Chapter 4: Ecoregion 6.2.3 Columbia Mountains/ Northern Rockies: Priest River Experimental Forest, Idaho

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Introduction

This chapter reviews and synthesizes research on factors associated with stream water quality at the Priest River Experimental Forest (PREF). In particular, it is intended to inform regional water quality regulatory agencies, such as Idaho Department of Environmental Quality (IDEQ) and Idaho Department of Lands (IDL) on PREF's available resources and its potential usefulness for conducting synthetic and field research designed to increase science-based knowledge on factors associated with stream water quality.

Research History

The PREF was established by the U.S. Forest Service (USFS) in 1911 to promote forest research. Early studies focused on the ecology of northern Rocky Mountain coniferous forests and reforestation problems that occurred after the "Big Burn," a regionwide, catastrophic, wildland fire in 1910. Over the years, USFS scientists and their partners have cooperated on long-term ecological research at the PREF. They have investigated factors influencing wildland fire, hydrology, silviculture, forest ecology, forest genetics, and the effects of insects and diseases on the health of Rocky Mountain conifers (see Graham 2004, Wellner 1976). Researchers from the University of Idaho, University of Montana, Washington State University, as well as federal, state, and Canadian land management agencies have also conducted a wide variety of studies at the PREF. Research conducted at the PREF has resulted in more than 650 publications.

Availability of Publications and Data

The PREF has been a monitoring site (site No. ID02) since 2003 within the National Atmospheric Deposition Program (NADP), which is a nationwide network that monitors precipitation chemistry, including acid rain, and is available online (NADP 2017). Streamflow data since 1939 for Benton Creek gaging dam are archived at the Moscow Forestry Sciences Laboratory in Moscow, Idaho, and the USFS Rocky Mountain Research Station (RMRS) archive and are available online (see Link et al. 2015). Daily weather records may also be accessed online (USDC NOAA 2017). Snowpack

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data collected since 1937 at Benton Meadow, elevation 710 m, and at Benton Spring (Station ID: 16A03), elevation 1470 m, are available online (see USDA NRCS 2017). Additional information on research products from the PREF are available on its website (USDA FS 2017).

Site Description

The PREF lies within the Idaho Panhandle National Forest and is administered by the RMRS, with assistance from the USFS Northern Region. The PREF headquarters is onsite and includes short-term housing for researchers, laboratory and office space, conference facilities, and an active forest nursery (fig. 4.1).

The PREF (lat. 48.351° N, long. 116.835° W) is located on federal land officially dedicated to research. It is within the moist mixed-coniferous forests of northern Idaho on the west slope of the Selkirk Mountains. The PREF encompasses 2521 ha of mountainous forest and includes major forest types found in the northern Rocky Mountains. Its elevation ranges from 671 to 1798 m. Within its boundaries there are two main drainages: Benton Creek and Canyon Creek watersheds which are tributaries of Priest River within the Columbia River basin.

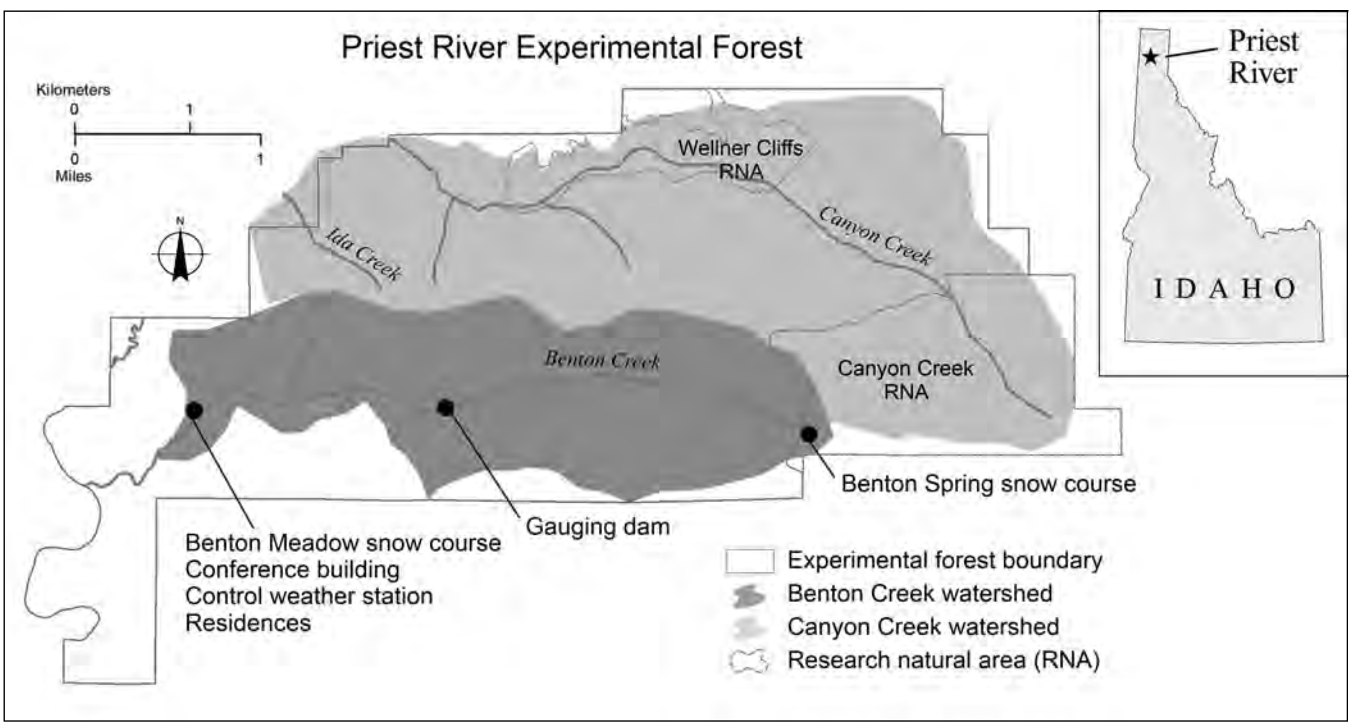

Figure 4.1—The Priest River Experimental Forest in northern Idaho (from Graham 2004).

The PREF's climate is transitional between northern Pacific coastal and continental (Finklin 1983) and resembles southeastern British Columbia's more than that of the neighboring Rocky Mountains or Cascade Range (Tinkham et al. 2015). Monthly mean temperatures at the headquarters weather station range from -4 ˚C in January to 18 ˚C in July. The average annual (water year) precipitation ranges from 817 mm at the PREF headquarters, elevation 710 m, to 925 mm at the Benton Spring rain gage, elevation 1455 m (Tinkham et al. 2015).

Soils at the PREF are derived from parent material of Belt Series bedrock that consists predominantly of gneiss and lesser inclusions of granite, sandstone, shale, and schist. Granitic bedrock is less resistant to weathering and usually has thicker soil mantles than gneiss or schist. Soils of lowland benches contain varves of silt, clay, and sand from glacial recession and outwash (McConnell 1965). Upland soil types differ with elevation and aspect. The most common soil types are (1) the Jughandle soil series, which has a coarse-loamy texture; (2) the Saltese soil series, which are mostly wet organic soils; and (3) the Springdale soil series, which have sandy-skeletal texture and a xeric moisture regime. Both Jughandle and Springdale soils contain pyroclastic material likely from the eruption of Mount Mazama, about 7,700 year BP (Zdanowicz et al. 1999).

Streams within the PREF have steep riffle-pool structure, with course boulder and gravel substrates and large wood in the streambed. Most first- through third-order streams are under a closed canopy of coniferous riparian vegetation consisting predominantly of western hemlock (*Tsuga heterophylla* Raf. Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), and western white pine (*Pinus monticola* Douglas ex D. Don).

About one-third of the PREF contains trees that originated following severe wildland fires in the mid-1800s and range in age from 120 to 160 years. Another third of the forest contains trees more than 200 years old, while some trees in riparian areas may exceed 300 years of age. The remaining forests consist of younger trees that have regrown after timber harvests or wildfires since the PREF was established, and of treeless alpine meadows and talus slopes. Analyses of forest cover and habitat types of the PREF found that plant communities were complex owing in part to abrupt changes in slope, aspect, and wet-to-dry habitats that promote intimately intermixed structural and successional vegetative stages among a diversity of plant species (Ferguson and Zack 2006).

The experimental forest contains a variety of actively managed and reserve areas, with ecological conditions ranging from recently manipulated to wild and pristine. There are two research natural areas (RNAs) within the PREF: Canyon Creek RNA, 395 ha, established in 1937, and Wellner Cliffs RNA, 125 ha, established in 2006 (fig. 4.1). These RNA sites are reserved for nondestructive research, education, and maintenance of biodiversity of climax vegetation and unique ecosystems. Within RNAs, permanent research installations, and experiments that might disturb soil or vegetation are not permitted. The remainder of the PREF is available for experimental manipulation of vegetation, soil, and other ecosystem components and has received a variety of treatments.

Reference Watershed

The Canyon Creek watershed is the closest approximation to an undisturbed drainage within the PREF and has, in the past, been considered a de facto reference (see Rabe and Cazier 1993). This status was applied to the Canyon Creek watershed because its headwaters originate from the pristine Canyon Creek RNA, and management activity applied downstream of the Canyon Creek RNA has been historically low in frequency and scale. Specifically, in 1970, a 23-ha buffered clearcut was applied in the farthest downstream area from the headwaters within the PREF (see Snyder 1973, Snyder et al. 1975); in 1978, harvest activities removed trees for road construction of three rights-of-way; and in 2004, thirty-seven small plots, each no more than 2.7 ha and totaling 80 ha (see Jain et al. 2008), were harvested to examine effects of fuel treatments on uplands away from Canyon Creek. The relatively low management activity within Canyon Creek watershed can be attributed to its limited road access compared with the adjacent Benton Creek drainage (fig. 4.1). Rabe and Cazier (1993) used Canyon Creek's water quality to represent relatively undisturbed, forested headwater basins in northern Idaho; however, this assumed status has not been validated through empirical study. In addition, future land management activities in Canyon Creek basin and how they will affect the condition of its streams are uncertain because, with the exception of the Canyon Creek and Wellner Cliffs RNAs, the USFS has not formally committed to maintain minimal human disturbance in this basin.

Biological Responses to Stream Nutrients N and P

Issues of concern—

Overenrichment of surface waters with nutrients can negatively affect ecosystem services, including water purification, fishing, hunting, recreational tourism, forest products, and storage of greenhouse gases (see Cummings et al. 2014). The economy of northern Idaho is largely dependent on many of these ecosystem services. Therefore, degradation of the surface waters of northern Idaho could have severe impacts on both the social and economic health of this region.

Expansion of urban land use and development in northern Idaho may lead to overenrichment of surface waters owing to the potential for increased discharge of nitrogen (N) and phosphorus (P). Although most of the land in the north Idaho counties is in public ownership, principally the USFS and the IDL, prime lake and river frontage has attracted increased seasonal and full-time residences, and resorts on private lands and leases from public agencies.

Surface water quality may also be threatened by large fires, which have occurred more frequently in northern Idaho in recent years owing, in part, to ongoing climate change (see Abatzoglou and Williams 2016). This is a concern because short-term increases in N and P in surface waters occur after disturbances to forest vegetation such as wildland fires and timber harvests. Retention of streamside vegetation as riparian buffers can reduce impacts of forest cutting on water quality and fish habitat (Kreutzweiser et al. 2005, Macdonald et al. 2003, Wilkerson et al. 2006), but severe wildland fires sometimes burn riparian vegetation along with the adjacent forest. Although, as burned lands revegetate several years after fires, water quality in streams returns to predisturbance conditions (see Minshall et al. 1997).

Findings From Studies

Baseline survey studies in Canyon Creek in 1993 and 1995 were conducted to describe the biotic and abiotic characteristics of this relatively undisturbed headwater stream (Rabe and Catts 1995, Rabe and Crazier 1993). The 1993 survey measured physical and chemical stream parameters in concurrence with stream macroinvertebrate community at the family level on the upper reaches of Canyon Creek. Chemical analyses found nitrate/nitrite levels of 0.2 mg/L and phosphate (PO_4^{3-}) were below detectable limits, although those limits were not reported. Stream sampling of the macroinvertebrate community found 33 taxa, which was similar to other reference streams. Rabe and Catts (1995) conducted a second biological survey of Canyon Creek in a reach downstream from the 1993 study. This study focused on surveying macroinvertebrate communities at the family level and stream physical characteristics but did not include chemical analyses of stream water. They found a diversity of 40 taxa, which was substantially different from the diversity observed in their Upper Canyon study as indicated by a 52 percent index of similarity between sites. Survey results (Rabe and Catts 1995, Rabe and Crazier 1993) provide a benchmark of stream conditions in two reaches of this relatively undisturbed mountain basin.

Other Factors Relevant to Biological Responses to Stream Nutrients N and P

A number of environmental factors that may directly or indirectly influence surface water quality and associated biological responses have been monitored and studied at the PREF, including weather (1911 to present), streamflow (1933 to present), snow accumulation (1937 to present), and atmospheric deposition chemistry (2003 to present). For example, Tinkham et al. (2015) analyzed long-term trends from 1912 to 2015 in streamflow, air temperature, and snowpack at the PREF. They found that the date of peak flow has shifted 3.75 days earlier each decade since 1950, and that there were significant trends of increasing mean annual temperature, decreasing snowpack, and earlier spring warming through the past century at the PREF (fig. 4.2). Collectively, these trends support the conclusion that climate has changed at the PREF over the past century.

The NADP precipitation chemistry monitoring at the PREF provides a record since 2003 of atmospheric deposition of nitrate (NO_3^-) in terms of both concentrations in precipitation and area loading. Nitrate deposition has shown large increases during years in which large, late-summer wildland fires occurred in the region (fig. 4.3). Measurements of orthophosphates (PO_4^{3-}) in atmospheric deposition only occasionally registered above the detection limit of 0.009 mg/L. Even when detectable, deposition of PO_4^{3-} is considered negligible at the PREF and is not included in the NADP annual summaries.

In the study of environmental pollutants, critical loads are science-based quantitative thresholds that define limits of atmospheric deposition below which significant harmful effects to the environment are not expected (cf. Nilsson and Grennfelt 1988). Critical loads for N, specific to the PREF and northern Idaho, have not been directly measured. However, critical loads of 2.7 to 9.2 kg N/ha/yr (Geiser et al. 2010), based on changes in lichen, and 5 to 7 kg N/ha/yr (Lilleskov 1999 as cited in Pardo et al. 2011), based on ectomycorrhizal fungi, both measured in the maritime forests of western Washington, have been used as proxies to estimate critical loads in northern Idaho. By comparison, McMurray et al. (2015) reported critical loads of 4 kg N/ha/yr based on changes in lichen assessed in northwestern Wyoming and eastern Montana, where climate is drier and more continental than at PREF. Comparing these estimated critical loads with the currently observed rate of atmospheric deposition of N at the PREF of 1.5 kg N/ha/yr suggests that this ecosystem has not been harmed by current levels of N deposition.

Cross-Site and Regional Studies

Atmospheric deposition data collected at the PREF have been included in national and regional analyses and maps regularly produced by the NADP, National Trends Network (NTN). These analyses have shown that atmospheric deposition of N and P at the PREF has been low compared to most sites in the continental United States and are typical of wildland sites in the northern Rocky Mountains. Atmospheric deposition measured at the NADP site in Glacier National Park (MT07), in northern Montana, showed similar high nitrate deposition in years when the region had large wildland fires. Climate and streamflow data from the PREF were used in long-term multisite analyses of ecological effects of climate change by Peters et al. (2013).

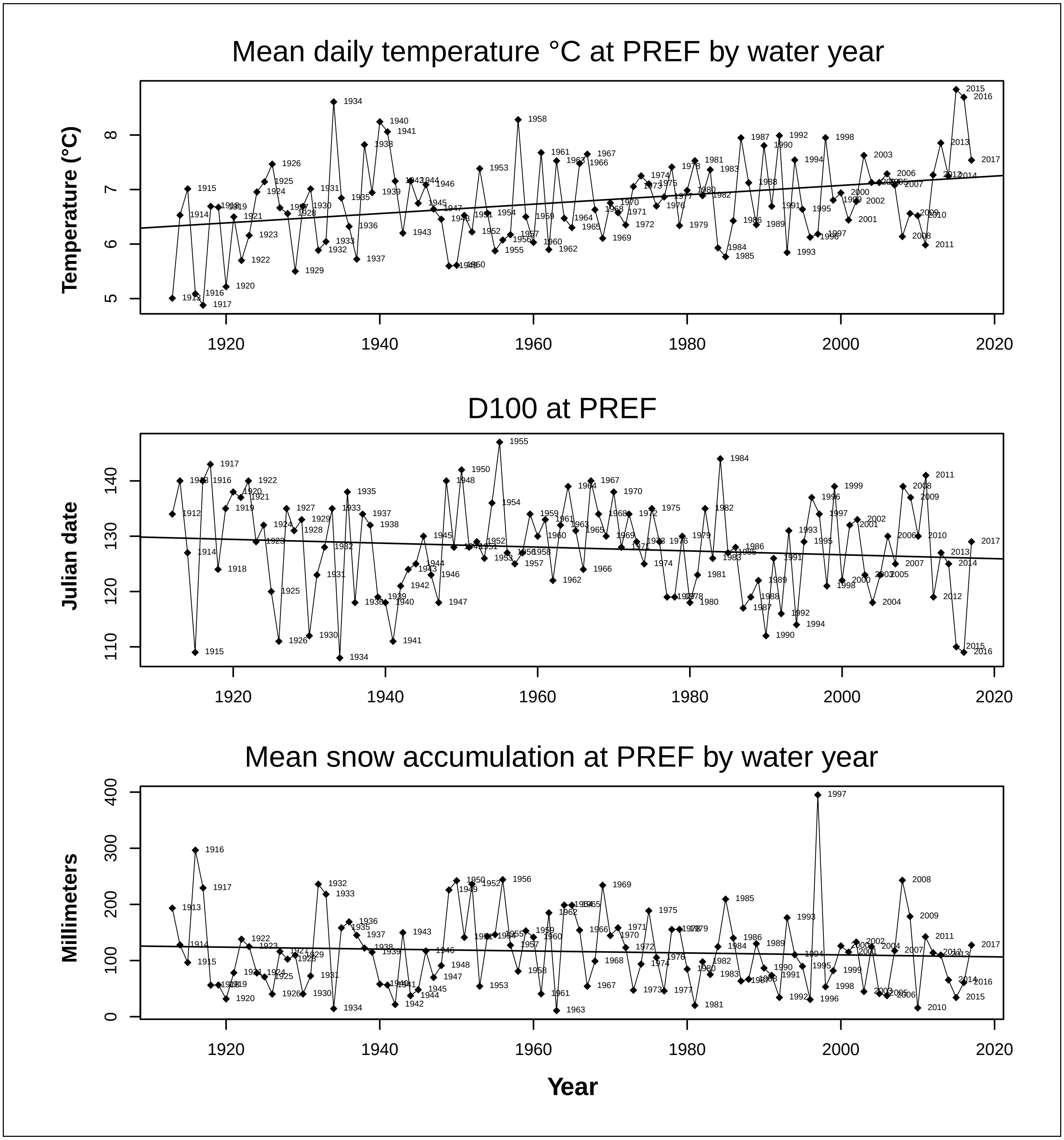

Figure 4.2—Climate variables from 1912 through 2015 at the Priest River Experiment Forest (PREF). D100 is a measure of the timing of spring warming calculated as the first Julian date on which cumulative degree-days in excess of 5 °C, beginning on January 1, are greater than 100.

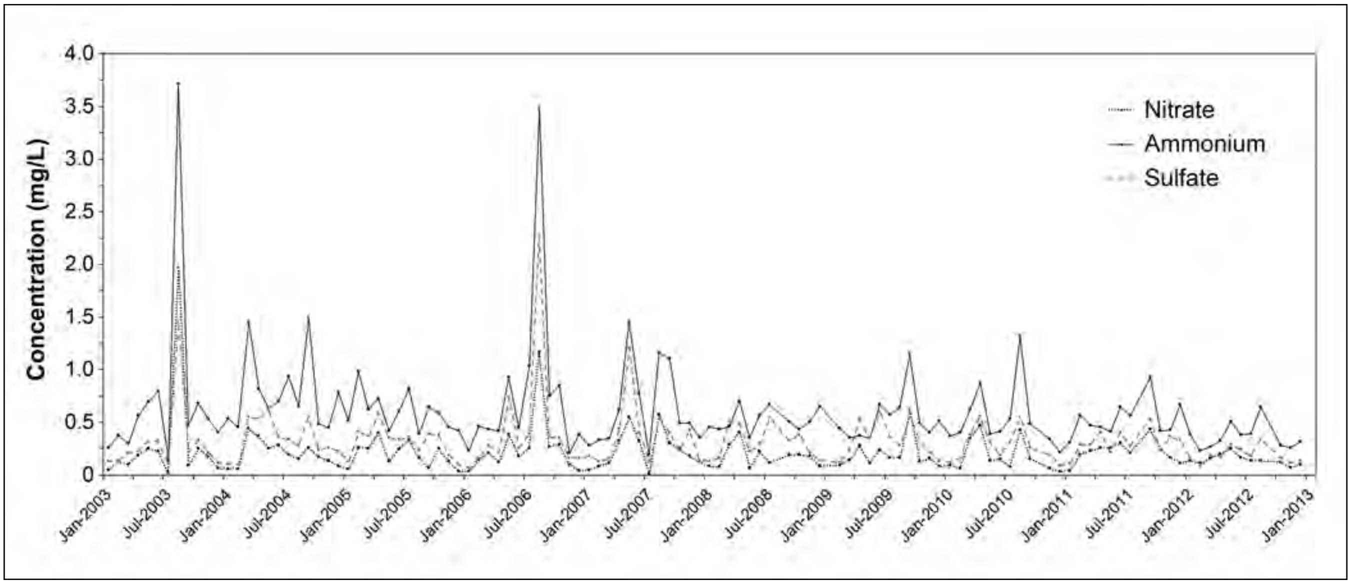

Figure 4.3—Concentrations of nitrate, ammonium, and sulfate in atmospheric deposition collected at the Priest River Experimental Forest National Atmospheric Deposition Program site from 2003 to 2012. The two outlier peaks in the deposition of nitrate in the summers of 2003 and 2006 coincided with large wildland fires in the region that occurred in late summer in both years (from Tinkham et al. 2015).

Dose-Response Studies

Dose-response studies have not been conducted at the PREF.

Responses to Management and Natural Disturbances

Only a few studies of limited scope have examined effects of harvesting on stream nutrients at PREF. Snyder (1973) and Snyder et al. (1975) examined the impact of forest harvest and slash burning treatments within the cedar-hemlock-grand fir ecosystem on stream water quality in Canyon Creek, Ida Creek, and Benton Creek (fig. 4.1) at the PREF. Their research used monitoring of stream water chemistry upstream, on, and downstream from, treatments over a 21-month period following treatment application. The treatments ranged in size from 2.6 to 44 ha with buffers ranging from 30 to 61 m. Results showed that NO_3^- concentrations were not detectibly different between sites upstream (control) and downstream from treatments although NO_3^- was eight times greater on treatment sites. Significant increases were detected downstream of the treatments for pH, electrical conductivity, turbidity, and suspended solids, although increases were not consistent among sites. Phosphorus and biological responses were not measured.

There is a long history of PREF studies of the effects of timber cutting on snowpack and water yield. Peak spring flows from snowmelt may affect water quality by increasing bank erosion and suspended sediment. Packer (1962) used PREF data to develop a model that accounted for 91.6 percent of variation in maximum snow water equivalent (SWE) based on elevation, aspect, snowpack density, and snowfall. He also reported that SWE increased with lower canopy density, with the highest SWE on clearcuts. From PREF studies, Haupt (1979a) reported that decreased canopy interception caused most of enhanced snow accumulation on clearcuts, and that this effect could persist for up to 34 years postharvest as canopy recovered. Haupt (1979b) further reported that north-facing clearcuts had greater SWE and contributed more to winter rain-on-snow flooding and spring peak flows than did south-facing clearcuts. He also found that spring snowmelt occurred earlier on south-facing clearcuts than in uncut forest and suggested that a mix of cut and uncut forest might reduce spring peak flows in south-facing basins by desynchronizing snowmelt. More recently, Elliot and Glaza (2009) monitored runoff and sediment loads from 10 small PREF watersheds (<7 ha) that received different harvesting treatments. Only an untreated watershed had perennial flows and, as expected, produced very low sediment yield. Dobre et al. (2011) studied the same watersheds and found large increases in SWE and snowmelt rates on the treatment that most drastically reduced canopy, a simulated wildland fire with salvage logging, but only minor effects on snowpack in treatments with less canopy reduction.

MacPhee and Cheng (1976) examined the effects on aquatic insects of a silicone-based chemical treatment that contained dimethylsiloxane polymers intended to increase soil moisture and water yield by inhibiting transpiration. It was hypothesized that the silicone emulsion might affect predator species of aquatic insects either directly from toxic exposure to the applied chemicals, or indirectly from loss of their food base. A spray of 375 L/ha of 5 percent antitranspirant was applied by helicopter directly to tree foliage on a 26-ha subwatershed of Benton Creek. Another untreated 20-ha subwatershed served as a control. Their results showed that aerially spraying the antitranspirant had little or no acute effect on aquatic insects for up to 96 hours after the treatment. No other study at the PREF has examined stream biological responses to management or research treatments.

No studies have been conducted to assess impact of natural disturbance on stream N and P within the PREF. Large-scale natural disturbances have been rare since the establishment of the PREF. The only significant wildland fire occurred in 1922 and burned about 160 ha on the Fox Creek drainage, south of the Benton watershed. Since then, spot fires from lightning have been quickly extinguished by effective fire suppression before any exceeded 2.8 ha. Insect-related tree mortality within the PREF has been typical of forests in the region. From 1998 to 2000, there was an outbreak of Douglas-fir bark beetles (*Dendroctonus pseudotsugae*) that seriously damaged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands.

Management response to this disturbance was a series of partial cuttings that removed infested or dying trees, followed by underburning and planting. These activities took place at mid-slope sites, presumably far enough from Benton and Canyon Creeks to have little or no effect on stream water quality, although no studies or monitoring were conducted to assess potential impacts.

Reliability and Limitations of Findings

Datasets and research results from the PREF can probably be applied to other forested headwater basins that have similar land uses in the northern Rocky Mountains. At sites that are dissimilar to the PREF, or where a high degree of accuracy is needed, a good option might be validation monitoring or experiments to test how well results from the PREF are representative of local conditions.

Research Needs

The highest priority need for the regional regulatory community is increased science-based knowledge on the impacts of timber harvesting on suspended sediments, streambank stability, and water temperature. This knowledge is needed, for example, to assist Idaho Department of Lands and its partners with validation or redesign of current Idaho state Forest Practices Act rules that protect water quality. The PREF might be used to conduct experimental studies to address this priority need.

Studies intended to test the effects of vegetative treatments on water quality at the PREF may, however, face two limitations: (1) topography and (2) INFISH (Inland Native Fish Strategy), (USDA FS 1995), which was incorporated into the 2015 Idaho Panhandle National Forest Plan (USDA FS 2015). Topography at the PREF may pose a challenge for study designs because it contains only two main streams with each stream having few definable tributaries. As a consequence, it may be difficult to identify enough subwatersheds for paired comparisons of treatment effects on water quality. Use of a nested study design approach might be necessary to overcome this limitation. INFISH includes riparian goals, riparian management objectives, standards, and guidelines that apply to management activities on national forests lands. Within PREF, INFISH requires riparian-dependent resources to receive primary emphasis within areas called riparian habitat conservation areas (RHCAs) that are adjacent to aquatic features. Management activities within RHCAs are subject to specific standards and guidelines intended to maintain the integrity of aquatic ecosystems and processes. This includes protection of associated fish habitats for west slope cutthroat trout (*Oncorhynchus clarkii lewisi*), which is a Northern Region sensitive species (IDFG 2019), and bull trout (*Salvelinus confluentus*), which is listed as threatened under the Endangered Species Act of 1973 (16 U.S.C. 15311536, 1538-1540) in accord with the "Biological Opinions" for bull trout (USDI FWS 1998). INFISH requirements may limit study designs because of restrictions on forest harvesting practices within RHCAs. For example, studies of forest thinning in stream buffers on federal land would be subject to INFISH requirements within RHCAs that extend a minimum of 91 m from perennial fish-bearing streams. Although, in principal, studies of forest harvest activities may be proposed within RHCAs, in practice, such studies would more likely be delayed or blocked by legal challenges under federal statutes than forest harvest activities outside of RHCAs. As a result, investigating tree harvesting with buffers less stringent than INFISH would probably be more feasible on private or state lands where state laws apply. Examples of management experiments performed on private lands were the studies of state-mandated buffers at the Mica Creek Experimental Watershed, where effects of road building and timber harvest on suspended sediment loads (Karwan et al. 2007), nutrient dynamics (Gravelle et al. 2009a), peak stream temperatures (Gravelle and Link 2007), and aquatic macroinvertebrate populations (Gravelle et al. 2009b) were investigated.

Management practices that comply with INFISH guidelines might be tested for effects of harvesting and other vegetative treatments on water quality at the PREF. Results of such experiments might be useful to land managers and regional regulators to better understand how management of federal lands affects water quality in the region as a whole, particularly given that federal lands make up a substantial portion of the land base in the northern Rocky Mountains.

Additional science-based knowledge that might be addressed through research at the PREF that is presently of lower priority to the regulatory community includes increased understanding of how stream nutrient concentrations and biological communities are affected by forest harvesting practices.

Potential Utility to Water Quality Regulatory Agencies

Long-term and ongoing monitoring datasets (weather, streamflow, snowpack, NADP) are immediately available and perhaps the most valuable asset that the PREF offers to address the knowledge needs of regional regulators. These data can be used to interpret the results of short-term studies by providing a baseline of water quality and its range of natural variability from day to day and season to season in the relatively undisturbed forest of Canyon Creek watershed.

PREF's long-term weather observations, snow surveys, and streamflow datasets provide evidence of local climate change and its impacts on ecosystem processes (e.g., Tinkham et al. 2015). These datasets can be used by regulatory agencies to assess how regional stream conditions may be changing under ongoing climate change. For example, the rising trend of mean annual temperature, decreasing snowpack, and increasingly earlier spring warming (fig. 4.2) may advance regional snowpack melt and boost peak runoff. These changes have many potential implications for water quality and aquatic processes (see Burns et al. 2011) that may be linked, for instance, to earlier onset of high flows in spring and low flows in summer and associated changes in streambank stability and the timing of surface water turbidity.

The IDEQ might benefit if it implemented aquatic biological monitoring at the PREF as part of its ongoing aquatic biology survey and water quality monitoring programs. By implementing its own monitoring at the PREF, IDEQ would ensure that results would be comparable with aquatic monitoring practices elsewhere in the state. Results from aquatic biological monitoring, particularly in relatively undisturbed Canyon Creek watershed, could also be used to detect whether stream conditions have changed in response to drivers such as climate change since they were last measured at the PREF decades ago (see Rabe and Catts 1995, Rabe and Cazier 1993). An example of a water quality monitoring and assessment program that might be advantageous for IDEQ to implement at the PREF is its Beneficial Use Reconnaissance Program (BURP) (IDEQ 2019a). This program is carried out by seasonal teams that have conducted aquatic biological surveys and collected stream habitat data throughout Idaho since 1993. Results of BURP monitoring at the PREF might be included in the Idaho Integrated Report (IDEQ 2019b), which summarizes the condition of waters throughout Idaho.

Key points:

- Long-term and ongoing monitoring at the PREF includes data on streamflow, stream water chemistry, weather, snowpack, atmospheric deposition chemistry, and vegetation composition. These datasets are immediately available and are a valuable asset that the PREF offers to support research on stream biological responses to N and P or other factors associated with stream water quality.
- Studies at the PREF on effects of forest management have primarily focused on the terrestrial components of the ecosystem, although a few studies have examined effects of harvesting on stream nutrients.
- Biological responses to stream N and P have not been studied at the PREF; however, stream surveys at the PREF have measured the composition of aquatic communities under low, ambient stream water concentrations of N and P characteristic of relatively undisturbed watershed conditions.
- The highest priority need of the regulatory community that may be addressed by research at the PREF is an increase of science-based knowledge on the effects of forest harvesting methods on stream water quality and stream channel stability. However, such studies at PREF would be constrained by topography and INFISH rules.

Biological Responses to Stream Nutrients Other Than N and P

Issues of Concern

There are currently no issues of concern related to nutrients other than N and P across the northern Rocky Mountain region. However, in some localized areas, drainage from active or abandoned mines or mine spoil disposal sites may degrade surface water quality by introducing high levels of suspended sediments, acidity, sulfate (SO_4^{2-}), and dissolved iron (Fe), magnesium (Mn), and toxic heavy metals (see Reece et al. 1978). Where it occurs, mine drainage may detract from beneficial uses such as fish habitat, drinking water supply, and water-contact recreation. The PREF has not been subjected to mining and spoil disposal disturbances, so its streams might be used as baseline for conditions in the absence of mining-related disturbances.

Findings From Studies

Rabe and Cazier (1993) analyzed Canyon Creek stream water for nutrients other than N and P, including calcium (Ca^{2+}), and magnesium (Mg^{2+}) concurrently with surveys of stream macroinvertebrates. They reported potassium (K^+), sodium (Na^+), aluminum (Al^{3+}), Fe, and zinc (Zn) were below the detectable limits of the analyses but gave no estimates of specific detectable limits. They also reported water temperature, pH, alkalinity, conductivity, turbidity, total dissolved solids, and fecal coliform.

Atmospheric deposition of several nutrients other than N and P have been monitored at the PREF since 2003 as part of the NADP network (see NADP 2017). Measurements consist of wet deposition that is collected weekly and analyzed for Ca^{2+}, Mg^{2+}, K^+, Na^+, chloride (Cl^-), SO_4^{2-}, pH, and conductivity. Current levels of deposition of these nutrients at the PREF are low.

Responses to Management and Natural Disturbances

Few studies have examined the treatment response of nutrients other than N and P in streams at the PREF. Snyder (1973) and Snyder et al. (1975) included nutrients other than N and P in their studies of effects on stream water of clearcutting and slash-burning treatments. Their analyses of stream chemistry included bicarbonate (measured as $Ca(HCO_3)_2$), SO_4^{2-}, Cl^-, Na^+, K^+, Mg^{2+}, and Ca^{2+}, as well as electrical conductivity, turbidity, and filterable solids. The management treatments they studied (see previous section under "Management Treatment Response Studies") did not affect these chemical constituents except for carbonate, which increased. Effects of natural disturbances on nutrients other than N and P and associated biological responses have not been studied at the PREF.

Reliability and Limitations of Findings

The few datasets and research results for the PREF related to nutrients other than N and P may apply to other forested headwater basins that have similar land uses in the northern Rocky Mountains. At sites that are dissimilar to the PREF, or where a high degree of accuracy is needed, validation monitoring or experiments might be considered to test how well results from the PREF predict local conditions.

Research Needs

Presently, there are no science-based knowledge needs that are a priority for the regional regulatory community related to nutrients other than N and P that could be addressed through research at the PREF.

Potential Utility to Water Quality Regulatory Agencies

The findings on the effects of forest management on streams (Snyder 1973, Snyder et al. 1975) may be useful for developing water quality standards and best management practices for forestry operations. The surveys of stream invertebrates and nutrients other than N and P in an undisturbed stream (Rabe and Cazier 1993) may provide data that agencies can use as a baseline for developing water quality criteria and desired future condition when restoring affected surface waters.

The NADP data available for atmospheric deposition of nutrients at the PREF are useful for assessing whether atmospheric inputs are affecting the water quality of the region. These data provide status and trends of deposition of a broad spectrum of potential pollutants and might serve as early warning if, in the future, deposition of a pollutant such as SO_4^{2-} were to approach levels that could affect water quality.

Key points:

- Stream surveys of relatively undisturbed Canyon Creek (Rabe and Catts 1995, Rabe and Cazier 1993) have documented physical and biological characteristics and ambient nutrients other than N and P, which might serve as a baseline for developing water quality criteria.
- Few studies have examined the treatment response of nutrients other than N and P in streams at the PREF.
- Atmospheric deposition monitoring at the PREF could serve as early warning if, in the future, deposition of pollutants from the air were to approach levels that could affect water quality.

Overview and Synthesis

The PREF contains headwater stream basins that are typical of mixed-conifer forests of the northern Rocky Mountains. Long-term monitoring at the PREF has included streamflow, stream water chemistry, weather, snowpack, atmospheric deposition chemistry, and vegetation composition. A small number of short-term studies of streams have been conducted at the PREF, including effects of forest harvesting on stream chemistry in the 1970s. Surveys of stream macroinvertebrate, water quality, and physical habitat measurements were simultaneously conducted in the 1990s in relatively undisturbed Canyon Creek, which served as a de facto reference basin. However, the future status of Canyon Creek basin is uncertain because it has not been officially reserved to be managed for minimal human disturbance.

Research at the PREF can provide regional regulators with a more comprehensive understanding of the effects of forest management and other disturbances on water quality for northern Idaho. However, experimental studies at the PREF will likely be constrained to study designs such as nesting of watersheds to compensate for the PREF's limited number of subwatersheds. Investigations within RHCAs within PREF will also likely be required to comply with relatively stringent INFISH requirements.

PREF's long-term and ongoing ecosystem monitoring and past stream surveys of relatively undisturbed forest in the Canyon Creek basin are ideally suited to support research designed to provide on-the-ground evidence of "potential natural vegetation," which would be useful for practical purposes such as development of total maximum daily loads, water quality criteria, and best management practices.

References

Abatzoglou, J.T.; Williams, A.P. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences. 113: 11770–11775.

Burns, D.A.; Lynch, J.A.; Cosby, B.J.; Fenn, M.E.; Baron, J.S. 2011. National Acid Precipitation Assessment Program Report to Congress 2011: an integrated assessment. Washington, DC: National Science and Technology Council. 114 p.

Cummings, T.; Blett, T.; Porter, E.; Geiser, L.H.; Graw, R.; McMurray, J.; Perakis, S.S.; Rochefort, R.M. 2014. Thresholds for protecting Pacific Northwest ecosystems from atmospheric deposition of nitrogen. National Park Service Natural Resource Report NPS/PWRO/NRR-2014/823. Washington, DC: U.S. Department of the Interior, National Park Service. 56 p.

Dobre, M.; Elliot, W.J.; Wu, J.Q.; Link, T.E.; Miller, I.S. 2011. Effects of forest cover and environmental variables on snow accumulation and melt. In: Medley, C.N.; Patterson, G.; Parker, M.J., eds. Proceedings of the fourth interagency conference on research in the watersheds: observing, studying, and managing for change. U.S. Geological Survey Scientific Investigations Report 2011–5169. Reston, VA: U.S. Department of the Interior, Geological Survey: 14–19. https://pubs.usgs.gov/sir/2011/5169/. (17 November 2020).

Elliot, W.J.; Glaza, B.D. 2009. Impacts of forest management on runoff and erosion. In: Webb, R.M.T.; Semmens, D.J., eds. Proceedings of the third interagency conference on research in the watersheds: planning for an uncertain future: monitoring, integration, and adaptation. U.S. Geological Survey Scientific Investigations Report 2009-5049: Reston, VA: U.S. Department of the Interior, Geological Survey: 117–127. https://pubs.usgs.gov/sir/2009/5049/. (17 November 2020).

Ferguson, D.E.; Zack, A.C. 2006. Establishment record for the Wellner Cliffs Research Natural Area. Gen. Tech. Rep. RMRS-GTR-170. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 40 p.

Finklin, A.I. 1983. Climate of Priest River Experimental Forest, northern Idaho. Gen. Tech. Rep. INT-GTR-159. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 53 p.

Geiser, L.H.; Jovan, S.E.; Glavich, D.A.; Porter, M.K. 2010. Lichen-based critical loads for atmospheric nitrogen deposition in western Oregon and Washington forests, USA. Environmental Pollution. 158: 2412–2421.

Graham, K.L. 2004. History of the Priest River Experiment Station. Gen. Tech. Rep. RMRS-GTR-129. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 71 p.

Gravelle, J.A.; Ice, G.; Link, T.E.; Cook, D.L. 2009a. Nutrient concentration dynamics in an inland Pacific Northwest watershed before and after timber harvest. Forest Ecology and Management. 257: 1663–1675.

Gravelle, J.A.; Link, T.E. 2007. Influence of timber harvesting on headwater peak stream temperatures in a northern Idaho watershed. Forest Science. 53: 189–205.

Gravelle, J.A.; Link, T.E.; Broglio, J.R.; Braatne, J.H. 2009b. Effects of timber harvest on aquatic macroinvertebrate community composition in a northern Idaho watershed. Forest Science. 55: 352–366.

Haupt, H.F. 1979a. Effects of timber cutting and revegetation on snow accumulation and melt in north Idaho. Res. Pap. INT-224. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 14 p.

Haupt, H.F. 1979b. Local climatic and hydrologic consequences of creating openings in climax timber of north Idaho. Res. Pap. INT-223. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 43 p.

Idaho Department of Environmental Quality [IDEQ]. 2019a. Beneficial Use Reconnaissance Program. http://deq.idaho.gov/water-quality/surface-water/monitoring-assessment/burp.aspx. (1 July 2019).

Idaho Department of Environmental Quality [IDEQ]. 2019b. Integrated Report. http://www.deq.idaho.gov/water-quality/surface-water/monitoring-assessment/integrated-report.aspx. (1 July 2019)

Idaho Department of Fish and Game [IDFG]. 2019. Species Conservation Status. https://idfg.idaho.gov/species/taxa/list?usfs1[]=Sensitive&usfs1[]=Threatened&usfs1[]=Endangered. (1 July 2019).

Jain, T.B.; Graham, R.T.; Sandquist, J.; Butler, M.; Brockus, K.; Frigard, D.; Cobb, D.; Sup-Han, H.; Halbrook, J.; Denner, R.; Evans, J.S. 2008. Restoration of northern Rocky Mountain moist forests: integrating fuel treatments from the site to the landscape. In: Deal, R.L., ed. Integrated restoration of forested ecosystems to achieve multi-resource benefits: proceedings of the 2007 national silviculture workshop. Gen. Tech. Rep. PNW-GTR-733. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 147–172.

Karwan, D.L.; Gravelle, J.A.; Hubbart, J.A. 2007. Effects of timber harvest on suspended sediment loads in Mica Creek, Idaho. Forest Science. 53: 181–188.

Kreutzweiser, D.P.; Capell, S.C.; Good, K.P. 2005. Macroinvertebrate community response to selective logging in riparian and upland areas of headwater catchments in a northern hardwood forest. Journal of the North American Benthological Society. 24: 208–222.

Lilleskov, E.A. 1999. Decline of above- and belowground ectomycorrhizal fungal diversity over an atmospheric nitrogen deposition gradient near Kenai, Alaska. Ithaca, NY: Cornell University. 198 p. Ph.D. dissertation.

Link, T.E.; Wei, L.; Denner, R.J. 2015. Streamflow data for the Priest River Experimental Forest. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2015-0006. (25 October 2020).

Macdonald, J.S.; MacIsaac, E.A.; Herunter, H.E. 2003. The effect of variable retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. Canadian Journal of Forest Research. 33: 1371–1382.

MacPhee, C.; Cheng, F. 1976. Aquatic studies with silicone antitranspirant. Tech. Rep. 3. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 10 p.

McConnell, R.C. 1965. Soil survey, Priest River Experimental Forest. [Progress Report (in-service)]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 7 p.

McMurray, J.A.; Roberts, D.W.; Geiser, L.H. 2015. Epiphytic lichen indication of nitrogen deposition and climate in the northern Rocky Mountains, USA. Ecological Indicators. 49: 154–161.

Minshall, G.W.; Robinson, C.T.; Lawrence, D.E. 1997. Postfire responses of lotic ecosystems in Yellowstone National Park, USA. Canadian Journal of Fisheries and Aquatic Sciences. 54: 2509–2525.

National Atmospheric Deposition Program [NADP]. 2017. Priest River Experimental Forest atmospheric deposition records. http://nadp.sws.uiuc.edu/data/sites/siteDetails.aspx?net=NTN&id=ID02. (25 October 2017).

Nilsson J.; Grennfelt, P., eds. 1988. Critical loads for sulfur and nitrogen. Copenhagen, Denmark: Nordic Council of Ministers.

Packer, P.E. 1962. Elevation, aspect, and cover effects on maximum snowpack water content in a western white pine forest. Forest Science. 8: 225–235.

Pardo, L.H.; Robin-Abbott, M.J.; Driscoll, C.T. 2011. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the United States. Ecological Applications. 21: 3049–3082.

Peters, D.P.C.; Laney, C.M.; Lugo, A.E. [et al.]. 2013. Long-term trends in ecological systems: a basis for understanding responses to global change. Technical Bulletin 1931. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. 394 p.

Rabe, F.W.; Catts, D. 1995. Survey of lower Canyon Creek located in the Priest River Experimental Forest, Idaho. 14 p. Unpublished report. On file with: Moscow Forestry Sciences Laboratory, 1221 S Main Street, Moscow, ID 83843.

Rabe, F.W.; Cazier, L.D. 1993. Survey of three steep gradient reference streams in northern Idaho. 37 p. Unpublished report. On file with: Moscow Forestry Sciences Laboratory, 1221 S Main Street, Moscow, ID 83843.

Reece, D.E.; Felkey, J.R.; Wai, C.M. 1978. Heavy metal pollution in the sediments of the Coeur d'Alene River, Idaho. Environmental Geology. 2: 289–293.

Snyder, G.G. 1973. The effects of clearcutting and burning on water quality. Moscow, ID: University of Idaho. 69 p. M.S. thesis.

Snyder, G.G.; Haupt, H.F.; Belt, G.H., Jr. 1975. Clearcutting and burning slash alter quality of stream water in northern Idaho. Res. Pap. INT-168. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 34 p.

Tinkham, W.T.; Denner, R.; Graham, R.T. 2015. Climate, snowpack, and streamflow of Priest River Experimental Forest, revisited. Gen. Tech. Rep. RMRS-GTR-331. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1995. Inland Native Fish Strategy (INFISH) environmental assessment: decision notice and finding of no significant impact. Land Management Plan: 2015 Revision. Idaho Panhandle National Forests. Federal Register. 60(150): 39927–39928. https://www.gpo.gov/fdsys/granule/FR-1995-08-04/95-19228/content-detail.html. (19 February 2021).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2017. Experimental forests and ranges: Priest River Experimental Forest. Rocky Mountain Research Station. http://www.fs.fed.us/rmrs/experimental-forests-and-ranges/priest-river-experimental-forest. (25 October 2020).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2017. Snow survey. Idaho. http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/id/snow. (19 February 2020).

U.S. Department of Commerce, National Oceanic and Atmospheric Administration [USDC NOAA]. 2017. Priest River Experimental Forest. Network ID 107386. National Centers for Environmental Information. https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00107386/detail. (25 October 2020).

U.S. Department of the Interior, Fish and Wildlife Service [USDI FWS]. 1998. Endangered and threatened wildlife and plants: determination of threatened status for the Klamath River and Columbia River distinct population segments of bull trout final rule. Federal Register June. 50 CFR Part 17, RIN1018-AB94. 63(111): 31647–31674.

Wellner, C.A. 1976. Frontiers of forestry research: Priest River Experimental Forest, 1911-1976. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 148 p.

Wilkerson, E.; Hagan, J.M.; Siegel, D.; Whitman, A.A. 2006. The effectiveness of different buffer widths for protecting headwater stream temperature in Maine. Forest Science. 52: 221–233.

Zdanowicz, C.M.; Zielinkski, G.A.; Germani, M.S. 1999. Mount Mazama eruption: Calendrical age verified and atmospheric impact assessed. Geology. 27: 621–624.