Chapter 12: Ecoregion 7.1.8 Coast Range: Olympic Experimental State Forest, Washington

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Introduction

The Olympic Experimental State Forest (OESF) covers more than 110 000 ha on the western Olympic Peninsula in the state of Washington. The forest consists of state trust lands that are administered by Washington Department of Natural Resources (WADNR). The OESF is a working forest, managed to produce commercial timber sustainably and to provide ecological values, such as biodiversity and long-term site productivity. The OESF has an additional mandate, unlike other state trust lands in western Washington, to experiment with innovative land management practices and to put the research results into practice for continuous improvement of forest management. The long-term vision for the OESF is "of a commercial forest in which ecological health is maintained through innovative integration of forest production activities and conservation" (WADNR 1997).

The focus of the OESF is environmental monitoring and applied research to reduce key uncertainties in natural resource management. It also facilitates scientific projects at OESF by external researchers on a variety of environmental topics.

Because the OESF consists of numerous parcels of state-owned land interspersed with private, federal, and tribal lands (fig. 12.1), this synthesis also includes research and data from neighboring lands that are within the same drainage basins as the OESF parcels.

Site Description

The OESF is located on the western Olympic Peninsula of Washington, near the town of Forks (lat. 47° 57' 37'' N, long. 124° 23' 30'' W) (fig. 12.1). The forest encompasses all state trust lands managed by WADNR within a polygon defined by Washington Department of Ecology's (WADOE) water resource inventory area No. 20 (Sol Duc/Hoh) and portions of areas No. 19 (Lyle/Hoko) and No. 21 (Queets/Quinault). Elevations range from 0 m near the Pacific Ocean to 1155 m at the upland border with the Olympic National Park (ONP).

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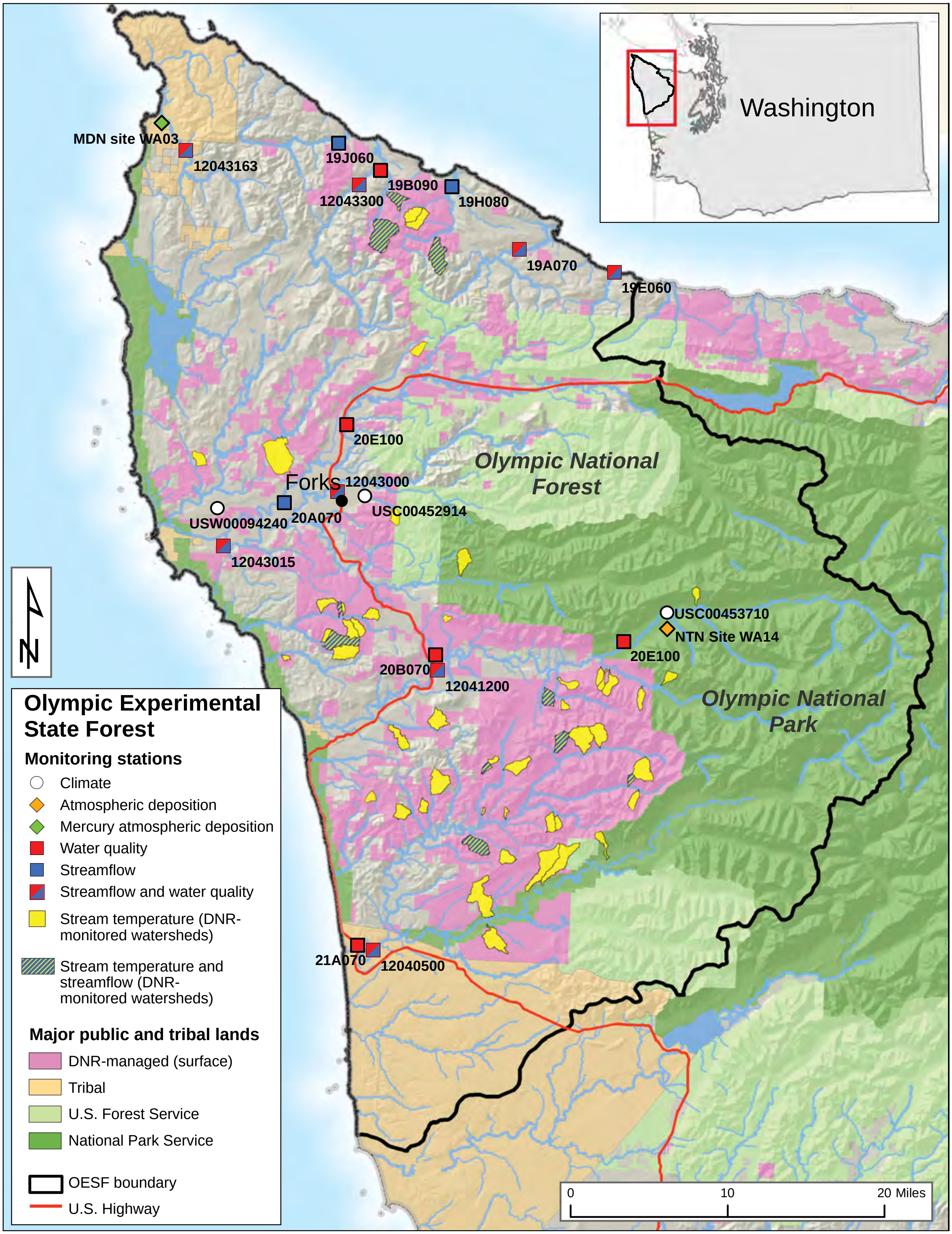

Figure 12.1—The Olympic Experimental State Forest (OESF) consists of all Washington Department of Natural Resources (DNR)-managed lands within the OESF boundary. Monitoring locations of mainstem rivers and of atmospheric deposition are identified by station ID. Small watersheds, monitored by Washington State DNR for stream discharge and water temperature, are color-coded. NTN = National Trends Network. MDN = Mercury Deposition Network.

Most soil parent material is uplifted marine sedimentary and basaltic rocks with surficial continental and alpine glacial deposits. The area is characterized by a maritime climate with annual precipitation of 200 to 457 cm, most falling as rain from October through May. Snowfall is rare in lower elevations, with snowpack usually only above ~600 m. Streamflows are largely rain dominated with pronounced seasonal low flows during drier summer months. Strong winds from the Pacific Ocean, floods, and debris flows are the major natural disturbance forces.

Major coastal river systems run through the OESF, including the Bogachiel, Clearwater, Hoh, Hoko, Pysht, Queets, and Quillayute Rivers. Steep erodible terrain and heavy annual precipitation produce high stream densities of ~3.6 km/km^2 and more than 4000 km of mapped streams. Most streams have high gradients and channel deposits of rocks and large wood mainly derived from unstable channel banks and debris flows that originate in steep tributary basins. The combination of high rainfall and soil layers that restrict water movement produces numerous wetlands.

The Sitka spruce (*Picea sitchensis* (Bong.) Carriere) vegetation zone dominates along the coast (Franklin and Dyrness 1973). Inland, the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) zone comprises a majority of the forest. In this zone, western red cedar (*Thuja plicata* Donn ex D. Don) occurs in the areas with wetter soils. Major seral components of vegetation are Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in all zones and red alder (*Alnus rubra* (Bong.) at lower elevations. The Pacific silver fir (*Abies amabilis* (Douglas ex Loudon) Douglas ex Forbes) zone, at higher elevation, comprises a minor portion of the OESF. Abundant moisture and a long growing season result in high tree-growth rates. Old-growth forests that once dominated the landscape still exist on about 11 percent of OESF. Around 50 percent of the OESF consists of younger stands resulting from extensive logging since the 1970s and 1980s (WADNR 2016b).

Streams and riparian areas in the OESF provide habitat for a diversity of fish, including at least nine resident or anadromous salmonid species: sockeye salmon (*Oncorhynchus nerka* Walbaum), pink salmon (*O. gorbuscha* Walbaum), chum salmon (*O. keta* Walbaum), Chinook salmon (*O. tshawytscha* Walbaum), coho salmon (*O. kisutch* Walbaum), steelhead (*O. mykiss* Walbaum), cutthroat trout (*O. clarkii* Richardson), bull trout (*Salvelinus confluentus* (Suckley)), and mountain whitefish (*Prosopium williamsoni* (Girard)). Seventeen other fish species, including lampreys, minnows, suckers, and sculpins, are known to occur in the OESF. The western Olympic Peninsula has more robust salmonid populations than other areas of the northwest Pacific coast, south of Canada (Huntington et al. 1996, NPCLE 2015). Bull trout and the Lake Ozette sockeye (an evolutionarily significant unit of *O. nerka*) are the only local fish species listed as threatened under the Endangered Species Act (ESA; 16 U.S.C. 153110536, 1538-1540).

A mandate from the state legislature directs WADNR, as a fiduciary of these trust lands, to actively manage the OESF to provide revenue in perpetuity for specific trust beneficiaries such as public schools and universities. Most revenue comes from timber harvest. On average, 600 ha, or 0.55 percent of the land area, were harvested annually in the OESF between 1999 and 2014. OESF is also managed to provide ecosystem values, including conservation of habitat for federally protected species, which is guided by a habitat conservation plan (HCP) (WADNR 1997). Details of OESF biophysical conditions and management are contained in the OESF forest land plan (WADNR 2016b).

Research History

The OESF was designated by WADNR in 1992 to learn how to integrate timber harvest and habitat conservation across the landscape and to implement new knowledge, such as innovative silvicultural techniques, into land management decisions. Under the HCP, the OESF research and monitoring program focused on addressing three main conservation strategies to restore and maintain habitat for salmon, northern spotted owls (*Strix occidentalis caurina*), and marbled murrelets *(Brachyramphus marmoratus*) (WADNR 1997). The majority of research and monitoring studies in the OESF, conducted or funded by WADNR, have focused on evaluating the habitat and species response to management typically practiced on state lands, specifically timber harvest and associated road management activities. Research on fundamental ecological processes has been primarily performed by scientists from cooperating agencies and universities.

Studies within the OESF have included silvicultural research (Ahrens and Bluhm 2016, Himes et al. 2013), species and habitat response to forest management (Cederholm and Reid 1987, Horton 2008, Raphael et al. 2008), long-term effects of forest management on soil and vegetation productivity (Homann et al. 2008), hillslope erosion (Reneau et al. 1989), regrowth response of vegetation to natural disturbances (Huff 1995), and long-term monitoring of aquatic and riparian conditions across the OESF (Minkova et al. 2012).

An important element of the OESF mission is to demonstrate an adaptive management process for integrating intentional learning into WADNR's decisionmaking on management of state lands. The process starts with identifying and prioritizing knowledge gaps that affect management of natural resources, followed by developing and implementing research and monitoring projects to address these needs, and finally using the scientific results to inform adjustments of future management activities and strategies (WADNR 2016b).

Several government agencies have conducted long-term environmental monitoring on lands adjacent to the OESF. Many of these environmental monitoring data are relevant to research projects on the OESF. The U.S. Geological Survey (USGS) and WADOE have monitored streamflow on main-stem rivers adjacent to the OESF since 1930, and intermittently measured water quality since 1960. The National Oceanic and Atmospheric Administration (NOAA) has monitored climate at Forks, Washington, since 1907. The National Park Service (NPS) has monitored atmospheric deposition chemistry at the ONP Hoh Ranger Station since 1980. Washington Department of Fish and Wildlife (WDFW) and tribal fisheries agencies have monitored adult salmon returns through redd surveys in main-stem rivers since 1973. In 2009, the OESF joined the experimental forests and ranges (EFR) network, under an agreement between WADNR and the U.S. Forest Service (USFS) Pacific Northwest Research Station that encouraged collaboration between the OESF and USFS scientists.

Availability of publications and data—

A bibliography of environmental research and monitoring carried out on the western side of the Olympic Peninsula through 2008, including the OESF, is available at the WADNR website (Teply and Phifer 2008). Descriptions and documentation of ongoing and recently completed research and monitoring projects are available at the WADNR website (WADNR 2017). Various datasets from ongoing and past projects as well as annotated bibliographies may be obtained by contacting the OEFS research and monitoring manager.

Locations and URLs of long-term monitoring sites on the OESF and its vicinity are in table 12.1 and figure 12.1. Daily climate and streamflow data from the USGS- and NOAA-operated stations near the OESF, formatted for ready comparison with other EFR sites, may be downloaded at the Long Term Ecosystem Research (LTER) Network data portal (LTER Network 2011). Stream temperature data collected by WADNR in 50 monitoring watersheds within the OESF and 4 watersheds within the adjacent ONP (fig. 12.1) are available at the NorWeST Regional Stream Temperature Database (USDA FS 2017).

Biological Responses to Stream Nutrients N and P

Issues of Concern

The western Olympic Peninsula is primarily a forested landscape with a relatively sparse human population and few sources of pollutants typically associated with urban, suburban, industrial, or agricultural areas (Klinger et al. 2008). Streams within the OESF are generally oligotrophic and mostly nitrogen (N) limited (Fevold 1998). Water quality concerns about N and phosphorus (P) primarily arise from forest management activities, such as timber harvest and road use, maintenance, and construction; reduced numbers of adult salmonid returns; and the potential for increased air pollution originating from eastern Asia.

Table 12.1—Long-term environmental monitoring stations on and near the Olympic Experimental State Forest[a]

Monitoring type	Station ID	Station name	Operated by	Period of available data	Reference
Climate	USW00094240	Qullayute State Airport	NOAA	1966–present	NOAA 2017a
Climate	USC00452914	Forks 1 E	NOAA	1907–present	NOAA 2017b
Climate	USC00453710	Hoh Ranger Station	NOAA	2004–present	NOAA 2017c
Streamflow and water quality	12043300	Hoko River near Sekiu, WA	USDI	1989–present	USDI GS 2017a
Streamflow and water quality	12043163	Tsoo-Yess River BLW Miller Creek near Ozette, WA	USDI	2010–present	USDI GS 2017b
Streamflow and water quality	12043015	Bogachiel River near La Push, WA	USDI	2017–present	USDI GS 2017c
Streamflow and water quality	12043000	Calawah River near Forks, WA	USDI	1989–present	USGS 2017d
Streamflow and water quality	12041200	Hoh River at U.S. Highway 101 near Forks, WA	USDI	1989–present	USDI GS 2017e
Streamflow and water quality	12040500	Queets River near Clearwater, WA	USDI	1988–present	USDI GS 2017f
Water quality	20B070	Hoh River at Department of Natural Resources Campground	WA DOE	1960–present	WADOE 2017h
Water quality	21A070	Queets River at Queets	WA DOE	1960–1972, 1994	WADOE 2017i
Water quality	19B090	Hoko River near Sekiu	WA DOE	1973 and 1974	WADOE 2017j
Water quality	20E100	Twin Creek and Upper Hoh Road Brook	WA DOE	2011–2015	WADOE 2017k
Water quality	20E100	Sol Duc River near Forks	WA DOE	1972–1974 and 1994	WADOE 2017l
Streamflow	20A070	Sol Duc River near Quillayute	WA DOE	2005–2012, 2013–present	WADOE 2017b
Streamflow	19J060	Sekiu River above Carpenter Creek	WA DOE	2006–2010, 2011–present	WADOE 2017k
Streamflow	19H080	Clallam River near Clallam Bay	WA DOE	2005 – present	WADOE 2017d
Streamflow and water quality	19E060	Deep Creek near Mouth	WA DOE	2005–2015	WADOE 2017e
Streamflow and water quality	19A070	Pysht River near Pysht	WA DOE	1972–1974	WADOE 2017e
Atmospheric deposition	NTN Site WA14	Hoh Ranger Station	NADP	1980–present	NADP 2019a
Mercury atmospheric deposition	WA03	Makah National Fish Hatchery	NADP	2007–present	NADP 2019b

NOAA = National Oceanic and Air Administration, USDI = U.S. Department of the Interior, USGS = U.S. Geological Survey, WA DOE = Washington Department of Ecology, NADP = National Atmospheric Disposition Program, NTN = National Trends Network.

[a] See figure 12.1 for general locations.

Forest management activities have been found to increase N in streams (Gravelle et al. 2009, McIntyre et al. 2017, Richardson and Béraud 2014). Changes in composition and age of riparian vegetation as a result of forest management practices, particularly N fixation associated with alder, can change N and P concentrations in riparian ecosystems (Boggs and Weaver 1994). Additionally, forest roads can be a source of fine sediments and both N and P within a watershed (Forsyth et al. 2006). Improved forest practices, such as the use of riparian buffers and upgrades and decommissioning of forest roads, have been implemented by WADNR and other land managers to reduce the effects of management activities on inputs of sediment and N and P to streams. While increases in N and P from forest management activities might be beneficial to streams with lower productivity, uncertainties remain around the timing and duration of these nutrient pulses as well as the responses of salmonids and other biota.

Although Olympic Peninsula salmon populations are considered relatively healthy compared to salmon populations in other areas of the continental United States, they have been significantly reduced from historical conditions (Cederholm et al. 1989, NPCLE 2015, PFMC 2001). Salmon are regionally important as a commercial and recreational fishery and as a cultural heritage of native peoples. When anadromous salmonids return to spawn and die, they transport marine N and P to the streams. These fish-transported nutrients promote biological productivity in riparian and stream ecosystems (Cederholm et al. 1989, Gresh et al. 2000, Helfield and Naiman 2001). The long-term decline of adult salmon may also alter food web complexity, including carnivore abundance in coastal streams and their watersheds. Current resident and juvenile anadromous salmonid populations within the OESF may be experiencing lower productivity owing to reduced marine-derived N and P in streams as a result of decreased adult returns.

The quality of salmon spawning and rearing habitat depends on an array of critical features, including water temperature, the composition and age of riparian vegetation, instream wood, suitable spawning gravels, and the number and size of pools (Hicks et al. 1991). Impacts of past forest management practices on these critical habitat features have been identified as a factor contributing to the long-term declines observed in northwestern salmon stocks (Cederholm and Reid 1987, Hartman et al. 1996, Lawson 1993, Tschaplinski 2000).

Rapid economic and industrial growth in upwind, eastern Asia might increase the deposition of pollutants to the Pacific Northwest in the future (Sheibley et al. 2014). Potential effects of increased deposition on streams are complex. For example, in the short term, increased atmospheric inputs of nutrients, such as N, might increase stream productivity (Volk et al. 2008), while over the longer term, this pollutant might acidify streams and negatively affect fish (Camargo and Alonso 2006). Other potential pollutants in deposition, such as toxic heavy metals and pesticides might accumulate in stream food chains with undesirable consequences (Kelly et al. 2008).

Findings From Studies

Regional monitoring—

Data on N and P in precipitation and stream water are available from several sampling stations maintained by various state and federal agencies (table 12.1; fig. 12.1). The WADOE has maintained a water quality monitoring site in the Hoh River on the OESF since 1960, with monthly measurements from 1994 to 2015 of ammonium (NH_4^+), nitrate (NO_3^-), total persulfate N and P, and nine other indicators of water quality. In addition, WADOE has collected intermittent water quality data from sites in the Hoko (1973 and 1974) and Queets (1960–1970, 1972, and 1994) Rivers.

Within the Hoh River drainage, stream water and precipitation chemistry, including N and P, were collected during 1984–2004 from West Twin Creek watershed in ONP and during 1999–2004 from Linder Creek watershed within the OESF (Stottlemyer et al. 2002). Stream water quality on local mainstem rivers has been monitored intermittently by USGS, including measurements of N and P, suspended sediment and dissolved oxygen (DO) in the Hoh River (1960–1980), the Calawah River in the mid-1970s, and the Queets River (1977–1993). A 1978 water quality assessment, including N and P, of the Hoh River watershed sampled 13 sites in the main-stem Hoh and 12 tributaries (Lum 1986). The ONP has participated in the National Atmospheric Disposition Program (NADP) monitoring atmospheric deposition of NH_4^+, NO_3^-, and inorganic N at Hoh Ranger Station since 1980.

Studies of N and P—

Studies of West Twin Creek, at the ONP and Linder Creek at the OESF, monitored precipitation, throughfall, stemflow, soil solution, stream chemistry, hydrology, vegetation, annual liter fall, and litter decomposition (Edmonds et al. 1998). Analyses of trends found significant increases in stream water NH_4^+ and NO_3^- over the period 1994–2001, but there was no significant long-term trend in phosphate (PO_4^{3-}). Possible sources of increased NO_3^- were speculated to be air pollution originating from Asia or unknown oceanic sources (Stottlemyer et al. 2002). Stream water NO_3^- concentration exhibited seasonal patterns with peaks in the fall and early winter probably from leaching of NO_3^- during the rainy season that accumulated in soils and sediments during the dry season (Edmonds and Blew 1997).

Volk (2004) compared streams dominated by N_2-fixing red alder in the Clearwater watershed with streams dominated by old-growth conifer forests in the Hoh watershed. Leaf litter, leaf detritus, and periphyton had higher concentrations of N and P in alder-dominated streams than in conifer-dominated streams. Algae and invertebrate communities in alder-dominated streams had higher production (biomass) and food quality, as measured by essential fatty acid and elemental nutrient contents. Higher production of invertebrate biomass in alder compared to conifer streams was also transferred downstream via drift and to adjacent terrestrial environments via insect emergence.

Volk and Kiffney (2012) conducted another study in the headwater streams of the Hoh and Clearwater watersheds to determine whether leaf litter inputs from alder influence the relative abundance of fatty acids of instream organisms. Primary producers are the only source of these fatty acids for higher trophic levels. Although the concentrations of N and P were significantly higher in fresh alder foliage than in conifer foliage, the results showed little evidence that riparian vegetation type influenced fatty acids and elemental nutrients in periphyton, invertebrates, or trout.

Jackrel and Wootton (2014) examined the effects of nutrient content and concentration in alder leaf litter on its decomposition in streams in the South Fork of the Pysht River drainages. Litter quality was manipulated by producing leaves high in P by fertilizing alder trees with triple super phosphate (P_2O_5) and leaves with a higher carbon (C)-to-N ratio were produced by punching holes in leaves of unfertilized alder trees to simulate herbivory. Leaf packs containing control, fertilized, or simulated-herbivory leaves were placed in streams. Fertilized leaves retained slightly more of their starting P content over time than control leaves, but there was no significant difference in P levels between treatment groups. Compared to the unmanipulated control, the rate of consumption of leaf litter by aquatic decomposers was suppressed by the simulated herbivory treatment, which increased the leaf C:N ratio, but was not affected by P fertilization.

Dose-Response Studies

A dose-response study by Volk et al. (2008) compared nutrient limitations in streams with riparian areas dominated by alder or by conifer species. The three conifer-dominated streams were relatively pristine and located in the ONP. The three alder sites were logged approximately 30 years prior to the study and were located on the OESF. Porous glass frits with N or P infused agar mediums (0.05 M, 0.1 M, and 0.5 M) were placed in high sunlit runs within 100-m sections of streams above fish barriers. Frits were removed from the stream after 14 days and analyzed for chlorophyll *a* (chl *a*). Concentrations of chl *a* in alder streams were double the concentrations found in conifer streams after treatment. In both alder and conifer streams, there was no significant differences in chl *a* response between nutrients added (N and P) or nutrient concentrations. Because both alder and conifer streams responded to N and P additions, the authors concluded that both nutrients were limiting production in both of these stream types.

Other Factors Relevant to Stream Nutrients N and P

The role of hydrologic processes—

Studies conducted by Bechtold et al. (2003) in the Queets River watersheds demonstrated the dominance of hydrologic processes in controlling N flux in aquatic ecosystems on the western Olympic Peninsula and specifically the seasonal movement of NO_3^- from riparian soils to aquatic areas. These data support a two-phase conceptual model of N leaching. During dry summer periods of low flow, the primary N source entering streams was water with low NO_3^- and insignificant dissolved organic carbon (DOC) concentrations, draining from unsaturated upland soils. During peak streamflows, typically associated with winter conditions and frequent precipitation, saturated soils bordering stream channels yielded water with high concentrations of NO_3^- and DOC that became the main source of solutes to streams. They hypothesized that, although the highest NO_3^- fluxes and surface water concentrations occurred during peak flows, the NO_3^- entering streams during low flows probably exerted a greater influence on stream productivity. During low flows, NO_3^- remained in the stream reach long enough to be available for uptake by aquatic biota, whereas during peak flows, NO_3^- was too rapidly flushed from the system to be absorbed by biota.

Effects of reduced salmonid populations—

When anadromous salmonids return to spawn, they make substantial contributions of nutrients to the stream, terrestrial vegetation, and to various species of wildlife. Several studies on marine-derived nutrients on the western Olympic Peninsula have included sites within the OESF. These studies have quantified marine-derived N in streams (Bilby et al. 2001) and examined the levels of retention and utilization of nutrients from salmon carcasses (Cederholm et al. 1989, 1999). These studies raised concerns that decreases in nutrients, as a result of salmonid population declines, may hamper salmon recovery efforts.

The role of physical habitat attributes—

In 2012, WADNR initiated an OESF-wide watershed monitoring project to determine the long-term status and trends in aquatic habitat within the OESF. The objective is to evaluate the changes in habitat attributes as WADNR implements planned management activities in the monitored watersheds. The monitoring information will be used to test WADNR projections for habitat recovery (WADNR 2016a), to conduct monitoring and experiments on salmonid response to managed landscapes, and to implement smaller scale aquatic ecology research. Fifty study watersheds, with an average size of 122 ha, were selected for monitoring in the OESF by using a random, stratified design from an inventory of all catchments within the OESF that are drained by the smallest fish-bearing streams (n = 848). WADNR has harvested timber on most of the selected OESF study watersheds in the past. Future timber management is planned in many of the monitored watersheds in accordance with the OESF forest land plan (WADNR 2016b).

Twelve reference basins, which are relatively pristine watersheds with minimum human disturbance, are also monitored as part of this project. Four of these reference basins are located on adjacent ONP lands under an agreement with the NPS, six are on ONF lands under an agreement with the USFS, and two are on state lands within the OESF.

The project systematically monitors indicators of aquatic and riparian habitat at the outlet of each study watershed, where disturbances within the basin are expected to be cumulatively expressed. The monitored habitat parameters are as follows: stream temperature, instream large wood, stream shade, coarse channel substrate, stream habitat units, classification of valleys and channel reaches, stream morphology, riparian microclimate, and riparian vegetation. In 2013, continuous monitoring of stream discharge and riparian microclimate (air temperature and humidity) was initiated on a subset of 10 of the study watersheds (Minkova and Vorwerk 2014). Monitoring of water chemistry (total N, total C, NH_4^+, nitrite (NO_2^-), NO_3^-, PO_4^{3-}, and DOC) and salmonid populations were added in a portion of the watersheds in 2016. The study watersheds are also monitored remotely with LiDAR and aerial photography and with operational records for ongoing and past disturbances such as windthrow, landslides, timber harvest, and road management. The first round of field sampling of habitat characteristics was completed on all 54 watersheds in 2015 and will be repeated every 3 to 5 years. The 2015 results show that most of the monitored streams are well-shaded, because of dense second-growth riparian forest; have cool summer stream temperatures that are generally below regulatory temperature thresholds for salmonids; and have relatively low volumes of instream large wood that is beginning to accumulate (Minkova and Devine 2016).

Reference Watersheds

The purpose of the reference basins is to provide the status and trends in aquatic and riparian habitat conditions in relatively pristine, unmanaged watersheds and to account for the natural background variation that might mask the OESF basins' response to management. All reference watersheds are in the vicinity of the OESF managed study watersheds; similar to them in study basin area, elevation range and other physiographic characteristics; and are dominated by conifer forests that have never been harvested.

Twelve reference study watersheds are being monitored within the OESF and on nearby lands within the ONP and ONF. The two reference watersheds on state lands in the OESF are within the Hoh and the Bogachiel River basins. The four reference watersheds established in the ONP are within the Hoh, the Queets, and the Bogachiel River drainages (shown in fig. 12.1) (Minkova et al. 2012). The six reference watersheds established within the ONF are all within the Bogachiel River basin. The eight reference watersheds located on the OESF and ONF lands have been established since 2017 and are not shown in figure 12.1.

The ONP reference watersheds have been formally protected from onsite human disturbance since the ONP was established in 1938, and even before that, probably had little human disturbance owing to their remote mountainous locations. Streams in these ONP reference watersheds have been monitored since 2012 for the same stream physical habitat attributes that were monitored on the managed study basins within the OESF. Long-term monitoring of fish populations, stream water inorganic N chemistry, and riparian vegetation were added in 2016.

The ONF reference watersheds have been formally protected from onsite human disturbance since the adoption of the Northwest Forest Plan in 1994. Streams, fish populations, and riparian vegetation have been monitored in the reference watersheds on ONF and OESF lands since 2018, following the same protocols as the reference basins within the ONP.

Cross-Site and Regional Studies

A number of cross-site studies have included observations made in the OESF or on adjoining ownerships that have been compared with other sites in the region or nation. These studies provide perspective about how streams in the OESF compare to streams in a larger geographic or ecologic context. Bilby et al. (2001) included six streams within basins that drain the OESF in a sample of 26 sites across western Washington to examine the relationship between the abundance of spawning coho salmon and the stable isotope ratio ^{14}N:^{15}N of young coho salmon parr. The study examined whether a saturation level for salmon-derived N could be identified. It found a relationship between the degree of enrichment with ^{15}N and abundance of spawning salmon and concluded that streams in western Washington were capable of incorporating substantially more marine-derived nutrients than they have received over the past several decades. The authors suggested a method for setting escapement goals that considers the importance of spawning anadromous salmon for productivity of the habitats in which subsequent generations hatch and rear.

A study on West Twin Creek conducted in the upper Hoh River watershed on the ONP between 1984 and 2004 was used in a nationwide synthesis of ecosystem monitoring sites in five national parks across the United States (Stottlemyer et al. 2002). The ONP had the second lowest input of atmospheric N among the five national parks. The study found no trend in ONP stream NO_3^- from 1985 to 1993, but found an increasing trend from 1994 to 2001 and attributed this trend to pollution from Asia or to oceanic sources.

Blinn (2015) correlated stream environment physiochemical conditions with assemblages of diatoms in 165 aquatic systems in Washington, including the Olympic Peninsula, to assess diatoms as environmental indicators of land use and elevation. Diatom species richness showed significant positive correlations with stream water total N, total P, pH, and specific conductance, channel embeddedness, and water temperature, and it showed a negative correlation with canopy cover.

Streams from the OESF were included in a biological assessment of small streams of the Washington Coast Range and inland Yakima Basin (Merritt et al. 1999). Macroinvertebrate and fish assemblages, physical habitat, and water chemistry were used as indicators. Stream water chemistry was measured, including N, P, suspended solids, temperature, and DO. Streams in the Coast Range had relatively low levels of nutrients, alkalinity, and conductivity; poor physical habitat conditions; and impaired biological integrity. The study reported average levels for nitrate + nitrite (0.11 mg/L), NH_4^+ (0.02 mg/L), total P (0.02 mg/L), and total persulfate N (0.23 mg/L) for all of the 47 Coast Range sites, of which 17 were within the OESF.

Moore et al. (2009) included the ONP in a cross-site analysis to determine the effects of climate change on glacial retreat across the western United States. The findings imply that, similar to glacier-fed streams in other western mountains, future glacier retreat in the Olympic Mountains will likely result in higher stream temperatures, possibly transient increases in suspended sediment, and changes in water chemistry in glacier-fed main-stem rivers that flow through the OESF, such as the Hoh, Queets, and Quinault Rivers. None of the headwater study basins currently monitored in the OESF, the ONF, and the ONP are glacier fed, so glacier retreat is unlikely to affect their waters directly, although anadromous fish migrations to and from the OESF, ONF, and the ONP study basins might be altered if conditions change in main-stem rivers through which these fish migrate..

Jones et al. (2012) included the OESF in a cross-site synthesis of climate effects, specifically air temperature and precipitation, on streamflow in a collection of 35 headwater basins at EFR and LTER sites across the United States. The OESF was among the sites with the highest annual precipitation and runoff, and water yield per unit land area, and the highest ratio of runoff to precipitation in this nationwide collection of intensively studied watersheds. The authors suggested that declining streamflow at several sites, including declines during the spring season at the OESF, may be the result of increased evapotranspiration in response to warmer temperatures.

Long-term atmospheric deposition data, collected by the NPS at its Hoh Ranger Station, in proximity to the OESF, have been used in nationwide analyses of atmospheric deposition by the NADP (NADP 2019a). These analyses showed that, in the vicinity of the OESF, atmospheric deposition of nutrients of nonmarine origin is very low, as is typical of coastal areas downwind of the Pacific Ocean and remote from local sources of air pollution. However, other studies in the ONP (Edmonds et al. 1998, Stottlemyer et al. 2002) and in nearby British Columbia (Wilkening et al. 2000) have documented increases in stream nitrates and sulfates and speculated that these increases might be from atmospheric deposition of airborne pollutants from Asia.

Federal land management agencies participate in the Aquatic and Riparian Effectiveness Monitoring Program (AREMP), which evaluates whether the Northwest Forest Plan's aquatic conservation strategy is achieving its goal of maintaining and restoring salmon habitat on federal lands in western Washington and Oregon and northwestern California (Reeves et al. 2004). This program was designed to systematically assess the long-term status and trends in salmonid stream habitat over ~10 million ha, a geographic scope and scale that was unprecedented. Five of the fifty watersheds that are monitored by this program are located on the ONF streams in the Queets, Quinault, Solduc, and Calawah watersheds in which the OESF is located. The long-term status and trends monitoring of riparian and aquatic habitat at OESF adopted study objectives and design and field methods that are similar to those used by AREMP (Minkova et al. 2012). AREMP analyses of the Olympic Peninsula basins on federal lands for 1993–2012 indicated moderate, broad-scale improvements in aquatic habitat quality and particularly channel substrate, water temperature, and macroinvertebrate diversity. This trend was attributed to regrowth of forest vegetation and road decommissioning (Miller

2017). It is possible that streams within WADNR lands of the OESF are showing a similar improvement, but because land management differs between the OESF and ONF, monitoring data currently being collected on stream habitat conditions in the OESF will be need to be analyzed to test whether conditions in OESF streams are following trends observed on federal lands.

Responses to Management and Natural Disturbances

On the western Olympic Peninsula, changes of stream temperature have mainly been studied in relation to harvest activities. Pollock et al. (2009) studied summer stream temperature at 40 locations in the Hoh and Clearwater drainages within the OESF in 2004 to relate stream temperature to basin harvest activities. They found that temperature was significantly higher in harvested basins compared with unharvested basins and that past harvest was still having an effect on temperature, even with the use of riparian buffers. Similarly, Hatten and Conrad (1995) found that temperatures in 28 streams within and around the OESF were significantly higher in managed forests than in unmanaged forests.

Murray et al. (2000) compared two partially harvested watersheds in the OESF with the Twin Creek reference site on the ONP for evidence of changes in stream chemistry, temperature, and turbidity. Partial harvesting (harvesting between 7 and 33 percent of the land area) had a minimal effect on these indicators 11 to 15 years after harvesting. Stream temperatures were more seasonally variable in the harvested streams compared to an unharvested old-growth site, with summertime maximums elevated by 3.5 ^{o}C. Higher and more prolonged NO_3^- levels were also observed in the disturbed watershed streams 11 to 15 years postharvest, a difference that may be attributed to N-fixation associated with red alder growing in harvested riparian areas. There appeared, however, to be little long-term influence of harvesting on stream pH, alkalinity, electrical conductivity, and total N and P concentrations. Total N and P concentrations were not different among streams and were generally low, with a range of 0.0 to 0.62 mg/L for N and 0.0 to 0.72 mg/L for P.

A replicated, large-scale experiment manipulated riparian vegetation along the South Fork Pysht River in 1994 (Wootton 2012) to investigate how reducing riparian vegetation cover would affect salmon rearing habitat. Experimental reduction of stream canopy cover did not affect water temperature, nutrient limitation, or other physical habitat characteristics. Nutrients NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, and DOC, and silicates were also not changed significantly by riparian treatments. In contrast, stream biological components responded strongly. Although reductions of stream canopy cover decreased detrital energy input via leaf litter, it increased incident solar energy (ultraviolet and photosynthetically active), which increased algal production. In response, benthic algae, most insect taxa, and juvenile salmonids density increased in manipulated streams. Stable isotope analysis found a predominant contribution of algal-derived energy to salmonid diets in manipulated reaches. The experiment found that reductions in riparian cover, under circumstances where it did not raise water temperature, strongly affected salmonids via increases in the energy content of river food webs. The author concluded that species-based management strategies can have unanticipated indirect effects on the target species, in this case salmonids, via the associated food web, and suggested that ecosystem-based management approaches may be useful for restoring depleted salmonid stocks.

An experiment to evaluate the effectiveness of riparian forested buffers, required by Washington Forest Practices on non-fish-bearing streams, was started in western Washington in 2006 (McIntyre et al. 2018). One of the study's 17 experimental sites is on the OESF. The study examines effects of different riparian buffers within harvested areas on riparian vegetation, stream temperature, instream wood, litterfall, detritus, nutrients, periphyton, macroinvertebrates, amphibians, and fish. Even small decreases in stream shade of <10 percent caused measurable increases in summer maximum stream temperature, with increases in maximum, minimum, and diel range of daily stream temperatures seen at nearly all treatment sites. Total P concentrations did not change significantly postharvest, but total N and NO_3^- were elevated significantly in response to harvest treatments. Studies of trophic pathways using C and N stable isotopes found no change in the contribution of algae to the stream trophic webs despite substantially increased light reaching the streams. A possible explanation for the lack of response was that the trophic structure in these small streams was so tightly coupled to the bordering terrestrial environment that increased light did not stimulate instream plant growth (McIntyre et al. 2018).

Natural disturbances such as debris flows and windthrow probably have effects on stream water quality, including N and P, but these effects have not been studied on the western Olympic Peninsula. Simulations of climate change effects on hydrology for the Olympic Peninsula predict significantly elevated stream temperatures, a shift from rain and snow transient runoff to a rainfall-dominate regime, more severe summer low flows, and more intense winter flooding (Mantua et al. 2010). Although such changes in physical conditions will likely have significant effects on water quality and on aquatic biota, including salmon, detailed predictions of such responses to climate change are not available for this region.

Research Needs

The research need of highest priority for regulatory agencies that could be filled at the OESF is a better understanding of the effects of alternative forest management practices on critical features of salmonid habitat, including stream water temperature, sediment production and routing through streams, and instream wood loading and function. Filling this need would improve regulators' understanding of the effectiveness of conservation measures, such as riparian buffers and forest road restoration and abandonment, and will aid in improving regulations aiming to protect critical salmonid habitat in northwestern streams. Filling this need would require implementing a range of harvesting regimes and stream protection practices, and systematically measuring their effects on salmonid habitat attributes. Within the OESF, WADNR has the ability to vary riparian buffer widths not only for research but as a standard management practice (WADNR 2016b). This management flexibility allows the agency to implement a wide variety of operational-scale experimental treatments that could be useful for addressing this need.

Management experiments within the OESF would be most informative if they included the responses of stream biological communities, especially salmonid populations. Because the impacts of forest management activities on anadromous salmonids interact with other factors, such as natural disturbances, ocean conditions, and marine fisheries (Lawson 1993, Tschaplinski 2000), there is a need to parse out the relative contributions of these factors. The OESF long-term status and trends monitoring watersheds, including unmanaged reference basins, have high potential to generate data that will be useful for understanding the role of forest management in these processes.

Another research need of interest to regulators that could be investigated at the OESF, although of lower priority for regulators, is the effect of forest land management practices on nutrient concentrations, fluxes in streams and wetlands, and instream processing and sequestration of stream nutrients, especially as they affect salmonids.

Potential Utility to Water Quality Regulatory Agencies

Regulatory agencies could use datasets and research from the OESF for developing a nutrient loading model that uses remote-sensing data and management information about watersheds to predict a nutrient transport rate in terms of kilograms of nutrients per hectare as a function of stand age, forest vegetation type, soil type, elevation/climate, road density, slope, management practices, and other factors. Such a model could be used to estimate how planned forest management activities would affect nutrient loading to water bodies at the scale of hydrologic unit code 12 subwatersheds. Developing such a model might draw upon existing OESF datasets, including long-term monitoring of streamflow and stream nutrients, forest vegetation inventories, results of forest management experiments and remotely sensed data such as LiDAR and aerial photos.

Research on the effects of forest management on water quality and other public resources, conducted on the OESF and neighboring lands, have been used as the best available science in the development of state forest practices rules (Washington State Legislature, Title 222 WAC, 2017). The OESF will continue to have an important role in testing the effectiveness of the rules and developing best management practices for forest management by providing scientific information from ongoing studies, as well as providing a land base for research. State lands on the OESF are amenable to conducting research on forest management activities because of the existing flexibility to perform a variety of potential management activities, the availability of rich data systems for operational and forest inventory records, the ability to maintain sample sites longer than private timber companies, and the availability of long-term reference sites within or near WADNR lands.

OESF research examining the effect of forestry on water quality and associated aquatic species could be useful to future updates of the state's water quality criteria. The reference watersheds on OESF, ONP, and ONF that are monitored by WADNR might provide valuable information on spatial and temporal natural variation of key water quality constituents. Research results on N and P biological dose response in Olympic Peninsula streams under different riparian vegetation could be useful to regulatory agencies for developing water quality criteria for Coast Range rivers. There are currently no information systems or processes that link the OESF data to regulatory agencies such as WADOE. WADNR might work with state regulators to assess how data from the OESF can be better used to help inform the improvement of forest practices. For example, WADOE might partner with WADNR to add the OESF network of long-term managed and reference monitoring streams to the WADOE Watershed Health Database (WADOE 2017a). Standardizing monitoring protocols and data management procedures would probably be required to make OESF data compatible with WADOE needs.

Streamflow monitoring data from the OESF, combined with the long-term river monitoring data from local river monitoring stations, can be used in drought forecasting. A statewide flow monitoring system is used to forecast runoff volume (WADOE 2017b) and to determine when conservation actions are needed in response to droughts, for example, when to stop stream fish distribution sampling.

Reliability and Limitations of Findings

Monitoring data on stream habitat attributes such as stream temperature, channel morphology, discharge (in 10 basins), instream wood, riparian vegetation, and microclimate (in 10 basins) from the same 62 monitored watersheds are collected following peer-reviewed monitoring protocols, including detailed quality assurance/quality control field and data management procedures (Minkova and Foster 2017).

Research findings and monitoring data from the OESF are probably applicable to forested watersheds in the Coastal Range of Oregon, Washington, and British Columbia. Results of OESF management experiments may be applicable across the region where management practices implemented by other land managers are similar to those tested on the OESF, for example riparian management by Washington's private landowners or by federal land managers under the Northwest Forest Plan. The degree to which OESF data and science findings predict conditions at other locations may depend on factors such as similarities in biophysical conditions and land use history. Where high reliability is required, similarity analysis and validation experiments are suggested to test how well data from the OESF fit local conditions.

Key points:

- The OESF has recently established long-term monitoring of 62 small watersheds in an area large enough to investigate landscape-scale effects of ongoing forest management on streams.
- Reference study watersheds, with minimal onsite human disturbance, have been established on the OESF, neighboring ONP, and ONF lands where long-term monitoring of stream habitat conditions and fish populations has started.
- Historically, long-term monitoring of water quality in this region has mostly been on main-stem rivers although smaller streams represent a disproportionally larger part of the stream networks.
- The highest priority research need of the regulatory community that could be filled at the OESF is an improved understanding of the effects of forest management practices on critical features of salmonid habitat, including stream temperature, fine sediment loading, and instream wood and food supply.
- Existing OESF datasets and research results may be useful to regulatory agencies for practical purposes such as developing state forest practices rules and water quality criteria.

Biological Responses to Stream Nutrients Other Than N and P

Issues of Concern

There are no current water quality concerns about nutrients other than N and P in this region (Eilers at al 1994, Lum 1986). However, early signs of a potential future issue may be high levels of mercury (Hg) that have been observed in trout from high-elevation lakes (Landers et al. 2008, Moran et al. 2007) and in largemouth bass in low-elevation Lake Ozette and Lake Dicky (Furl et al. 2010) on the Olympic Peninsula. These elevated Hg concentrations were suspected to be caused by air masses arriving from east Asia (Jaffe et al. 2005, Stottlemyer et al. 2002, Wilkening et al. 2000) or by increased sedimentation from logging (Furl et al. 2010). Hg, in the form of methylmercury (MeHg), is a neuro-toxin that is concentrated by aquatic food chains to which humans can be exposed by eating contaminated fish. Although Hg is not a nutrient, findings from other parts of the country, including Marcell Experimental Forest (see chapter 2), suggest that atmospheric deposition of sulfate (SO_4^{2-}) may increase production of MeHg in wetlands (Jeremiason et al. 2006). If air pollution originating from Asia continues to increase, the effects from atmospheric deposition of Hg and SO_4^{2-} on water quality in the Pacific Northwest might be significant.

Findings From Studies

Long-term monitoring of nutrients other than N and P in atmospheric deposition has been consistently conducted on the western Olympic Peninsula, but stream water monitoring of these nutrients has been intermittent (table 12.1 and fig. 12.1). The ONP has regularly monitored precipitation at the Hoh Ranger Station for SO_4^{2-}, hydrogen ion (H^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), and chloride (Cl^-) as part of NADP since 1980. Stream and precipitation chemistry, including bicarbonate (HCO_3^-), K^+, Mg^{2+}, Cl^-, SO_4^{2-}, Ca^{2+}, and Na^+, were collected in West Twin Creek from 1984 to 2004 and Linder Creek from 1999 to 2004 (Stottlemyer et al. 2002). Stream water quality, including measurements of HCO_3^-, Ca^{2+}, Na^+, K^+, Cl^-, and several metals, in main-stem rivers was monitored intermittently by the USGS, in the Hoh (1960–1980), Calawah (mid-1970s), and Queets (1977–1993) River. A water quality assessment of the Hoh River watershed from 1977 through 1980 measured Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, and SiO_2 at 13 sites in the main-stem and 12 sites on tributaries (Lum 1986). Wootton and Pfister (2012) collected DOC in nine streams from the northern part of the OESF in 2001 and again in 2010 to estimate stream inputs to near-shore waters.

Short-term studies have investigated nutrient cycles and biological processes involving nutrients other than N and P within the Hoh River basin. From the study of West Twin Creek, Edmonds et al. (1998) found that precipitation chemistry was dominated by Na^+ and Cl^- of marine origin, while stream chemistry was dominated by Ca^{2+} and SO_4^{2-} that typically results from rock weathering. They also reported that marine-related nutrients Cl^-, SO_4^{2-}, Mg^{2+}, and Na^+ were highest in precipitation near the ocean.

Volk (2004) found that nutrient concentrations in fresh leaf litter decreased by 36 to 67 percent for Ca^{2+}, copper, K^+, Mg^{2+}, manganese, and strontium (Sr^{2+}) as it aged over 18 days in streams with alder-dominated riparian vegetation. In hemlock-dominated streams, the concentration of iron and zinc in fresh leaf litter significantly increased.

Brenkman et al. (2007) studied the relationships between bull trout otolith element ratios and water chemistry to investigate migration between near-shore marine environments and aquatic habitats in the Hoh River watershed. They found Sr/Ca was higher in otolith layers from fish while they were in salt water compared to periods when the fish were in freshwater. This provided evidence that these stream fish spent significant portions of their life cycle in the ocean.

Other Factors Relevant to Stream Nutrients Other Than N and P

Studies and monitoring within the OESF of other environmental factors that might limit biological responses to nutrients other than N and P are the same as reported earlier in this chapter for nutrients N and P. The water chemistry monitoring initiated by WADNR and The Evergreen State College in 2016 in a subset of watersheds monitored for stratus and trends of habitat conditions (Minkova et al. 2012) includes DOC, which is a source of energy in trophic webs and may affect responses to nutrients.

Dose-Response Studies

Dose-response studies for nutrients other than N and P have not been conducted on the OESF.

Reference Watersheds

See the description of the monitored reference watersheds located in the OESF, ONP, and ONF described under nutrients N and P.

Cross-Site and Regional Studies

Long-term atmospheric deposition of SO_4^{2-}, H^+, Ca^{2+}, Mg^{2+}, K^+, Na^+, and Cl^-, collected at the Hoh Ranger Station in proximity to the OESF, has been used in nationwide analyses of atmospheric deposition by the NADP (NADP 2019a). These analyses showed that atmospheric deposition of nutrients of nonmarine origin are very low, as is typical of coastal areas downwind of the Pacific Ocean, and remote from local sources of air pollution. However, an assessment of ecological and biological effects of hazardous air contaminants in 20 national parks in the Western United States and Alaska found that fish Hg concentrations in the ONP were among the highest of all parks sampled (Landers et al. 2008).

Responses to Management and Natural Disturbances

Murray et al. (2000) compared the changes in concentrations and seasonal patterns of stream nutrients, other than N and P, on two partially harvested watersheds in the OESF and the Twin Creek reference site on the ONP. Overall, the partial harvesting had little influence on Na^{+}, Cl^{-}, Ca^{2+}, K^{+}, and Mg^{2+} 11 to 15 years postharvest. Cation concentrations were generally higher in the old-growth watershed. The differences were attributed partially to the sites' physical differences such as aspect and distance from the ocean, and possibly in part to differences in canopy cover and streamflow between harvested and unharvested sites.

Reliability and Limitations of Findings

Research findings and monitoring data from the OESF, related to nutrients other than N and P, are probably applicable to forested watersheds in the coastal ranges of Oregon, Washington, and British Columbia. OESF results may be extrapolated broadly across the region to areas where the management practices implemented by local land managers are similar to those tested on the OESF. The extent to which OESF data and science findings predict conditions at other locations may depend on factors such as similarities in biophysical conditions and land use history. Where high reliability is required, similarity analyses and validation experiments or monitoring are suggested to test how well data from the OESF fit local conditions.

Research Needs

The highest priority research need of the regulatory community related to nutrients other than N and P that might be filled at the OESF is, What are the levels and trends of Hg in aquatic food chains in low-elevation waters of the western Olympic Peninsula, and are they being affected by atmospheric deposition or forest management?

Better stream data on Hg levels and trends would be important to regulatory agencies for developing regulations or management guidelines that better protect human health from hazardous exposure to environmental Hg. Deposition of Hg and SO_4^{2-} might also be sensitive indicators of potential impacts of atmospheric transport from distant sources in Asia. Filling this need at the OESF would require continuing current NADP monitoring of atmospheric deposition of SO_4^{2-} and adding monitoring of Hg deposition. Regular monitoring of Hg in aquatic food chains and SO_4^{2-} in the OESF streams affected by various forest management treatments and OESF, ONF, and ONP reference streams would also need to be established. If high levels or increasing trends of Hg were detected, further investigations of environmental sources that introduce Hg into food chains might be warranted.

Another research need of interest to regulators, but of lower priority, is additional information on cloud water deposition of nutrients to coastal forests, which may contribute to nutrient cycling and potential pollution effects in the region (Bormann et al. 1989).

Potential Utility to Water Quality Regulatory Agencies

The OESF and neighboring ONF and ONP could be suitable sites for regulatory agencies to use for the early detection of effects from long-range pollution as these sites have few confounding local sources of air pollution. Existing long-term monitoring datasets of nutrients, such as SO_4^{2-}-S in stream water and atmospheric deposition at the OESF and ONP, are examples of early warning signals that regulatory agencies could use for potential impacts on regional streams from long-range atmospheric transport of pollutants from Asia.

The OESF is also well suited as a study site to investigate the effects of forest management practices on stream water quality, including nutrients other than N and P, and will continue to provide data and a land base for scientific investigations that test the effectiveness of forest practices rules and develop best management practices for forest management.

Key points:

- There are currently no pressing concerns regarding nutrients other than N and P in the forested streams on the western Olympic Peninsula.
- The only study that has been done at the OESF to examine effects of forestry practices on stream nutrients other than N and P (Murray et al. 2000) found no effects.
- The highest priority research need of regulatory agencies, related to nutrients other than N and P would be intensive monitoring of Hg in aquatic food chains and studies to assess how environmental factors, such as forest land management and atmospheric deposition of Hg and the nutrient sulfur, may influence human exposure to this neurotoxin.

Overview and Synthesis

The OESF offers extraordinary advantages as a site for scientifically investigating issues of concern to regional water quality regulatory agencies. The OESF is unusual among EFRs because it encompasses a land base large enough to do landscape-scale investigations of effects of replicated land management treatments on streams. The OESF is actively managed to produce timber, and its manager, WADNR, has considerable latitude to use this land management as an experimental tool for investigating effects on streams. The extensive operational records, forest inventory data, and other ecological information are public and readily available to researchers. Unlike many other parts of the Pacific Northwest, where multiple ESA-listed anadromous fish runs tightly constrain management experiments, the relatively healthy condition of runs at the OESF provide opportunities to test a wider range of experimental treatments and to study not only effects on habitat but also on fish. Furthermore, as a member of the EFR network, the OESF can draw upon the deep pool of scientific and technical expertise built over many decades within the network. These assets combine to make the OESF an important field research laboratory for investigating critical issues in this region, such as the effects of forest land management on riparian habitat and anadromous fish.

The OESF aquatic and riparian monitoring in 50 managed and 12 reference watersheds is designed to produce long-term environmental data and to provide a research platform on which a variety of forest management experiments can be implemented. For example, the effects of forest management practices with varied intensities and spatial and temporal patterns can be tested on riparian vegetation, nutrients, and vertebrate and invertebrate assemblages in streams and wetlands. The extensive environmental and land use datasets maintained by WADNR create a baseline of pretreatment conditions and an estimate of variability of habitat attributes that can be used for “before and after” assessments. The 12 reference watersheds that are managed for minimal onsite human disturbance are well-suited for long-term ecological monitoring both to investigate effects of natural disturbances, such as climate change, and for parsing the effects of natural disturbances from those of management.

The WADNR-led stream research and monitoring at the OESF is an integral part of the state trust lands adaptive management process, which will use scientific findings as feedback to continuously improve management practices. Empirical data and research findings about ecological relationships and management effects will be used to refine the models used in forest land planning, to reduce uncertainties in the analyses of environmental effects, and to test habitat recovery projections in existing management plans. The lessons learned from applying adaptive management on the OESF have the potential to be useful to forest managers from other organizations, for example, on federal lands under the Northwest Forest Plan and private lands regulated by Washington forests practices.

Water quality regulatory agencies might benefit if they developed cooperative relationships with WADNR to plan and implement studies at the OESF that address questions that are of high priority to regulators.

Key points:

- A large, dedicated land base, flexible management mandate, and landscape-level research approach combine to make the OESF a potentially important source of scientific information for water quality regulatory agencies.
- The highest priority science needs of regulatory agencies that might be filled at the OESF would be an improved understanding of alternative harvest management practices that would provide better protection for water quality and aquatic biota, and a better understanding of sources of Hg in aquatic food chains such as land management and atmospheric deposition of Hg and the nutrient sulfur.
- Existing environmental monitoring datasets and research from the OESF might be of immediate use to regulatory agencies, and additional benefits might be gained by cooperating with WADNR to plan and implement experiments on the OESF that address questions of high regulatory interest.

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