For this project, the drainage around the smallest fish-bearing (Type 3) stream identified for sampling through GIS and subsequent field reconnaissance.

Outlet – Terminus or mouth of a stream where if flows into a larger water body.

Riparian zone – A narrow band of moist soils and distinctive vegetation along the banks of lakes, rivers, and streams.

Sample Reach – A portion of a stream where field sampling takes place.

Signal-to-Noise Ratio – The ratio of the variation in a measured parameter (“signal”) to the variation in that parameter among repeated measurements (“noise”) (Kaufman et al. 1999).

Sinuosity – An index (K) of a stream’s meander as a function of stream length. In this project, channel sinuosity is calculated as the ratio of sample reach length measured along the thalweg (using a reel tape) to the straight-line distance between the beginning and the end of the sample reach (measured with resource-grade GPS).

Thalweg – Path of a stream that follows the deepest part of the channel.

Type 3 Watershed – The drainage around the smallest fish-bearing (Type 3) stream (WADNR 1997).

Type 3 Stream – smallest fish-bearing stream as identified through biological criterion (fish presence) or through physical criteria (a stream $\geq$ 2 ft (0.7 m) wide and $\leq$16% gradient for watersheds up to 50 ac (20 ha) or with a gradient between 16% and 20% for watersheds larger than 50 ac). Type 3 streams can be considered loosely equivalent to Strahler’s 3rd order streams (WADNR 1997).

Wetted width – Width of a water surface measured perpendicular to the direction of flow at a specific discharge. Widths of multiple channels are summed to represent the total wetted width.

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Appendix 1. Completed Field Protocols

Watershed #	*Permanent Cross Sections*	*Elevation Reference Points*	*Channel Gradient*	*Channel Width and Depth*	*Channel Coarse Substrate*	*Channel Azimuths*	*Stream Shade (first year)*	*Channel Sinuosity*	*In-stream Large Wood*	*Classification of Habitat Units*	*Channel & Valley Type*	*Active Erosion*	*Stream Temp.*	*Stream Discharge*	*Photo Station*	*Microclimate*	*Riparian Vegetation*
145	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	2013	2013	2013	2014
157	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	▨	2013	2013	2014
158	2014	**2015**	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013	▨	2014	▨	**2015**
165	2013	2014	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	2013	2013	▨	**2015**
196	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	2013	2013	2013	2014
328	2013	2013	2014	2014	2014	2014	2014	2013	2014	2014	2014	2014	2013	2013	2013	▨	
433	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	2013	2013	2013	2014
443	2013	**2015**	2014	2014	2014	2014	2014	2013	2014	2014	2014	2014	2013	▨	2013	▨	**2015**
488	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013	▨	2014	▨	**2015**
542	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013	▨	2014	▨	**2015**
544	2 013	**2015**	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	2013	2013	▨	**2015**
545	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	▨	2013	2013	2014
550	2013	2013	2014	2014	2014	2014	2014	2013	2014	2014	2014	2014	2013	▨	2013	▨	**2015**
567	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013	▨	2014	▨	**2015**
568	2013	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013	▨	2013	▨	**2015**
582	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013	▨	2013	▨	**2015**
584	2013	**2015**	2014	2014	2014	2014	**2015**	2014	2014	2014	2014	2014	2013	2013	2013	▨	**2015**
597	2014	2013	2014	2014	2014	2014	**2015**	2014	2014	2014	2014	2014	2013	▨	2014	▨	**2015**
605	2014	2013	2014	2014	2014	2014		2014	**2015**	**2015**	**2015**	**2015**	2013	▨	2014	▨	**2015**
619	2014	2013	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013	▨	2014	▨	**2015**
621	2014	2013	2014	2014	2014	2014	2014	**2015**	2014	2014	2014	2014	2013	▨	2014	▨	**2015**
625	2014	2013	2014	2014	2014	2014	2014	**2015**	2014	2014	2014	2014	2013	▨	2014	▨	**2015**
637	2014	2013	2014	2014	2014	2014	2014		2014	2014	2014	2014	2013	▨	2014	▨	**2015**
639	**2015**	2013	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013	▨	▨	▨	**2015**
642	2013	2013	2014	2014	2014	2014	**2015**	2013	2014	2014	2014	2014	2013	2013	2013	2013	2014
653	2014	**2015**	2014	2014	2014	2014	2014		2014	2014	2014	2014	2013	▨	2014	▨	**2015**
658	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013	▨	▨	▨	**2015**
687	2013	2013	**2015**	**2015**	**2015**	**2015**	**2015**	2013	**2015**	**2015**	**2015**	**2015**	2013	▨	2013	▨	**2015**

Watershed #	*Permanent Cross Sections*	*Elevation Reference Points*	*Channel Gradient*	*Channel Width and Depth*	*Channel Coarse Substrate*	*Channel Azimuths*	*Stream Shade (first year)*	*Channel Sinuosity*	*In-stream Large Wood*	*Classification of Habitat Units*	*Channel & Valley Type*	*Active Erosion*	*Stream Temp.*	*Stream Discharge*	*Photo Station*	*Microclimate*	*Riparian Vegetation*
688	2013	2013	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013		2013		**2015**
690	2013	2013	2014	2014	2014	**2015**	2014	2014	2014	**2015**	2014	2014	2013		2013		**2015**
694	2013	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013	2013	2013	2013	2014
716	2013	2013	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**	2013		2013		
717	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	2013	2013		**2015**
718	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		**2015**
724	2013	2013	2014	2014	2014	2014	2014	2013	2014	2014	2014	2014	2013	2013	2013	2013	2014
730	2014		2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		**2015**
737	2013	2013	2014	2014	2014	2014	2014	2013	2014	2014	2014	2014	2013	2013	2013	2013	2014
750	**2015**	2013	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013				
760	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2013		
763	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		**2015**
767	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		**2015**
769	2013	2013	2013	2013	2013	**2015**	**2015**	2013	2013	2013		2013	2013	2013	2013		**2015**
773	2014	2013	2014	2014	2014	2014	**2015**	2014	2014	2014	2014	2014	2013		2014		
776	2013	2013	2014	2014	2014	2014	**2015**	2014	2014	2014	2014	2014	2013		2013		
790	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013		2013	2013	2013	2013	2013	2014
796	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		
797	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		
804	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		**2015**
820	**2015**	2013	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**		**2015**	2013				
844	2014	2013	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2013		2014		**2015**
*BOG**	**2015**	2013	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013				
*HOH**	**2015**	2013	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013				
*QUEETS**	**2015**	2014	**2015**	**2015**	**2015**	**2015**		**2015**	**2015**	**2015**	**2015**	**2015**	2013				
*SFHOH**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**			**2015**	**2015**	**2015**	**2015**	2013				
2013 Total	*26*	*42*	*10*	*10*	*10*	*9*	*9*	*17*	*10*	*10*	*0*	*10*	*54*	*14*	*26*	***10***	***0***
2014 Total	*20*	*4*	*32*	*32*	*32*	*31*	*26*	*22*	*31*	*30*	*31*	*31*	*0*	*0*	*20*	***0***	***10***
2015 Total	*8*	*7*	*12*	*12*	*12*	*14*	*8*	*12*	*13*	*14*	*12*	*13*	*0*	*0*		***0***	***31***
TOTAL	*54*	*53*	*54*	*54*	*54*	*54*	*43*	*51*	*54*	*54*	*43*	*54*	*54*	*14*	*46*	***10***	***41***

* Reference sample reaches in Olympic National Park

Appendix 2. Summary Description of Sample Reaches

Watershed #	*Reach Elevation (m)*	*Reach Aspect*	*Reach Gradient (%)*	*Reach Bankfull Width (m)*	*Reach Bankfull Depth (cm)*	*Reach Length (m)*	*Reach Type*	*Reach Sinuosity*	*Reach Confinement Category*
145	28.3	NW	4.13	4.8	19.2	110	-	1.16	Confined
157	76.1	E	3.96	4.0	19.8	100	-	1.05	Confined
158	74.7	N	8.06	4.2	19.6	100	Cascade	1.08	Mod. Confined
165	81.7	N	2.81	9.9	33.7	190	-	1.54	Confined
196	85.5	N	4.61	7.3	27.4	148	-	1.04	Confined
328	143.3	W	2.62	3.0	14.7	100	Pool-riffle	1.25	Confined
433	36.6	NW	1.35	9.4	44.5	160	-	1.08	Confined
443	45.7	SW	1.74	3.9	16.4	100	Pool-riffle	1.15	Confined
488	140.2	N	4.07	3.7	16.5	108	Pool-riffle	1.25	Mod. Confined
542	68.7	S	7.06	5.8	34.1	105	Step-pool	1.09	Confined
544	90.4	S	6.32	2.7	22.8	100	-	1.08	Mod. Confined
545	101.0	SW	6.72	2.1	10.0	100	-	1.20	Confined
550	123.1	SW	7.12	6.7	25.7	120	Step-pool	1.10	Confined
567	102.9	N	5.45	6.0	24.3	100	Step-pool	1.12	Confined
568	90.7	NW	4.41	6.9	23.6	100	Step-pool	1.06	Confined
582	92.0	W	1.79	2.6	22.7	100	Pool-riffle	1.09	Confined
584	95.5	W	1.81	7.8	34.6	150	Pool-riffle	1.05	Mod. Confined
597	114.7	W	1.82	5.6	28.2	106	Pool-riffle	1.07	Mod. Confined
605	33.0	NW	9.48	3.2	22.1	97.5	Cascade	1.12	Mod. Confined
619	150.6	N	4.49	2.9	14.8	100	Pool-riffle	1.07	Confined
621	148.5	NE	6.57	3.4	15.9	100	Step-pool	1.20	Mod. Confined
625	143.5	N	6.6	5.3	28.0	130	Step-pool	1.26	Mod. Confined
637	126.6	W	8.58	3.5	22.7	100	Step-pool	-	Mod. Confined
639	200.5	N	21.14	5.6	35.4	100	Cascade	1.09	Mod. Confined
642	156.5	N	2.06	2.6	13.7	100	Pool-riffle	1.02	Confined
653	216.9	N	13.07	2.8	16.1	100	Cascade	-	Mod. Confined
658	137.2	W	1.99	5.3	20.2	135	Step-pool	1.22	Confined
687	245.5	S	8.46	5.7	32.5	100	Step-pool	1.15	Confined

Watershed #	*Reach Elevation (m)*	*Reach Aspect*	*Reach Gradient (%)*	*Reach Bankfull Width (m)*	*Reach Bankfull Depth (cm)*	*Reach Length (m)*	*Reach Type*	*Reach Sinuosity*	*Reach Confinement Category*
688	51.4	N	4.6	4.4	16.8	102	Step-pool	0.99	Confined
690	228.2	S	6.43	6.7	29.1	205	Cascade	1.14	Confined
694	262.8	SW	4.53	4.3	24.2	100	Step-pool	1.17	Mod. Confined
716	358.0	NE	6.1	6.7	30.2	100	Step-pool	1.13	Mod. Confined
717	181.7	E	2.06	2.1	19.0	100	-	1.07	Confined
718	171.4	SW	1.26	4.7	22.5	125	Pool-riffle	1.19	Confined
724	170.7	SW	5.84	3.3	12.7	100	Step-pool	0.99	Confined
730	125.3	S	1.48	6.2	23.5	116.5	Pool-riffle	1.70	Confined
737	362.2	S	11.61	2.3	13.7	100	Cascade	1.17	Confined
750	392.3	NE	10.72	6.0	22.4	114.15	Cascade	1.09	Confined
760	90.0	SE	2.39	5.3	24.3	100	Step-pool	1.12	Mod. Confined
763	89.0	SE	3.12	4.5	19.5	100	Step-pool	1.06	Confined
767	98.5	S	13.77	2.7	16.6	107	Cascade	1.04	Confined
769	95.0	S	5.4	1.9	9.6	100	-	1.08	Confined
773	200.5	NE	7.53	4.3	20.5	106	Cascade	1.18	Mod. Confined
776	226.7	NE	9.85	3.2	17.7	100	Cascade	1.31	Confined
790	80.7	N	4.45	5.6	26.4	100	-	0.96	Confined
796	62.6	S	2.5	7.7	23.3	100	Braided	1.08	Mod. Confined
797	68.0	SW	3.34	7.8	27.5	204	Step-pool	1.13	Confined
804	197.9	NW	4.57	5.4	15.5	105	Pool-riffle	1.11	Confined
820	40.3	S	0.82	7.3	36.3	156	Pool-riffle	1.23	Confined
844	45.3	N	1.72	5.6	19.7	100	Pool-riffle	1.10	Confined
BOG*	118.6	S	16.1	5.5	35.9	119.85	Cascade	1.09	Confined
HOH*	210.0	SE	10.86	3.2	14.7	102.1	Cascade	1.08	Confined
QUEETS*	97.5	S	1.74	4.2	16.1	104.83	Pool-riffle	1.23	Mod. Confined
SFHOH*	237.8	SW	16.59	5.0	23.3	100	Cascade	-	Confined

* Reference sample reaches in Olympic National Park

Appendix 3. Summary Description of Monitored Watersheds

Watershed #	*Area (km^2)*	*Managed by WADNR (%)*	*Median slope (%)*	*Elevation range (m)*	*Lithology (%)*			*Long-term deferrals (%)*	*Harvest (% of watershed)*		*Stream density (km/ km^2)*	*Road density (km/ km^2)*	*Total stream length (km)*	*Road crossings (no./km stream)*
					Glacial deposits	*Tertiary sediment*	*Volcanic rock*		*Completed 1999-2015*	*Modeled for decade 2011-2021*				
145	1.82	96.3	16	27 - 268	39.0	61.0	0	6.5	29.6	2.8	2.5	3.0	4.6	1.3
157	1.91	100	23	74 - 442	6.4	93.6	0	0.0	20.1	3.1	4.6	4.2	8.8	0.5
158	2.11	100	27	75 - 443	13.3	86.7	0	16.3	34.1	23.7	3.7	3.3	7.8	0.3
165	6.69	100	38	76 - 597	13.1	75.2	11.8	7.2	27.6	16.2	4.4	2.8	29.6	1.0
196	4.54	52.4	38	73 - 544	5.7	94.3	0	6.2	23.9	6.5	3.4	3.2	15.2	0.4
328	1.32	94.1	19	136 - 380	0	90.0	10.0	22.0	17.6	0.0	2.9	2.0	4.0	0.5
433	7.89	68.1	4	36 - 233	87.0	13.0	0	6.0	8.8	20.9	2.1	3.1	17.3	1.0
443	1.45	50.7	20	39 - 145	54.3	45.7	0	7.9	0.0	0.0	6.1	3.2	8.9	0.9
488	1.28	55.7	33	140 - 393	0	100.0	0	0.0	53.0	6.2	5.8	1.6	7.5	0.1
542	1.50	100	17	69 - 373	66.7	33.3	0	50.1	0.3	0.0	3.7	1.9	5.5	0.0
544	0.47	100	20	89 - 373	15.4	84.6	0	0.3	14.7	7.7	6.5	1.1	3.1	0.3
545	0.31	100	23	101 - 356	33.3	66.7	0	0.0	24.2	2.5	3.9	3.9	1.2	0.8
550	1.48	66.8	7	120 - 244	100.0	0	0	0.0	47.2	28.5	2.8	3.0	4.2	0.9
567	1.36	100	11	103 - 322	100.0	0	0	27.4	12.4	11.3	2.3	2.7	3.1	0.6
568	1.79	100	12	91 - 319	100.0	0	0	43.3	18.2	25.9	3.7	3.0	6.7	0.7
582	0.71	100	18	92 - 329	100.0	0	0	65.8	0.0	0.0	3.9	1.7	2.7	0.0
584	3.97	100	20	95 - 358	71.0	29.0	0	34.7	2.5	11.1	4.3	1.9	17.2	0.2
597	3.31	68.3	24	112 - 359	30.7	69.3	0	14.9	0.0	12.7	7.7	1.8	25.4	0.0
605	0.35	100	14	31 - 168	0	100.0	0	0.9	0.0	0.0	7.0	2.4	2.4	0.0
619	1.00	100	25	150 - 795	26.1	73.9	0	29.8	7.2	21.5	4.2	2.4	4.2	0.7
621	0.69	100	60	148 - 860	20.0	80.0	0	24.3	0.0	10.4	7.7	1.7	5.3	0.4
625	1.92	100	55	143 - 896	10.4	89.6	0	23.5	0.0	11.1	6.8	2.7	13.0	0.8
637	1.22	100	46	127 - 699	16.1	83.9	0	21.3	1.0	0.0	4.5	3.2	5.5	0.5
639	1.23	100	64	200 - 917	0	100.0	0	29.2	0.0	1.5	5.0	2.8	6.1	0.3
642	1.79	100	5	156 - 578	67.5	32.5	0	0.0	41.2	23.0	3.6	3.3	6.4	2.2
653	0.58	100	65	217 - 734	0	100.0	0	11.8	0.0	0.0	6.1	3.0	3.6	1.1

					Lithology (%)				*Harvest (% of watershed)*					
Watershed #	*Area (km^2)*	*Managed by WADNR (%)*	*Median slope (%)*	*Elevation range (m)*	*Glacial deposits*	*Tertiary sediment*	*Volcanic rock*	*Long-term deferrals (%)*	*Completed 1999-2015*	*Modeled for decade 2011-2021*	*Stream density (km/ km^2)*	*Road density (km/ km^2)*	*Total stream length (km)*	*Road crossings (no./km stream)*
658	2.71	80.5	8	137 - 360	75.8	24.2	0	28.7	2.9	2.5	2.5	2.9	6.8	1.2
687	2.78	100	58	245 - 895	0	100.0	0	6.9	0.0	0.0	4.7	1.5	13.1	0.5
688	2.27	70.7	4	51 - 322	94.4	5.6	0	11.5	0.0	0.2	3.2	4.2	7.3	1.7
690	4.40	100	50	215 - 895	0	100.0	0	1.4	0.0	0.4	5.7	3.0	25.3	0.6
694	2.14	100	54	262 - 853	0	100.0	0	19.3	0.0	0.1	5.3	1.3	11.3	0.0
716	3.63	100	57	357 - 1038	0	100.0	0	28.9	0.0	0.0	3.7	1.8	13.6	0.1
717	0.55	100	44	182 - 505	23.1	76.9	0	0.2	0.0	0.8	6.8	3.3	3.7	1.1
718	2.47	100	18	171 - 745	50.0	50.0	0	9.5	16.3	18.2	3.2	4.3	8.0	0.9
724	0.66	100	44	168 - 512	0	100.0	0	13.1	0.0	18.3	6.1	3.9	4.1	1.0
730	3.66	87.0	39	125 - 482	0	100.0	0	15.5	0.0	5.7	6.4	3.2	23.5	1.0
737	0.60	100	64	362 - 836	0	100.0	0	15.1	0.0	0.0	3.5	1.3	2.1	0.5
750	1.33	100	57	391 - 902	0	100.0	0	38.1	0.0	0.0	3.2	2.5	4.3	0.0
760	1.03	100	34	89 - 319	0	100.0	0	1.5	0.0	0.4	8.5	2.9	8.7	0.0
763	1.85	76.8	30	88 - 452	0	100.0	0	6.9	0.0	3.2	7.0	3.6	12.9	1.2
767	0.31	100	25	100 - 388	28.6	71.4	0	21.9	9.2	0.4	6.4	3.9	2.0	2.0
769	0.15	100	38	94 - 345	0	100.0	0	29.3	0.0	0.0	5.2	2.7	0.8	0.0
773	1.64	100	53	200 - 663	0	100.0	0	17.8	0.0	1.0	5.1	1.1	8.4	0.0
776	0.79	100	46	215 - 643	0	100.0	0	39.4	0.0	0.0	4.3	3.3	3.4	0.0
790	3.40	100	39	81 - 387	15.2	81.0	3.8	9.3	22.0	17.1	5.8	2.3	19.8	0.1
796	5.31	97.0	15	62 - 608	98.4	1.6	0	42.0	9.7	1.4	3.2	2.3	17.2	0.9
797	4.66	73.6	14	68 - 692	95.2	4.8	0	36.8	14.1	2.3	3.1	2.8	14.6	0.5
804	1.73	100	22	196 - 430	65.0	35.0	0	6.8	33.2	18.4	5.3	3.9	9.2	0.9
820	5.79	88.5	5	38 - 393	100.0	0	0	50.7	3.5	2.7	2.3	2.5	13.4	0.7
844	3.71	98.0	4	45 - 147	100.0	0	0	8.5	24.2	2.3	1.0	4.0	3.6	0.5
BOG*	2.55	0.0	50	114 - 665	20.0	80.0	0	-	-	-	-	0.0	13.4	0.0
HOH*	0.89	0.0	68	210 - 1288	0	100.0	0	-	-	-	-	0.0	1.7	0.0
QUEETS*	1.30	19.5	37	97 - 708	18.8	81.2	0	-	-	-	-	0.4	5.0	0.0
SFHOH*	1.18	0.0	69	237 - 1147	3.7	96.3	0	-	-	-	-	0.0	2.8	0.0

* Reference sample reaches in Olympic National Park

Appendix 4. Data Sources for Watershed-Level Statistics

Attribute	Location in report	Data source	Data subset
Area (ha)	Appendix 3	Monitoring watershed polygons revised in 2015	none
Managed by WADNR (%)	Appendix 3	<ROPA.PARCEL_SV>	none
Median slope (%)	Appendix 3	USGS 10-m DEM: <RASTER.SLOPE_PERCENT_10M>	none
Elevation range (m)	Appendix 3	<elv_2m> raster dataset from: \\WADNR\agency\lidar\lidar_derivatives.gdb and USGS 10-m DEM: <RASTER.DEM_10M>	<elv_2m> was used for all but the 5 watersheds that it did not cover. <RASTER.DEM_10M> was used for those 5 watersheds.
Lithology (%)	Appendix 3	<ROPA.GEOL_GEOLOGIC_UNIT_POLY_500K>	none
Long-term deferrals (%)	Appendix 3	\\WADNR\divisions\FR_DATA\forest_info_2\gis\ldo\ldo_20160106\ldo_database.gdb	Used the DFR_RS_RPT field to identify deferrals. Excluded all values representing exclusion zones and all values of “-1”.
Harvest (%): 1999-2015	Appendix 3	<ROPA.TS_FMA_ALL_SV>	Harvests completed from 1999 through 2015.
Pathway decade 1	Appendix 3	Combined “ACT – Alt LP Decade 1” from <SHARED_LM.OESF_RDEIS_ACT_ALL> with the <fcPATHWAY_picks_20160106> to create the Pathway alternative dataset for decade 1.	Excluded deferral polygons so that only harvests remained.
Road density (km/km^2)	Appendix 3	<ROPA.ROAD>	none
Stream density (km/km^2) and total stream length (km)	Appendix 3	<ROPA.WCHYDRO>	none
Road crossings (no./km streams)	Appendix 3	<ROPA.ROAD> and <ROPA.WCHYDRO>	none
Land use	Figure 45	\\WADNR\divisions\FR_DATA\forest_info_2\gis\ldo\ldo_20160106\ldo_database.gdb	Used the DFR_RS_RPT field to identify deferrals. Excluded all values representing exclusion zones and all values of “-1”.
Modeled unstable slopes	Figure 45	Large Data Overlay	All instances of modeled unstable slopes.

Planned harvest, by type, under Pathway (%)	Figure 46	Combined “ACT – Alt LP Decade 1” from <SHARED_LM.OESF_RDEIS_ACT_ALL> with the <fcPATHWAY_picks_20160106> to create the Pathway alternative dataset for decade 1.	Excluded deferral polygons so that only harvests remained. Divided harvests into two categories: (1) thinnings, and (2) variable retention harvests.
Road density by surface type (km/km^2)	Figure 47	<ROPA.ROAD>	none
Road density in riparian zones (km/km^2)	Figure 48	<ROPA.ROAD> and <ROPA.WCHYDRO>	Created buffer polygons around all streams (0-20, 20-40, and 40-60 m) and extracted the length of roads within those polygons.
Stream length by type (km)	Figure 49	<ROPA.WCHYDRO>	none
Hydrologic maturity (% of watershed)	Figure 51	<SHARED_LM.RS_FRIS_ORIGIN_YEAR>	Selected pixels representing forest 25 years of age and older.