U.S. Fish and Wildlife Service

Pilot project to develop a long-term aquatic monitoring program for climate change at National Wildlife Refuges in the Columbia-Pacific Northwest Region

Final Report

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On the cover: *Personnel conduct electrofishing survey in Bridge Creek at Malheur NWR. (Photo: S. Lohr)*

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PILOT PROJECT TO DEVELOP A LONG-TERM AQUATIC MONITORING PROGRAM FOR CLIMATE CHANGE AT NATIONAL WILDLIFE REFUGES IN THE COLUMBIA-PACIFIC NORTHWEST REGION FINAL REPORT

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PILOT PROJECT TO DEVELOP A LONG-TERM AQUATIC MONITORING PROGRAM FOR CLIMATE CHANGE AT NATIONAL WILDLIFE REFUGES IN THE COLUMBIA-PACIFIC NORTHWEST REGION
FINAL REPORT

Executive Summary – The U.S. Fish and Wildlife Service has developed and is implementing a strategic plan to help ensure the long-term sustainability of natural resources (i.e., fish, wildlife, plants, and their habitats) under conditions expected from climate change and other environmental stressors. To support the strategic plan in the Columbia-Pacific Northwest Region, Service programs (Refuges, Fish and Aquatic Conservation (FAC), and Water Resources) are collaborating to develop and implement a long-term aquatic monitoring program for evaluating effects of climate change at National Wildlife Refuges (NWRs). The goal of the monitoring program is to evaluate evidence of climate change in physical and habitat attributes at NWRs and associated changes in aquatic communities. Specific objectives are to: 1) establish long-term sentinel sites representing NWRs across the range of ecoregions in the Columbia-Pacific Northwest Region; 2) describe how physical and habitat attributes vary through time; 3) describe how biological attributes vary through time; 4) analyze for potential temporal change in attributes by ecoregion; and 5) assess relationships in physical, habitat, and biological attributes by ecoregion.

The project has three stages: reconnaissance; pilot application; and long-term implementation. Reconnaissance consisted of screening and geospatial assessment of streams relative to various factors (e.g., ecoregion, ability to wade, existing information, location and length within a NWR, prevalence of non-climate stressors within the watershed) to assess potential sentinel sites. Sentinel sites were established at five NWRs each representing one of three major ecoregions—Marine West Coast Forest (Muddy Creek at William L. Finley NWR and Omeara Creek at Willapa NWR), Northwestern Forested Mountains (Little Pend Oreille River at Little Pend Oreille NWR and Myrtle Creek at Kootenai NWR), and North American Deserts (Bridge Creek at Malheur NWR).

Pilot application was conducted during 2015–2017 using methods developed by the Environmental Protection Agency. The intent of the pilot application was to assess our ability to consistently generate temperature and stream flow data, to describe variability of four categories of habitat variables and judge their relevance to potential effects of climate change based on annual habitat surveys, and to describe fish assemblage characteristics based on up to three fish surveys during each year of the pilot project. Metrics characterizing fish assemblages included: 1) general descriptors (e.g., species richness among all surveys at a sentinel site); 2) indices of similarity between surveys based on species presence-absence and relative abundance; 3) ecological classification based on species frequency of occurrence and relative abundance among all surveys; and 4) indices of temperature class and tolerance for each survey. Purposes for assessing information from the pilot application were to generate a baseline, which would facilitate comparisons with data collected in the future; and allow evaluation of the performance, logistical constraints, and sustainability of our activities, from which recommendations were developed for long-term implementation.

We generated complete records for air and water temperature at four of the five sites, with air temperature records provided by Water Resources for one. We were unable to generate stream flow records at two sites, however a limited record was generated for one site and Water Resources provided records for two. The stream channel and riparian habitat categories were less variable among years than the substrate and fish cover habitat categories. Although stream conditions precluded conducting some surveys, we successfully characterized fish assemblages at all sites. A total of 30 species were collected, and the majority of assemblage indices indicated substantial similarity in species presence-absence and relative abundance between surveys at most sites. Overall, we concluded that performance and logistical challenges precluded our ability to adequately monitor stream flow at most sites. In addition, consistently high variability in two categories of habitat variables, fish cover and substrate composition, likely limits their utility for long-term monitoring. Although we concluded that the level of effort to continue the pilot application was not sustainable for long-term implementation, the pilot application generated an adequate baseline to which data generated from future surveys conducted at sustainable frequencies and intensities can be assessed.

Recommendations for the third stage, long-term implementation of the monitoring program, are intended to improve the efficiency of monitoring physical, habitat, and biological attributes at sentinel sites, and encourage sustainability of the program. For physical and habitat attributes, recommendations are to: maintain loggers to continuously monitor air and water temperature at each sentinel site; continue using stream flow data generated by Water Resources at two sentinel sites and discontinue efforts to monitor stream flow at three sites; assess ability to make inferences about stream flow at the three ungauged sites based on nearby existing gauge stations; and focus habitat surveys on variables that can be consistently collected and likely most responsive to anticipated effects of climate change (i.e., stream channel and riparian vegetation categories of variables). For habitat and biological attributes, recommendations are to: conduct habitat and fish surveys at one sentinel site per year; establish a rotating schedule so that each sentinel site is surveyed at 5-year intervals; identify conditions that would necessitate surveying more frequently; conduct all surveys with a composite crew representing personnel from all FAC offices to enhance sustainability and encourage continuity in the application of program protocols over time; and personnel from each office would annually update databases and perform analyses.

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Introduction

Effects of accelerating climate change on natural resources and associated ramifications for humans represent an unprecedented conservation challenge. In response, the U.S. Fish and Wildlife Service (Service) has developed and is implementing a strategic plan (USFWS 2010) to help ensure the long-term sustainability of natural resources (i.e., fish, wildlife, plants, and their habitats) under conditions expected from climate change and other environmental stressors. The Strategic Plan for Climate Change acknowledges considerable uncertainties in the specific conditions and rate of change for habitat attributes anticipated to result from climate change, and describes three strategies—adaptation, mitigation, and engagement—that the Service will use to address conservation under predicted environmental conditions and accompanying uncertainties.

To support implementation of the Service's Strategic Plan for Climate Change relative to fisheries and aquatic resources in the Columbia-Pacific Northwest Region, Fish and Aquatic Conservation (FAC) Project Leaders identified three areas of emphasis during their coordination meeting in 2011. These areas were: 1) National Fish Hatchery programs and operation, 2) key aquatic species, and 3) aquatic resources at National Wildlife Refuges (NWRs). All areas of emphasis were intended to support actions primarily addressing a better understanding of the status and trends of aquatic species and their habitats relative to climate change, potential adaptation strategies, and inventory and monitoring. For the third area, the primary action was for FAC to assist NWRs in designing and implementing a long-term aquatic monitoring program for evaluating effects of climate change.

Lohr et al. (2016) described in detail the development of a long-term aquatic monitoring program for climate change at the Columbia-Pacific Northwest Region NWRs. The goal of the monitoring program is to evaluate evidence of climate change in physical attributes at NWRs and associated changes in aquatic communities. Specific objectives include the following:

1. Establish long-term sentinel[1] sites representing NWRs across the range of ecoregions in the Columbia-Pacific Northwest Region.
2. Describe how physical and habitat attributes vary through time.
3. Describe how biological attributes vary through time.
4. Analyze for potential temporal change in attributes by ecoregion.
5. Assess relationships in physical, habitat, and biological attributes by ecoregion.

In general, the monitoring program relies on temporal analyses of physical, habitat, and biological attributes at each sentinel site. Because questions of climate change effects primarily focus on long-term patterns in temperature, precipitation, stream flow, aquatic habitats, and biotic variables (EPA 2012), physical and habitat attributes selected for the monitoring program were air and water temperatures, stream flow, and stream habitat. Because aquatic vertebrates are relatively long-lived and their assemblages reflect the integration of prevailing conditions through time, biological attributes selected were various characteristics of fish assemblages.

[1] As used here, sentinel sites are NWRs where a stream reach has been identified and standardized methods to describe and measure physical, habitat, and biological attributes are applied through time, allowing assessment of temporal changes and associations among attributes at each reach.

The Service implemented the program during a three-year period (2015–2017) as a pilot project to assess its performance, logistical constraints, and sustainability for long-term implementation, as well as to establish baseline information. Specifically, the pilot project addressed the ability to consistently generate temperature and stream flow data, to collect precise data on variables characterizing habitat and their relevance to potential effects of climate change, and to collect information on the variability of fish assemblage characteristics within and among annual surveys. This report describes the activities and results for the pilot implementation of the monitoring program at each sentinel site during 2015–2017 and lists recommendations for long-term implementation.

Methods

Sentinel Site Selection

A two-phase approach was used to assess potential sentinel sites for long-term monitoring, which involved an initial screening and a geospatial assessment (Lohr et al. 2016). A cross-program workgroup, with representatives from NWRs, FAC, and Water Resources, identified the following attributes of streams, NWRs, and associated watersheds to consider in the initial screening (i.e., first phase):

- Stream habitat (non-tidal and wadeable)
- Fish fauna diversity (relatively high)
- Prevalence of non-climate-related stressors (relatively unlikely to be severely affected by water diversion, development, logging)
- Stream length and watershed within NWR (substantial portion of stream and watershed on a NWR)
- Existing information or ongoing data collection (substantial amount of relevant information exits or currently being generated)
- NWR location (at least one suitable sentinel site represented in each of the three Level I ecoregions (Commission for Environmental Cooperation 1997) of the Columbia-Pacific Northwest Region–Marine West Coast Forest, Northwestern Forested Mountains, and North American Deserts)
- Interest to pursue monitoring (NWR and FAC in agreement)

Based on these considerations, sites that appeared most suitable for monitoring were then subjected to a geospatial assessment (second phase). The lowermost points for potential stream survey reaches (e.g., at a NWR boundary, stream gauge station, or upstream of tidal influence) were identified, and regional and national datasets (i.e., U.S. Geological Survey Streamstats application, Bureau of Land Management Federal Ownership layer, National Land Cover Dataset) were used to characterize potential sites. Variables assessed included the following: 1) stream length to the NWR boundary upstream; 2) total watershed area upstream; 3) landownership in watershed upstream (i.e., percent private, Service, Federal); 4) land cover in watershed; and, 5) basin characteristics (mean annual precipitation, mean maximum/minimum air temperatures, mean and maximum elevations). The workgroup considered landownership and cover as primary indicators for the prevalence of non-climate-related stressors, and used

aerial photos to indicate areas most likely susceptible to these stressors. Variables at all sites were discussed among workgroup members and NWR personnel, and consensus was reached on sentinel site selection.

Physical, Habitat, and Biological Attributes

Approaches selected for collection of physical, habitat, and biological attributes were largely based on methods recommended or developed by the Environmental Protection Agency (EPA). The EPA developed guidance for continuous monitoring of temperature and flow in wadeable streams, which assists the agency's work to establish regional monitoring networks (EPA 2014). The EPA's guidance was applied at sentinel sites for collecting air and water temperature data (i.e., use of temperature loggers set to record at 30-minute intervals) and flow at ungauged sites (i.e., use of pressure/temperature loggers in air and water set to record at 15-minute intervals and periodic flow measurements). Temperature loggers and pressure/temperature loggers (TidbiT v2 and HOBO U20-001-01, respectively) manufactured by the Onset Computer Corporation were used. Files of temperature data were inspected for suspect values (Sowder and Steel 2012), which were removed. Temperature and flow data also were provided by Water Resources for sites where gauge stations are maintained (i.e., Little Pend Oreille and Malheur NWRs). Temperature and flow data were summarized (e.g., monthly mean, maximum, and minimum) and presented in graphs for all sentinel sites.

Methods developed for wadeable streams under EPA's Environmental Monitoring and Assessment Program (EMAP; Peck et al. 2006) were used to monitor habitat and biological attributes at sentinel sites. The EMAP manual describes standardized field methods for which results of regional pilot applications throughout the United States have successfully characterized ecological conditions using multiple biological assemblages in conjunction with physical and chemical habitat characteristics (Hughes et al. 2000). The EMAP approach identifies nine ecological indicators for assessing chemical, physical, habitat, and biological conditions of streams. Measurements are made during the typical low-flow period relative to stream reaches of standardized length (approximately 40 mean wetted channel widths or a minimum of 150 m for small streams). Reaches are selected using a Generalized Random-Tessellation Stratified (GRTS) design to identify spatially-balanced random points in a stream network.

Various aspects of the EMAP approach (e.g., scope, reach selection, and component indicators) were modified, or not used, in employing its methods for the monitoring program to address our goal, objectives, and considerations. Whereas EMAP survey design allows extrapolation of conditions observed at sites to a broader target population (e.g., streams in a state or region), the scope of the monitoring program focuses on conditions at specific sites through time. Thus, a GRTS sampling design was not used; rather, stream reaches were selected based on a variety of considerations (see Sentinel Site Selection). The following subset of EMAP's component indicators were selected to increase the likelihood of the program's long-term sustainability: water chemistry (i.e., pH, conductivity, and dissolved oxygen, all point measurements made during a survey); habitat characterization (e.g., thalweg profile, woody debris, and channel and riparian measurements); and aquatic vertebrates (i.e., results of an electrofishing survey).

A habitat survey was conducted at sentinel sites annually during each of three years of the pilot project. Variables included in the surveys represented four categories of habitat variables,

characterizing stream channel, substrate, fish cover, and riparian canopy and vegetation structure. Each category consisted of 9–11 variables for a total of 41, and included those most frequently used in applying EMAP methods (Kaufmann et al. 1999). To assess variability in estimates of habitat variables, the coefficient of variation (CV) was calculated among surveys for variables at each sentinel site, and displayed as box-plots of the categories of variables. The box portions encompassed the second and third quartiles and median of the variables for a category, and whiskers represented the first and fourth quartiles, except in cases where outliers were identified (i.e., values exceeding 1.5 of the inter-quartile range; Velleman and Hoaglin 1981). These box-plots were used to visually assess relative variability of the estimates of habitat variables at each sentinel site. Overall variability for categories of habitat variables among sentinel sites was assessed by ranking CVs among all sentinel sites and a Kruskal-Wallis test and nonparametric multiple range test (Zar 1996) were used to test for significant differences (α=0.05) among categories of variables.

The 41 habitat variables were assessed in the field using various classes of metrics (e.g., presence-absence, counts, quantitative measurements, visual assessments). To further assess variability of the variables, each was assigned to a class of measurement after Kaufmann et al. (1999). Classes were:

- Quantitative measurement of stable and easily defined features;
- Quantitative measurement of flow-dependent or difficult-to-define features;
- Semi-quantitative measurements of determinations of presence-absence;
- Visual estimates of areal cover.

Overall variability for classes of measurement among sentinel sites was assessed by ranking CVs among all sentinel sites and a Kruskal-Wallis test and nonparametric multiple range test (Zar 1996) were used to test for significant differences (α=0.05) among classes of measurements.

To describe biological attributes, up to three fish surveys were conducted annually during 2015–2017, which consisted of single-pass electrofishing (Peck et al. 2006) each sentinel site and returning fish to the stream after processing. Each subreach was a tenth of the sentinel site length, and adequacy of the total reach length was gauged by calculating Jaccard Index of similarity comparing species collected in even– to odd–numbered subreaches, for which values $\geq$ 0.70 were considered adequately sampled (see Peck et al. 2006). For each subreach, all or a subsample of fish were measured for total length (mm) and weighed to the nearest 0.1 gram so that condition factor (Anderson and Gutreuter 1983) could be calculated. During surveys, other vertebrates were noted, and benthic macroinvertebrates were collected according to EMAP methods and archived for processing in the future.

Various metrics were used to describe fish assemblages at each sentinel site, and included: 1) general descriptors; 2) indices of similarity; 3) ecological classification; and, 4) indices of temperature class and tolerance. Assemblage descriptors were species richness and number of native and non-native species encountered during surveys. Two indices of similarity were calculated, one based on species presence-absence and the other based on species relative abundance. For species presence-absence, Jaccard Index of similarity was calculated (Kwak and Peterson 2007; Krebs 2014; i.e., proportion of shared to total species collected in two samples)

between surveys (i.e., pairwise comparisons for all surveys within a year at a sentinel site to describe variability in assemblage structure during a field season and pairwise comparisons for all surveys among years to describe overall variability in assemblage structure during the pilot project). The index ranges from 0, indicating no species shared between surveys, to 1.0, indicating identical species composition. Index values less than 0.60 are thought to indicate substantial differences in species presence-absence (Gauch 1982; Rahel 1990). For species relative abundance, Morisita Index of similarity was calculated (Kwak and Peterson 2007; Krebs 2014; i.e., interpreted as probability of the same species being drawn from two samples to probability of two individuals of the same species being drawn from one sample) between surveys (i.e., also pairwise comparisons within a year and pairwise comparisons of all surveys among years). The index ranges from 0, indicating no similarity, to slightly greater than 1.0, indicating identical species composition and relative abundance. Index values less than 0.50 are thought to indicate low similarity in species relative abundance and values greater than 0.75 are thought to indicate high similarity (Matthews 1986, 1988; Matthews et al. 1994). Values of Jaccard and Morisita indices were presented as box-plots for comparisons both within years and among years, and outliers identified.

Ecological classification of species was applied to each sentinel site, which results in the assignment of species to one of four categories based on their relative abundance and frequency of occurrence (González-Acosta et al. 2005). The analysis produces a scatter plot with quadrants defined by grand means of relative abundance and frequency of occurrence for all species and surveys combined. The quadrants in which means for each species occur are classified as either dominant (relative abundance and frequency of occurrence greater than the grand means), rare (relative abundance and frequency of occurrence less than the grand means), common (relative abundance less than grand mean but frequency of occurrence greater than the grand mean), and occasional (relative abundance greater than the grand mean but frequency of occurrence less than the grand mean).

To describe prevalent traits of fish assemblages, two assemblage indices were calculated for each survey based on species tolerance and temperature class. For species tolerance, Whittier et al. (2007) developed values representing species overall tolerance to habitat degradation due to human disturbance based on extensive surveys and assessment of disturbance (i.e., chemical, physical, and landscape indicators, many of which affect water temperature) in lotic systems across 12 western states. Values were positively related to increasing tolerance to degradation (e.g., a value of 0.7 for Bull Trout (*Salvelinus confluentus*) and 9.0 for Common Carp (*Cyprinus carpio*)). These tolerance values were weighted by species relative abundance and summed to produce an assemblage tolerance index (ATI; i.e., mean tolerance value among all individuals) for each survey performed during 2015–2017. For temperature class, Coker et al. (2001) assigned fish species to one of five temperature classifications (cold, cold/cool, cool, cool/warm, and warm) based primarily on preferred summer temperatures reported in the literature. To develop an index, we assigned an integer value to each classification (i.e., 1–5, with a value of 1 assigned to the cold classification, 2 to the cold/cool…….5 to the warm classification). These values were weighted by species relative abundance and summed to produce an assemblage index specifically for water temperature (i.e., mean temperature class value among all individuals) for each survey performed during 2015–2017. To determine the relation between the two types of assemblage indices (i.e., ATI based on empirically-derived values representing

species tolerance broadly to habitat degradation and temperature class index based on ordinal values representing species preferred temperature), the association between the ATI and temperature class index was assessed with the Spearman rank correlation coefficient (Zar 1996) for surveys at all sentinel sites combined.

Data generated during the pilot project consisted of numerous variables in various formats, which were processed and stored using spreadsheet and database software. For temperature and stream flow, data loggers produced electronic files for which the manufacturer's software (HOBOware Pro, Onset Computer Corporation) was used to export text files. These text files, as well as data for periodic measurements of stream flow, were placed in Excel workbooks that summarized data. All habitat and fish survey data were recorded on standard EMAP forms included in Peck et al. (2006). Because habitat data for a relatively small number of survey sites can be efficiently processed using existing agency spreadsheets (P. Kaufmann, EPA, pers. comm.), an Excel workbook developed by Virginia Department of Natural Resources was modified for the pilot project, and used to summarize habitat variables and store data. For fish surveys, an Access database was developed to store and summarize water chemistry and biological data. Additional Excel workbooks were created to calculate fish assemblage metrics (i.e., similarity indices, ecological classification, ATI, and temperature class index) using output from the fish survey database.

Results

Sentinel Site Selection

At the time of our assessment, a total of 45 NWRs occurred in the Region of which 32 were eliminated from further consideration during the initial screening phase because they primarily lacked suitable stream habitat to establish sentinel sites (see Appendix A). Areas of interest were identified on the remaining 13 NWRs and subjected to the geospatial assessment. Five sentinel sites were selected: two representing the Marine West Coast Forest Ecosystem (Muddy Creek at William L. Finley NWR, Omeara Creek at Willapa NWR), two representing the Northwestern Forested Mountains Ecoregion (Little Pend Oreille River at Little Pend Oreille NWR, Myrtle Creek at Kootenai NWR), and one representing the North American Deserts Ecoregion (Bridge Creek at Malheur NWR). Specific survey reaches at the five sites were based on field visits and consultation with NWR personnel.

Physical, Habitat, and Biological Attributes at Each Sentinel Site

Muddy Creek

Muddy Creek was inspected at various areas along its 14-km course within William L. Finley NWR during a reconnaissance trip in October 2014. Portions suitable for wading were located in the vicinity of McFadden's Marsh, downstream of Bruce Road, where mean wetted width was 8 m. During summer 2015, the upper limit of the survey reach (transect K) was established downstream of the largest water control structure between McFadden's Marsh and Muddy Creek, and extended 320 m downstream in the channel (transect A, Figure 1). Temperature loggers were deployed at the upper and lower limits of the survey reach, and a staff gauge and

pressure/temperature logger installed on the abutments of the bridge at Bruce Road. A temperature logger and pressure/temperature logger also were installed in a solar radiation shield attached to a tree near the bridge to record barometric pressure and air temperature.

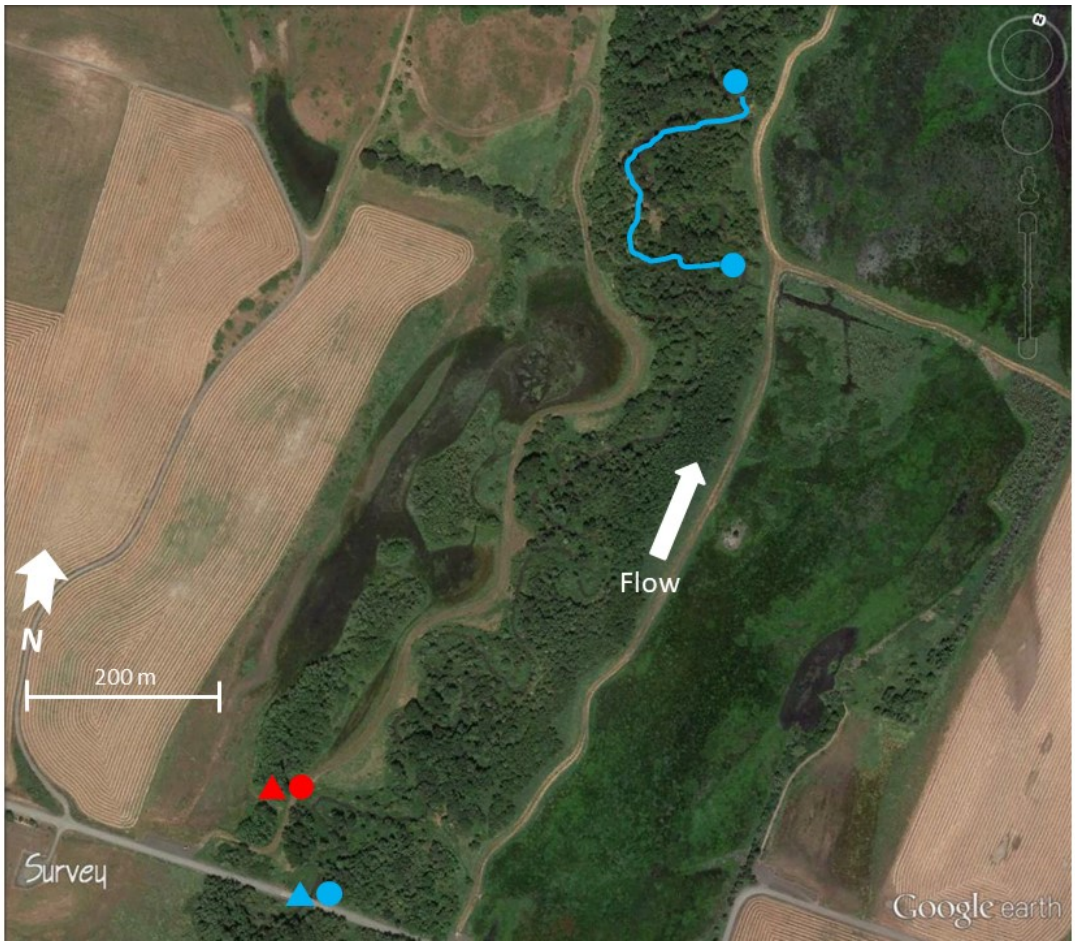

Figure 1. Aerial photograph of Muddy Creek survey reach (blue line) showing locations of loggers (temperature logger (circle) and pressure/temperature logger (triangle) in water (blue shading) and air (red shading)).

Continuous temperature data were collected during September 2015–August 2017. Ranges in monthly mean, maximum, and minimum temperatures for air were 1.8–19.7˚C, 11.0–37.8˚C, and -9.6–7.8˚C, respectively, and for water were 4.2–21.1˚C, 7.5–26.3˚C, and 0.2–17.7˚C, respectively (Figure 2). August consistently was the warmest summer month (June–August) at Muddy Creek (see Appendix B and Appendix C).

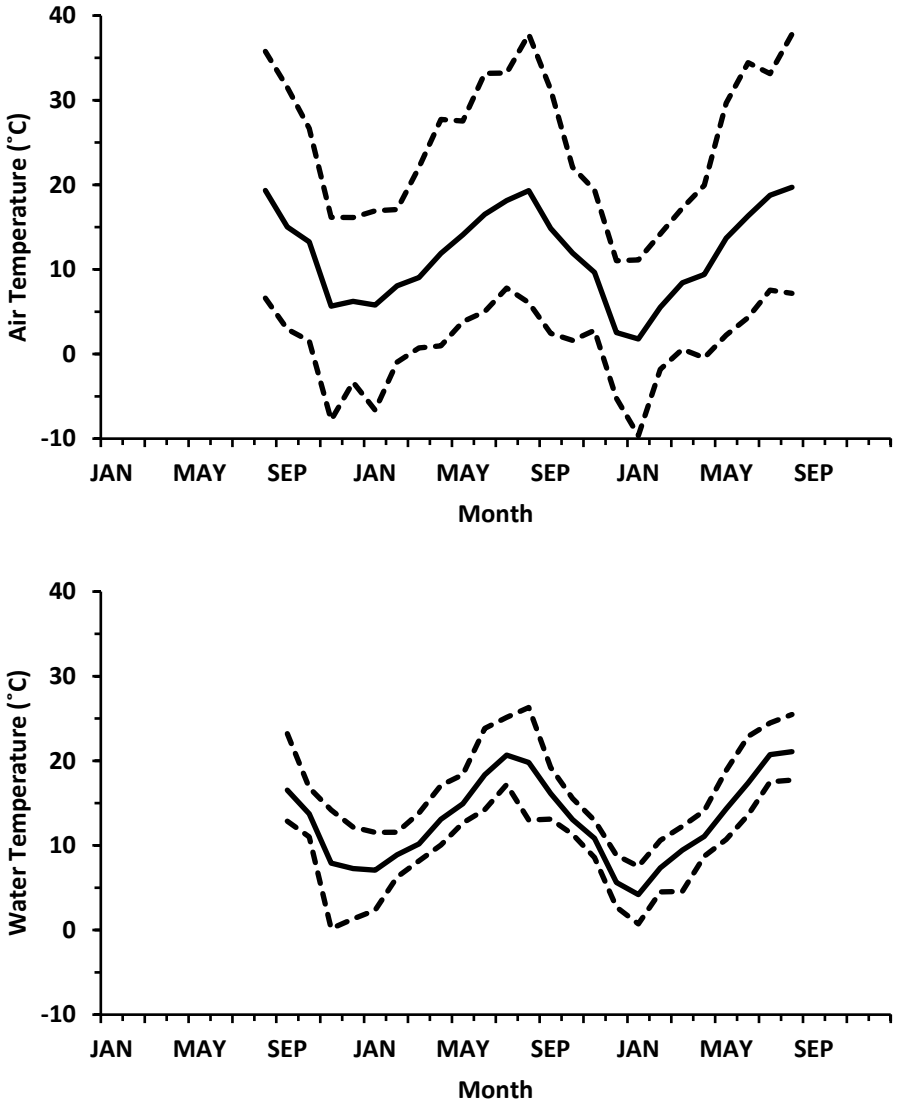

Figure 2. Monthly mean (solid line), maximum, and minimum (dashed lines) air and water temperatures at Muddy Creek, September 2015–August 2017. (Data presented from logger 10563308 for air temperature, and logger 10563325, located downstream of survey reach, for water temperature.)

For stream flow, data from the pressure/temperature loggers were used to determine water depth above the pressure sensor and combined with a stage-flow relationship to estimate stream flow (range of <1–44 cubic feet per second (cfs), see Appendix D). The pressure/temperature logger was periodically dewatered during summer, primarily July–early September. Range in estimated monthly mean, maximum, and minimum flow was <1 cfs and up to 151, 186, and 131 cfs, respectively, during August 2015–December 2017 (Figure 3). Stream flow greater than 88 cfs exceeded the appropriate limit for extrapolation of our stage-flow relationship (i.e., twice the maximum flow measured (EPA 2014)).

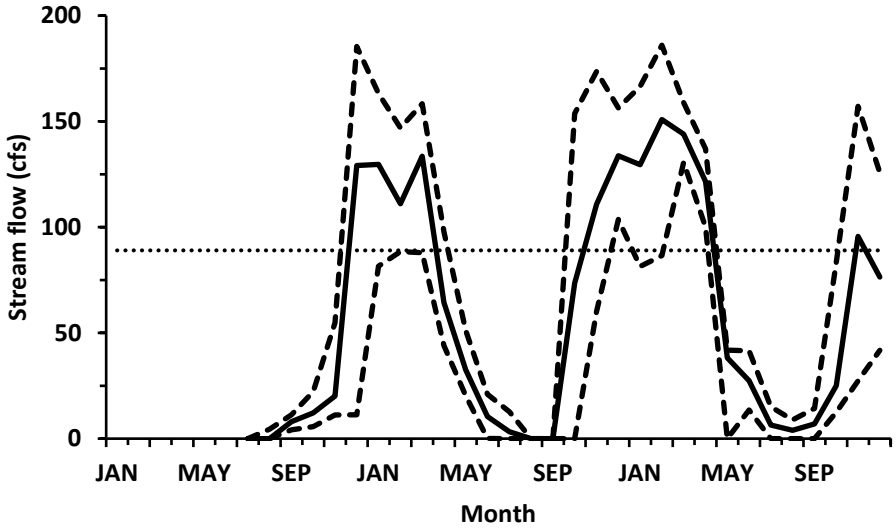

Figure 3. Monthly mean (solid line), maximum, and minimum (dashed lines) stream flow at Muddy Creek during 2015–2017. Horizontal line represents limit above which our rating curve is inappropriate.

Habitat was assessed once annually in August or September during each of the three years of the pilot project. Overall characteristics for the four categories of habitat variables (i.e., channel, substrate, fish cover, and riparian vegetation) at Muddy Creek included: channel widths up to 10 m and heights up to 1 m; substrate dominated by fines and bedrock (i.e., hardpan); fish cover consisting primarily of overhanging vegetation and presence of large woody debris; and moderate mid-channel canopy cover (~45%) and riparian area dominated by understory of woody vegetation and canopy of large trees (see Appendix E). Stream channel characteristics and riparian vegetation were the least variable habitat categories among years assessed, and were followed by fish cover and substrate (Appendix F).

A total of eight fish surveys were conducted in Muddy Creek during 2015–2017 (Appendix G). Water temperatures exceeded permitted limits (18˚C) for electrofishing during much of summer 2015 so that only two surveys were possible after temperatures had declined. Number of species collected during each survey was 5–10 (Appendix H), which represented a total of 12 species (7 native and 5 non-native) for all surveys combined. Electrofishing effort in the 320-m survey reach appeared adequate for application of EMAP methods based on values of Jaccard Index comparing species collected in even- to odd-numbered subreaches for five of the eight surveys (i.e., values ≥ 0.70; Peck et al. 2006). Species represented by 1–2 individuals were prevalent in surveys with low values of Jaccard Index.

For fish assemblage indices, there was substantial similarity in species presence-absence for comparisons made between surveys within years, as indicated by the majority of Jaccard Index values > 0.60 (Figure 4; Appendix I). However, species presence-absence was substantially different for all pairwise comparisons made among years (i.e., majority of Jaccard Index values < 0.60). For assemblage structure based on species relative abundance, overall similarity was high for both comparisons within years and all pairwise comparisons among years (i.e., majority

of Morisita Index > 0.75; Figure 4), indicating consistency of the most abundant species among surveys.

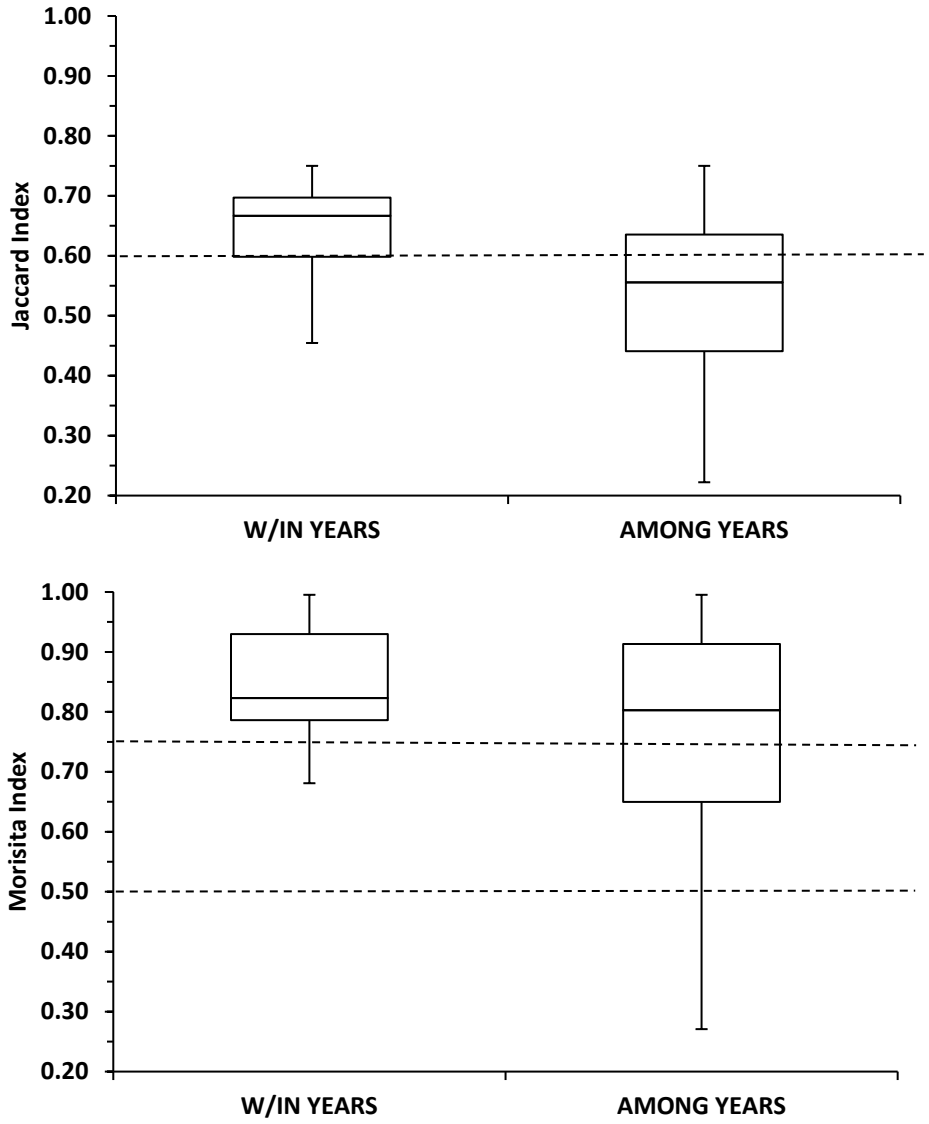

Figure 4. Indices of similarity between surveys conducted within years and all pairwise comparisons among years in Muddy Creek during 2015–2017, based on species presence-absence (Jaccard Index) and species relative abundance (Morisita Index). Horizontal dashed lines indicate thresholds (see Methods).

All surveys and species were combined to conduct ecological classification of species. A total of 1,663 individuals were collected in Muddy Creek (Appendix H). Mean (SD) relative abundance and mean (SD) frequency of occurrence were 8.3% (15.3) and 56.2% (31.8), respectively (Figure 5). Three species were classified as dominant (Reticulate Sculpin (*Cottus perplexus*), Western Moquitofish (*Gambusia affinis*), and Threespine Stickleback (*Gasterosteur aculeatus*)); three as common (Northern Pikeminnow (*Ptychocheilus oregonensis*), Redside Shiner (*Richardsonius*

balteatus), and Goldfish (*Carassius auratus*)), and six as rare (Bluegill (*Lepomis macrochirus*), Common Carp (*Cyprinus carpio*), Largescale Sucker (*Catostomus macrocheilus*), Western Brook Lamprey (*Lampetra richardsoni*), Coastal Cutthroat Trout (*Oncorhynchus clarki clarki*), and Warmouth (*Lepomis gulosus*)).

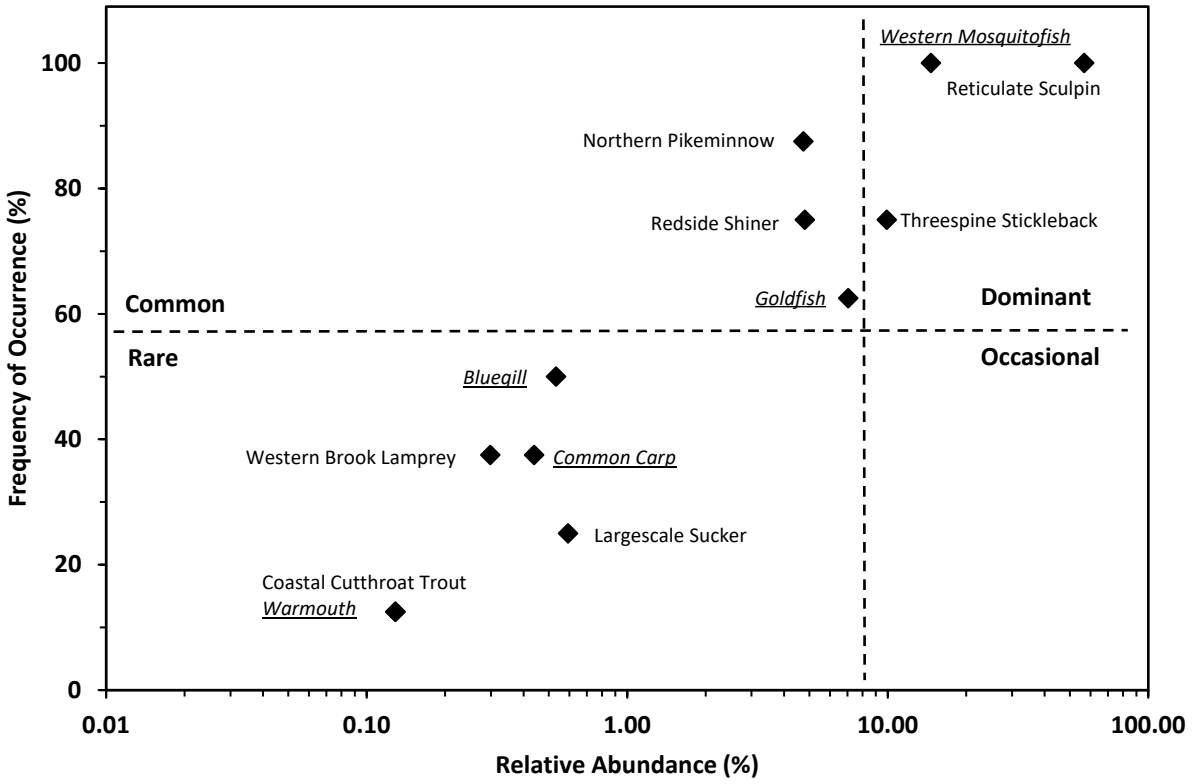

Figure 5. Ecological classification of 12 species collected during 8 fish surveys in Muddy Creek during 2015–2017 (non-natives in underlined italics).

Fish species collected in Muddy Creek represented four of five temperature classes, cold, cold/cool, cool, and warm (assigned ordinal values 1, 2, 3, and 5, respectively, Appendix I). All five non-native species are assigned to the warm temperature class. Largescale Sucker was the only species in the cool temperature class, and the remaining six species are evenly assigned to the cold and cold/cool classes. The survey conducted on 14 October 2015 represented the maximum value of the temperature class index (Figure 6), which primarily was due to high relative abundance of Western Mosquitofish. The remaining index values were lower, and indicative of the predominance of native species in the cold and cold/cool temperature classes. Although differing in scale, the relative pattern of the temperature class index through time was similar to that of the assemblage tolerance index.

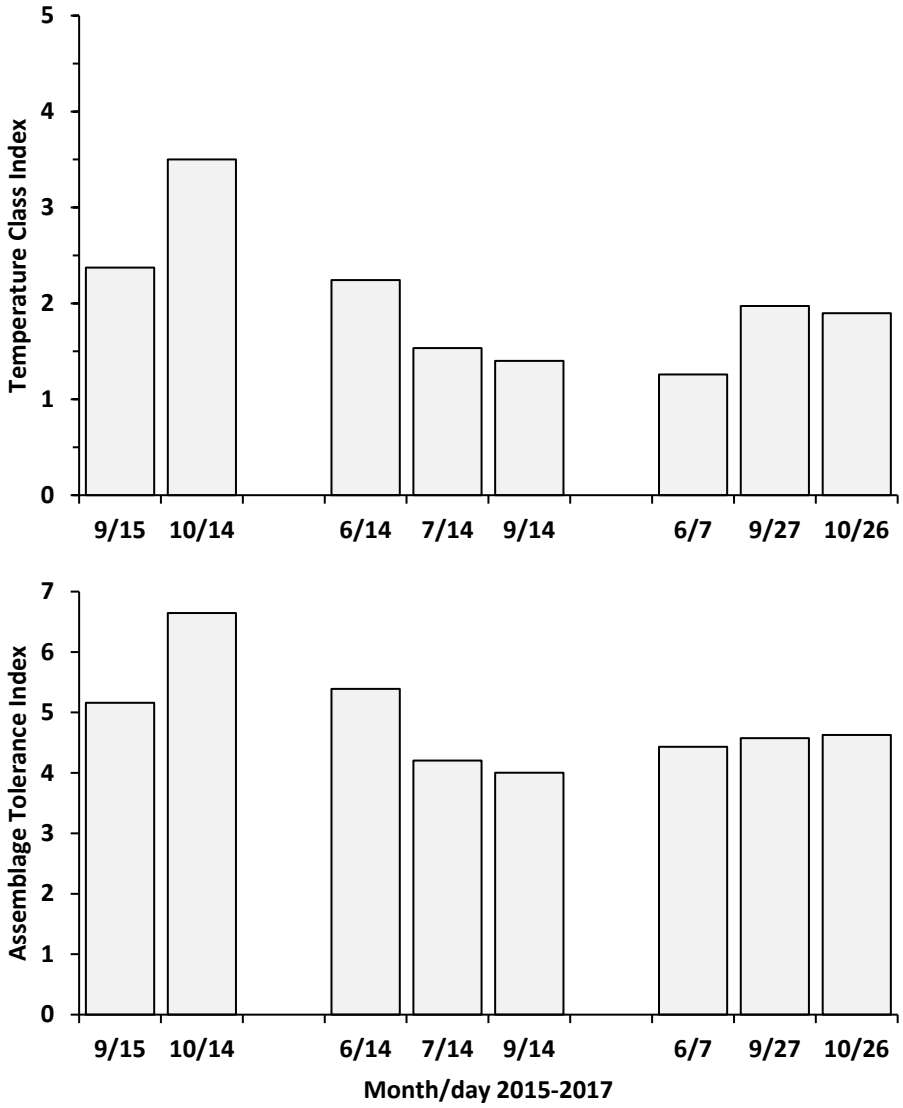

Figure 6. Temperature class index and assemblage tolerance index for surveys in Muddy Creek 2015–2017.

Omeara Creek

The lower 400 m of Omeara Creek within Willapa NWR was inspected during October 2014. A section of the creek beginning at the refuge boundary located just upstream of tidal influence was considered suitable for establishing a survey reach for the sentinel site. Temperature loggers were installed in five locations within the creek in November 2014. One was installed below the reach, two within it, and two above it. In addition, an air temperature logger and temperature/pressure logger were installed in a solar radiation shield attached to a large tree above the survey reach. The specific location of the survey reach was determined in July of 2015 (Figure 7). Based on mean wetted widths less than 3 m, a 150-m survey reach was established (Peck et al. 2006). A staff gauge and pressure/temperature logger were installed within the lower portion of the reach in June 2016.

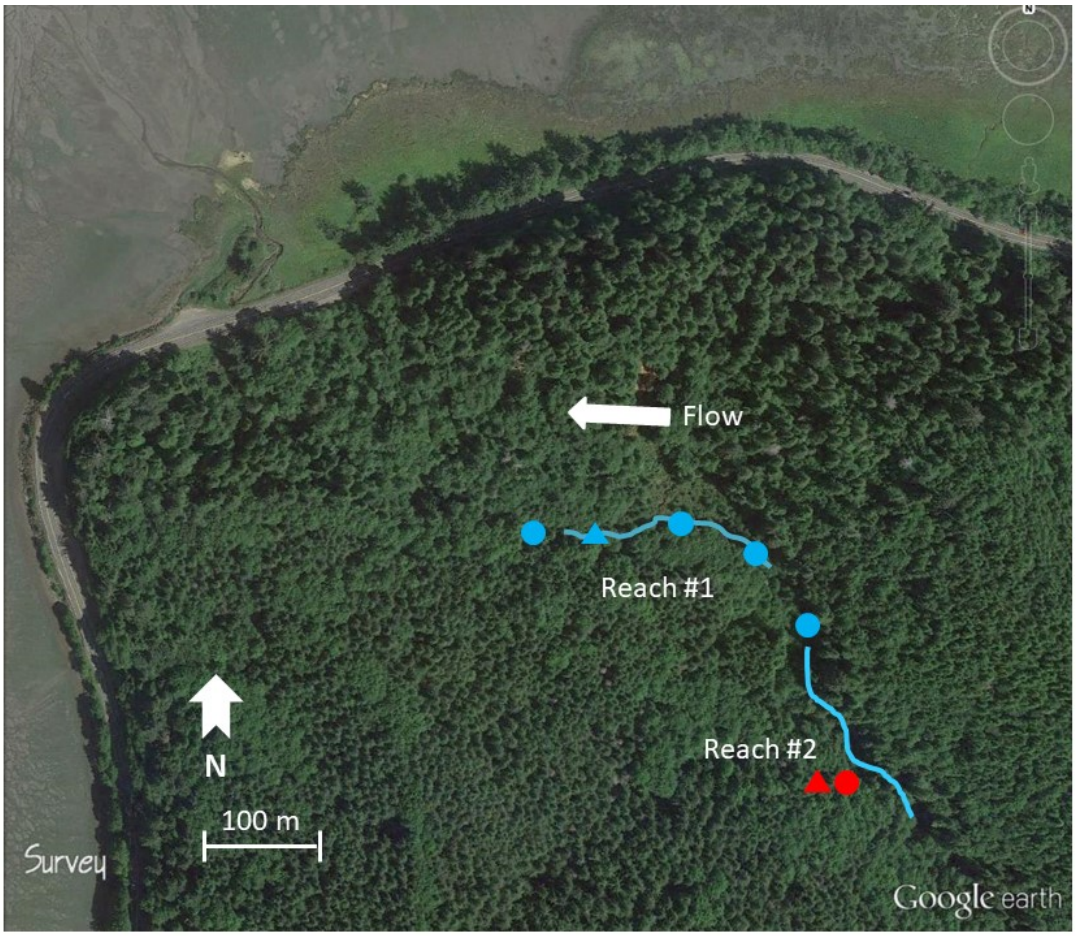

Figure 7. Aerial photograph of Omeara Creek survey reaches (blue lines) showing locations of loggers (temperature logger (circle) and pressure/temperature logger (triangle) in water (blue shading) and air (red shading)).

About a third of the survey reach was logged in August 2017 and debris pushed into the stream channel. We learned that this portion of the reach (#1) was actually on a private parcel adjacent

to the NWR. Areas on the NWR upstream of this private parcel were inspected, and a new survey reach (#2) established in September 2017.

Some temperature loggers were lost during the pilot project, however, continuous air and water temperature data were collected during January 2015–December 2017. Ranges in monthly mean, maximum, and minimum temperatures for air were 3.3–15.8˚C, 10.8–25.2˚C, and -4.2–11.2˚C, respectively, and for water were 6.0–14.3˚C, 8.0–16.3˚C, and 3.6–13.1˚C, respectively (Figure 8). August consistently was the warmest summer month (June–August) at Omeara Creek (see Appendix B and Appendix C).

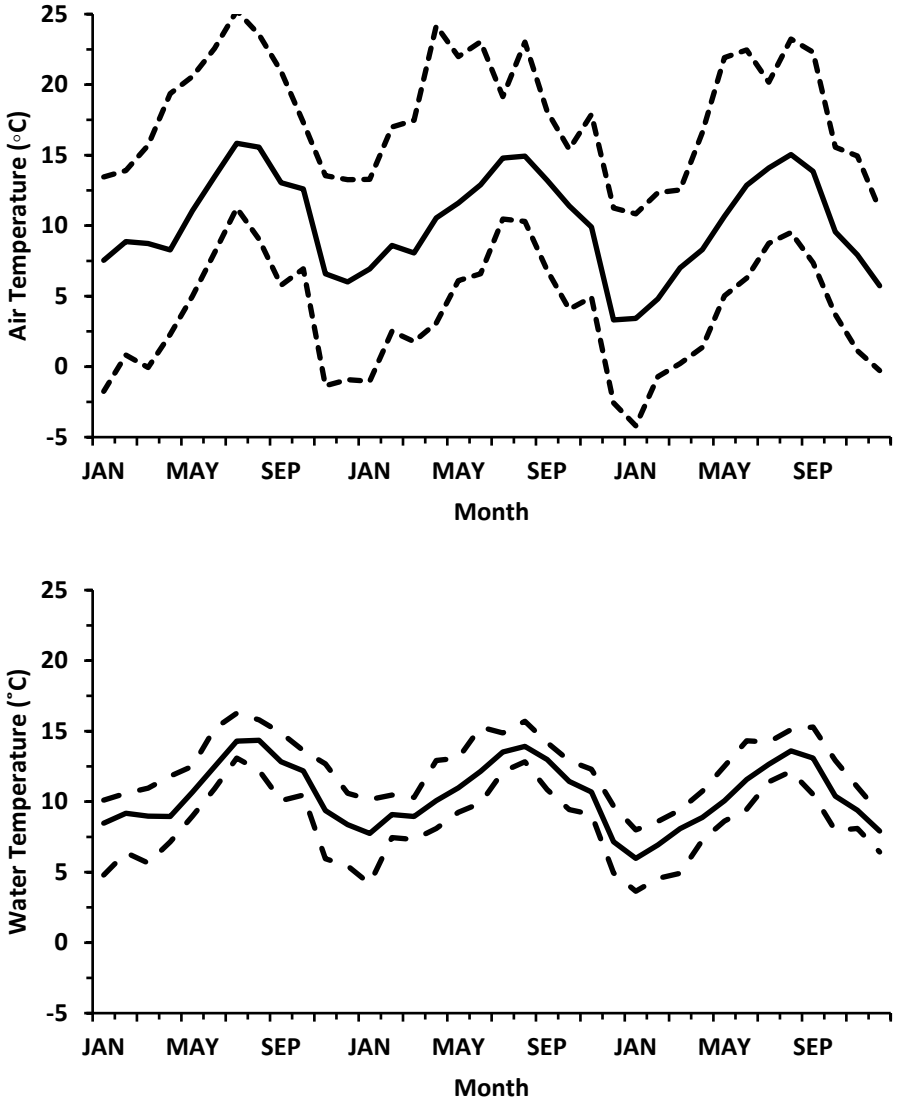

Figure 8. Monthly mean (solid line), maximum, and minimum (dashed lines) air and water temperatures at Omeara Creek, January 2015–December 2017. (Data presented from logger 10563312 for air temperature, and logger 10563329 for water temperature.)

For stream flow, high flows during winter 2016–2017 caused substantial substrate movement, which buried the staff gauge and pressure/temperature logger and shifted the creek to the opposite side of the channel. A staff gauge and pressure/temperature logger was reinstalled downstream in July 2017, but no data were collected. Stream flow was estimated using a current meter in July 2015 and 2017, which was 0.22 and 0.30 cfs, respectively. Although Omeara Creek is subjected to relatively high flows during winter months (based on movement of substrate and large pieces of wood), we assume that flow was considerably lower than 1 cfs during habitat and fish surveys.

Habitat was assessed in the original survey reach (#1) in July 2015 and September 2016, and the new reach (#2) in October 2017 (Appendix E). Habitat data for the original reach (#1) only are addressed here. Overall characteristics for the four categories of habitat variables (i.e., channel, substrate, fish cover, and riparian vegetation) at Omeara Creek included: channel width up to 2 m and heights up to 1 m; substrate dominated by coarse and fine gravel; fish cover consisting primarily of undercut banks, overhanging vegetation, and woody debris; substantial mid-channel canopy cover (~80%); and riparian area dominated by ground cover of non-woody vegetation and canopy of small trees (see Appendix E). Riparian vegetation and stream channel characteristics were the least variable habitat categories among survey years, and were followed by fish cover and substrate (Appendix F).

A total of seven fish surveys were conducted in Omeara Creek during 2015–2017 (Appendix G). Three surveys were conducted in 2015, but high flows during October limited the number of surveys to two in 2016. In 2017, a single survey each was conducted in the original and new survey reaches. Because species composition and relative abundance for the new reach were similar to those of the original reach, results from surveys from both reaches were considered here. Number of species collected during each survey was 3–5 (Appendix H), which represented a total of 5 species (all native) for all surveys combined. Electrofishing effort in the 150-m survey reach appeared adequate for application of EMAP methods based on values of Jaccard Index comparing species collected in even- to odd-numbered subreaches for six of the seven surveys (i.e., values ≥ 0.7; Peck et al. 2006). Two species were represented by single individuals in the survey with a Jaccard Index value < 0.70.

For fish assemblage indices there was substantial similarity in species presence-absence for comparisons made between surveys within years and all pairwise comparisons made among years (Figure 9; Appendix I). Values of Jaccard Index indicated substantial similarity in species presence-absence (≥ 0.60) for all comparisons. In addition, species relative abundance exhibited high similarity (Morisita Index > 0.75) for both comparisons within years and all pairwise comparisons among years (Figure 9).

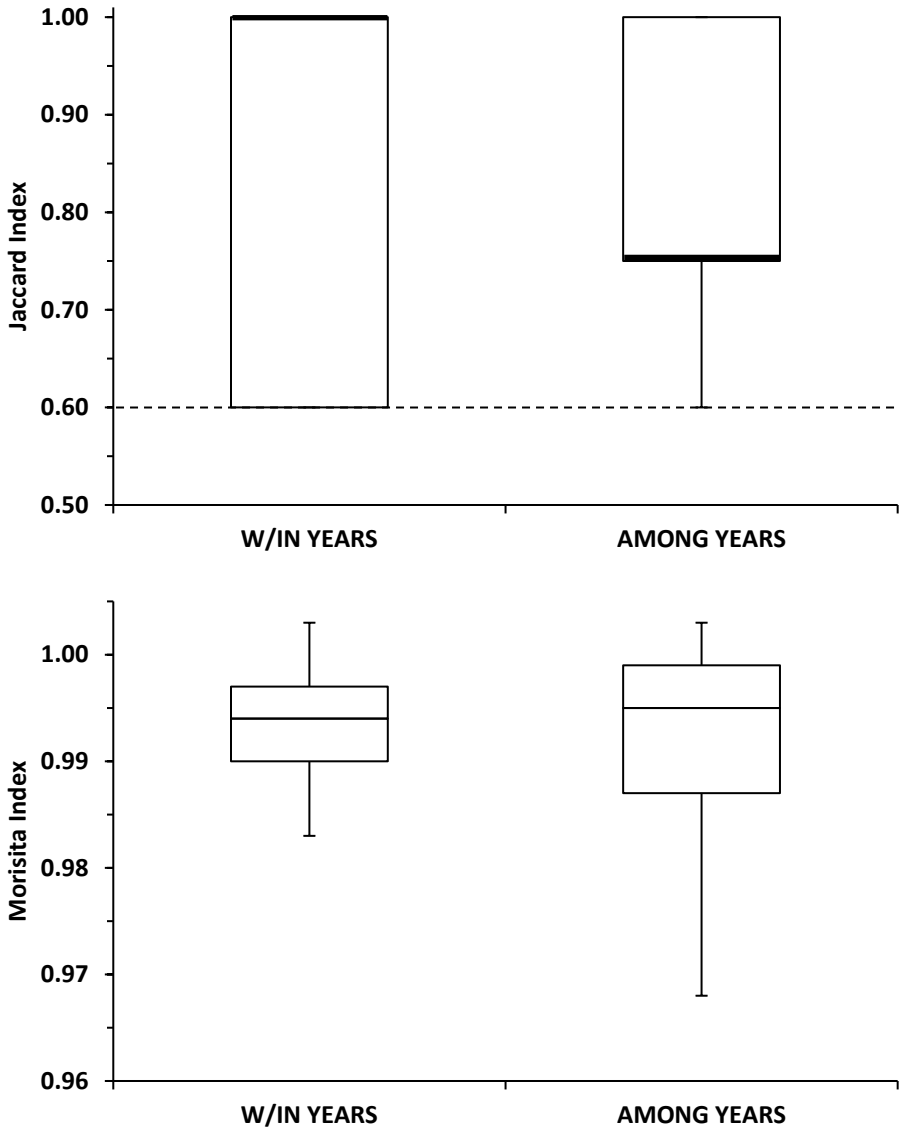

Figure 9. Indices of similarity between surveys conducted within years and all pairwise comparisons among years in Omeara Creek during 2015–2017, based on species presence-absence (Jaccard Index) and species relative abundance (Morisita Index). Horizontal dashed line indicate threshold (see Methods).

All surveys and species were combined to conduct ecological classification of species. A total of 1,150 individuals were collected in Omeara Creek (Appendix H). Mean (SD) relative abundance and mean (SD) frequency of occurrence were 20.0% (32.2) and 71.4% (40.4), respectively (Figure 10). One species was classified as dominant (Riffle Sculpin (*C. gulosus*)); two as common (Coastal Cutthroat Trout and Coho Salmon (*O. kisutch*)); and two as rare (steelhead/Rainbow Trout (*O. mykiss*) and Pacific Lamprey (*Entosphenus tridentatus*)).

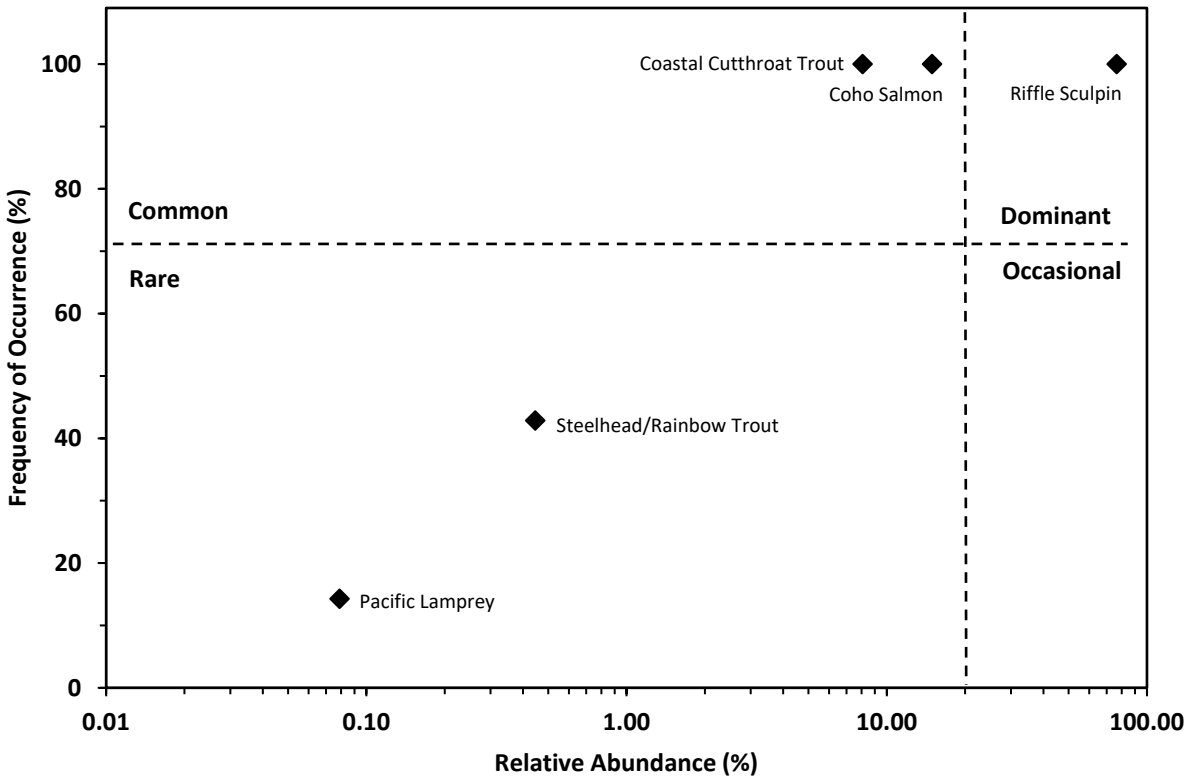

Figure 10. Ecological classification of five species collected during seven fish surveys in Omeara Creek during 2015–2017.

The five fish species collected in Omeara Creek represented a single temperature class, cold (assigned an ordinal value of 1, Appendix I). Hence, values of the temperature class index for all fish surveys were 1.0 (Figure 11). Species tolerance values ranged from a low of 1.5 for Coastal Cutthroat Trout up to 3.1 for Riffle Sculpin. Because Riffle Sculpin was the only dominant species (minimum relative abundance of 67% in all surveys), values of the assemblage tolerance index were nearly 3 for all fish surveys.

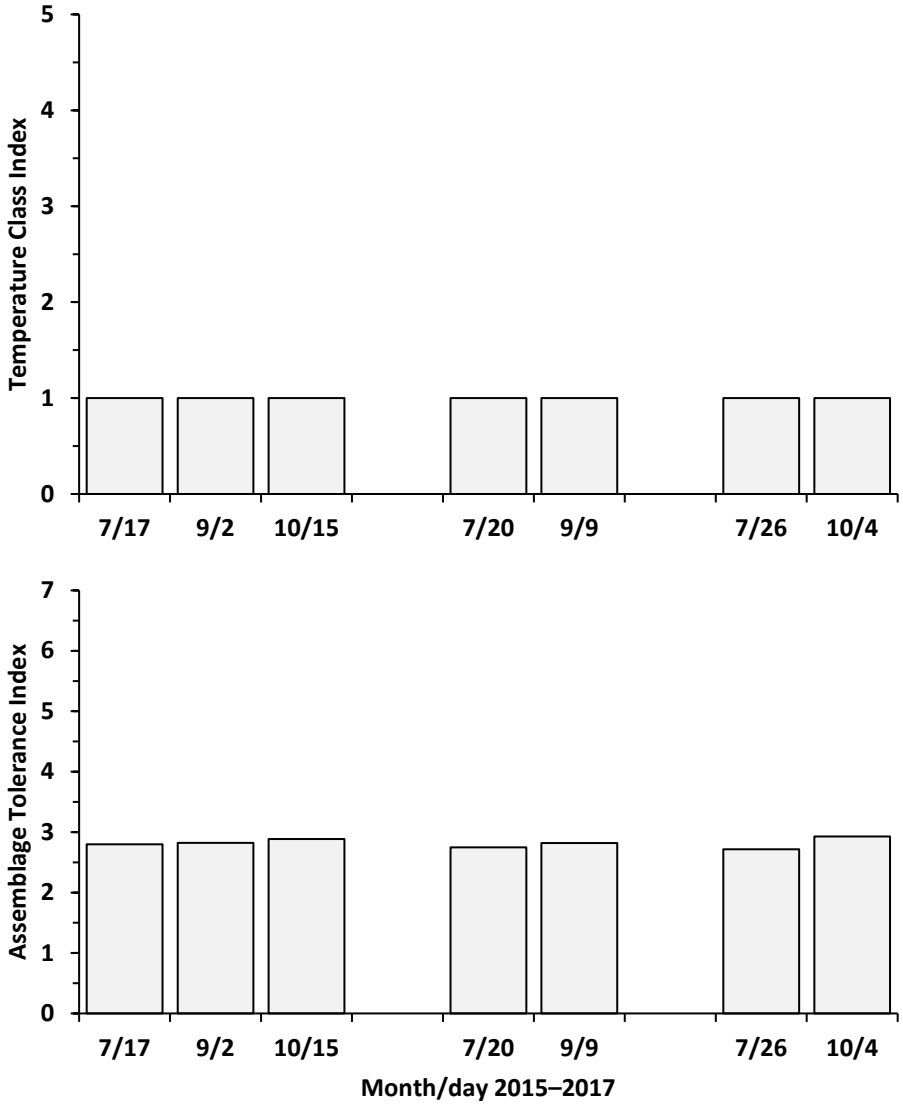

Figure 11. Temperature class index and assemblage tolerance index for surveys in Omeara Creek 2015–2017.

Little Pend Oreille River

Little Pend Oreille River was inspected at various locations within the NWR during a reconnaissance trip in September 2014. Wetted widths of 7 m were measured in the area upstream of the FWS Water Resources stream gauge station during the trip. In addition to monitoring stream flow, Water Resources also records air and water temperatures at 1-hour intervals. The 280-m survey reach was established upstream of the gauge station during a field survey in July 2015 (Figure 12), when temperature loggers were installed in the upper and lower limits of the survey reach. The survey reach was within an area of the highest fish species diversity (five species) observed during the MCFWCO fish and habitat survey in 1996 (Kelly Ringel 1998) and was also within a reach surveyed by the MCFWCO in 2014 to develop a three-dimensional model useful to monitor changes in the stream and riparian areas through time (Parrish and Muir 2016).

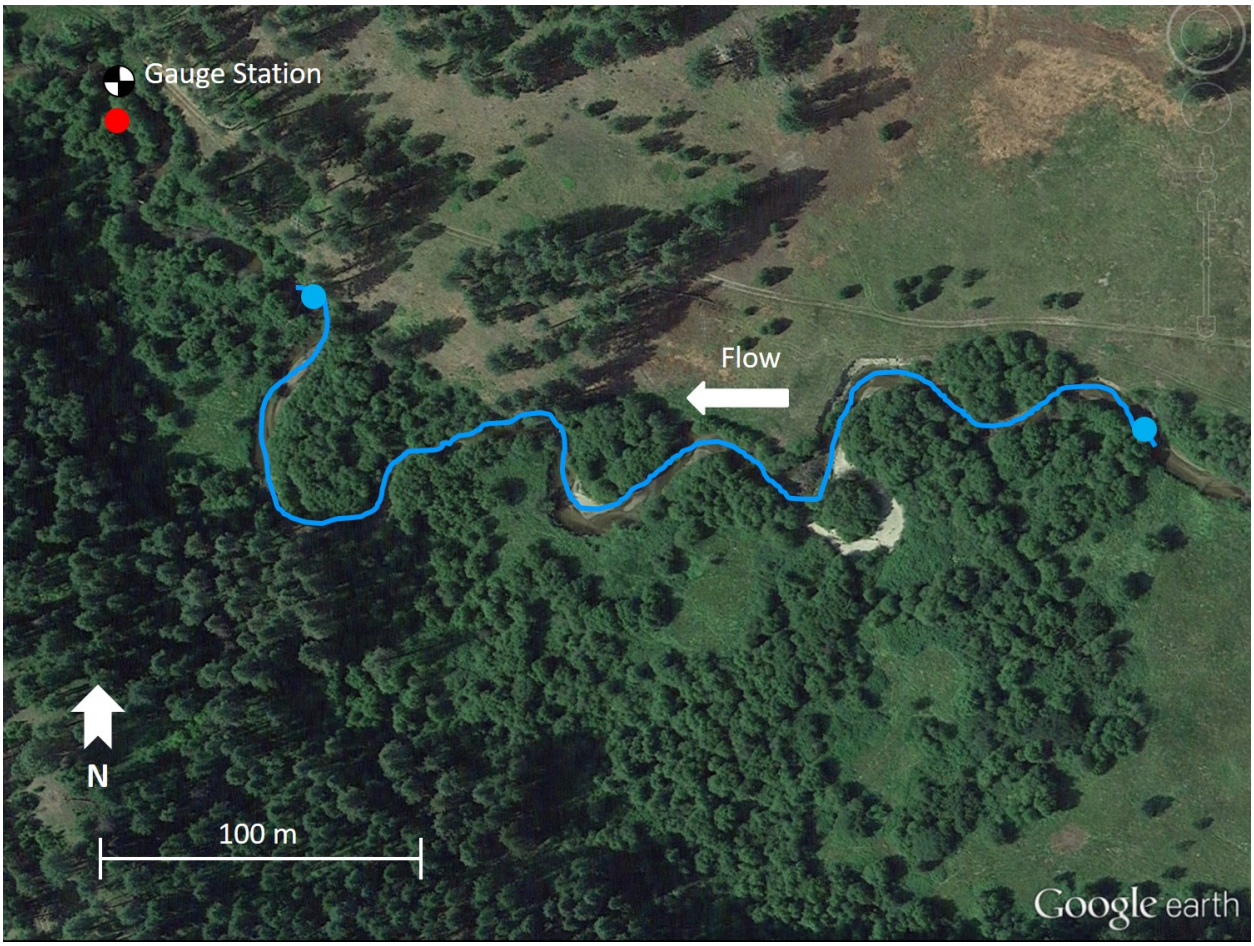

Figure 12. Aerial photograph of Little Pend Oreille River survey reach (blue line) showing locations of loggers (temperature logger (circle) in water (blue shading) and air (red shading) and Water Resources gauge station.

Continuous air temperature data (1-hour intervals) were collected during January 2015–August 2017 by FWS Water Resources. Ranges in monthly mean, maximum, and minimum air temperatures were -7.7–19.7˚C, 3.1–38.9˚C, and -27.1–4.8˚C, respectively (Figure 13). We collected continuous water temperature data at the survey site during August 2015–August 2017. Ranges in monthly mean, maximum, and minimum water temperatures were 0.2–15.9˚C, 1.2–21.9˚C, and 0.0–11.5˚C, respectively. July consistently was the warmest summer month (June–August) at Little Pend Oreille River (see Appendix B and Appendix C).

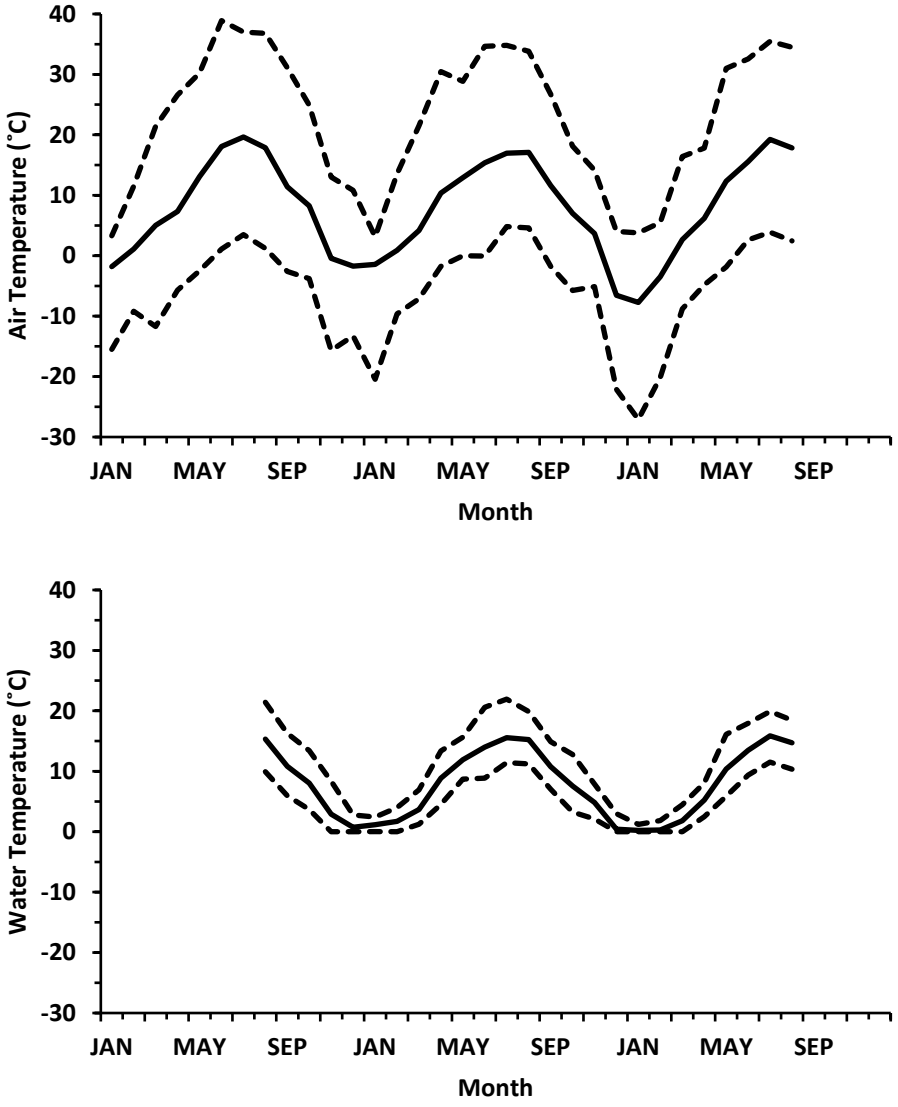

Figure 13. Monthly mean (solid line), maximum, and minimum (dashed lines) air temperatures at Little Pend Oreille River, January 2015–August 2017, and water temperatures, August 2015–August 2017. (Data presented from FWS Water Resources logger for air temperature, and logger 10563317 for water temperature.)

Stream flow was continuously recorded at the FWS Water Resources gauge station during April 2015–December 2016 and March 2017–December 2017. Range in monthly mean, maximum, and minimum flow was 12–433 cfs, 15–555 cfs, and 11–355 cfs, respectively (Figure 14). Range in daily flow was 14–47 cfs for dates on which habitat and fish surveys were conducted.

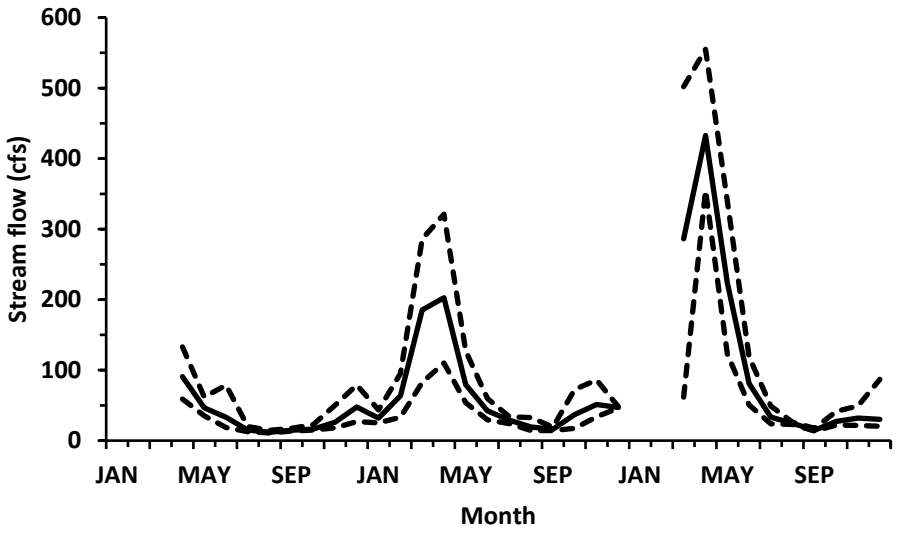

Figure 14. Monthly mean (solid line), maximum, and minimum (dashed lines) stream flow at Little Pend Oreille River during 2015–2017. (Data provided by FWS Water Resources)

Habitat was assessed once annually in July or August during each of the three years of the pilot project. Overall characteristics for the four categories of habitat variables (i.e., channel, substrate, fish cover, and riparian vegetation) in the Little Pend Oreille River included: channel widths up to 9 m and heights less than 1 m; substrate dominated by sand and fine and coarse gravel; fish cover consisting primarily of brushy/woody debris and overhanging vegetation, and the presence of large woody debris; and moderate mid-channel canopy cover (~40%) and riparian area dominated by non-woody ground cover (see Appendix E). Stream channel and substrate characteristics were the least variable habitat categories among survey years, and were followed by riparian vegetation and fish cover (Appendix F). As a response stream reach in an area that has had extensive cattle grazing, the stream channel noticeably moved during the three years, and the brushy/woody material in the stream had some annual changes in volume and location.

A total of nine fish surveys were conducted in the Little Pend Oreille River during 2015–2017 (Appendix G). Number of species collected during each survey was 2–7 (Appendix H), which represented a total of seven species (four native and three non-native) for all surveys combined. Electrofishing effort in the 280-m survey reach appeared adequate for application of EMAP methods based on values of Jaccard Index comparing species collected in even- to odd-numbered subreaches for six of the nine surveys (i.e., values ≥ 0.70; Peck et al. 2006). The three surveys with low Jaccard Index values were conducted in July, August, and September 2017 (values of 0.50 for July and 0.60 for both August and September). High water during the July survey (47 cfs compared to 12–28 cfs for all other surveys) limited electrofishing efficiency and accessibility of all areas of the survey reach as evidenced by a total catch of four individuals

representing two species. Both surveys in August and September collected five species, of which two species were represented by low numbers of individuals (i.e., one or three).

For fish assemblage indices, there was substantial similarity in species presence-absence (Jaccard Index values ≥ 0.60) for the majority of comparisons made between surveys within years and all pairwise comparisons made among years (Figure 15; Appendix I). All comparisons with the 12 July 2017 survey, which was conducted during high water and collected two species, indicated substantial differences in species presence-absence (index values < 0.60). Species relative abundance exhibited high similarity (Morisita Index > 0.75) for comparisons within years, except for an outlier involving the 12 July 2017 survey (Figure 15), and for the majority of all pairwise comparisons among years. The lowest index values for among year comparisons indicated moderate similarity in species relative abundance (values 0.50–0.74).

All surveys and species were combined to conduct ecological classification of species. A total of 920 individuals were collected in the Little Pend Oreille River (Appendix H). Mean (SD) relative abundance and mean (SD) frequency of occurrence were 14.3% (18.0) and 63.5% (40.4), respectively (Figure 16). Two species were classified as dominant (Brook Trout (*Salvelinus fontinalis*) and Shorthead Sculpin[2] (*C. confusus*)); two as common (Brown Trout (*Salmo trutta*) and Rainbow/Redband Trout[3] (*O. mykiss*)); and three as rare (Pumpkinseed (*Lepomis gibbosus*), Redside Shiner, and Speckled Dace (*Rhinichthys osculus*)).

Fish species collected in the Little Pend Oreille River represented three of five temperature classes, cold, cold/cool, and warm (assigned ordinal values 1, 2, and 5, respectively, Appendix I). Pumpkinseed, a non-native, is the only species in the warm temperature class, whereas Redside Shiner, Speckled Dace, and Brown Trout, a non-native, are in the cold/cool temperature class. The remaining three species, Shorthead Sculpin, Rainbow/Redband Trout, and Brook Trout, a non-native, are in the cold temperature class. Surveys conducted on 2 August and 22 September 2016 represented the maxima values of the temperature class index (Figure 17), which were due to high relative abundance of Pumpkinseed (see Appendix F). Although differing in scale, the relative pattern of the temperature class index through time was similar to that of the assemblage tolerance index.

[2] Provisional designation pending further assessment of cottid species composition (See Mettler (2014) for additional Sculpin species collected in the watershed).

[3] Individuals resulting from introgression among coastal Rainbow Trout, inland Redband Trout, and Westslope Cutthroat Trout (see Proebstel 1996).

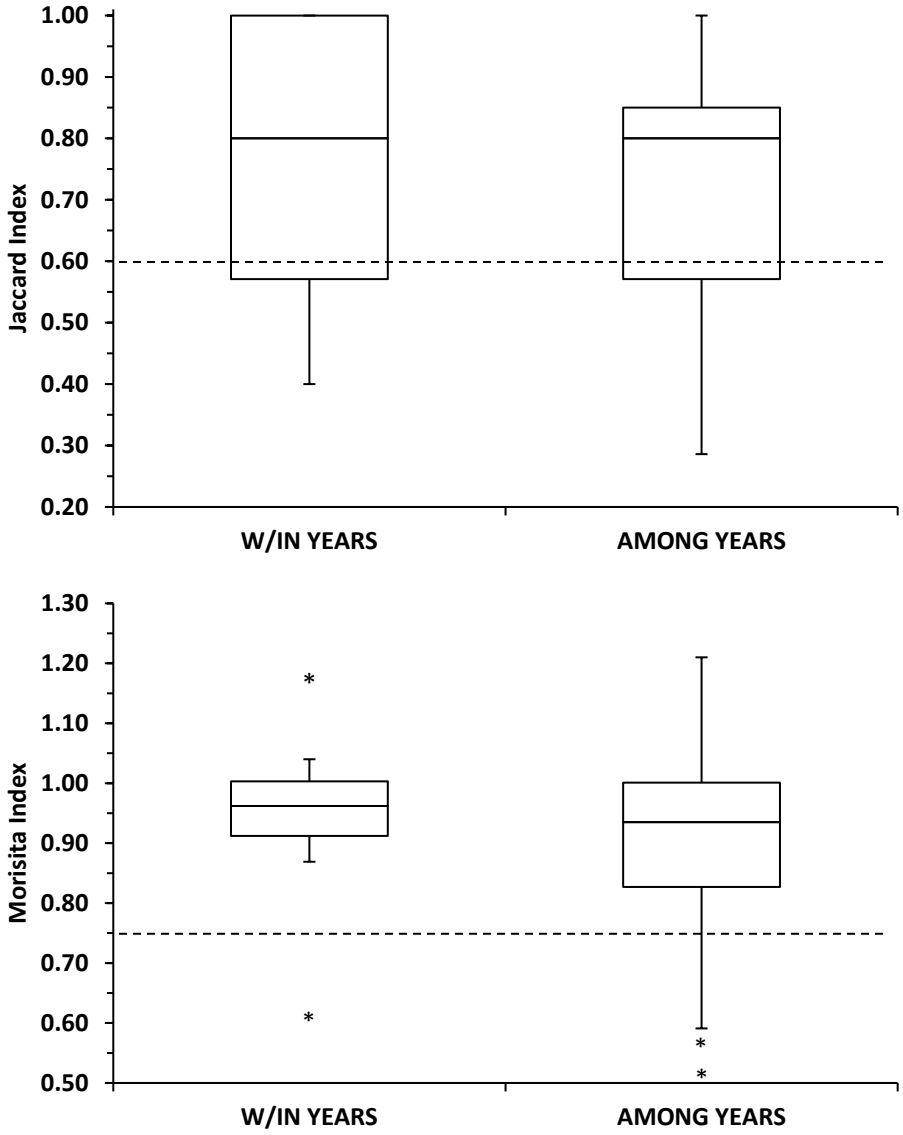

Figure 15. Indices of similarity between surveys conducted within years and all pairwise comparisons among years in the Little Pend Oreille River during 2015–2017, based on species presence-absence (Jaccard Index) and species relative abundance (Morisita Index). Horizontal dashed lines indicate thresholds (see Methods).

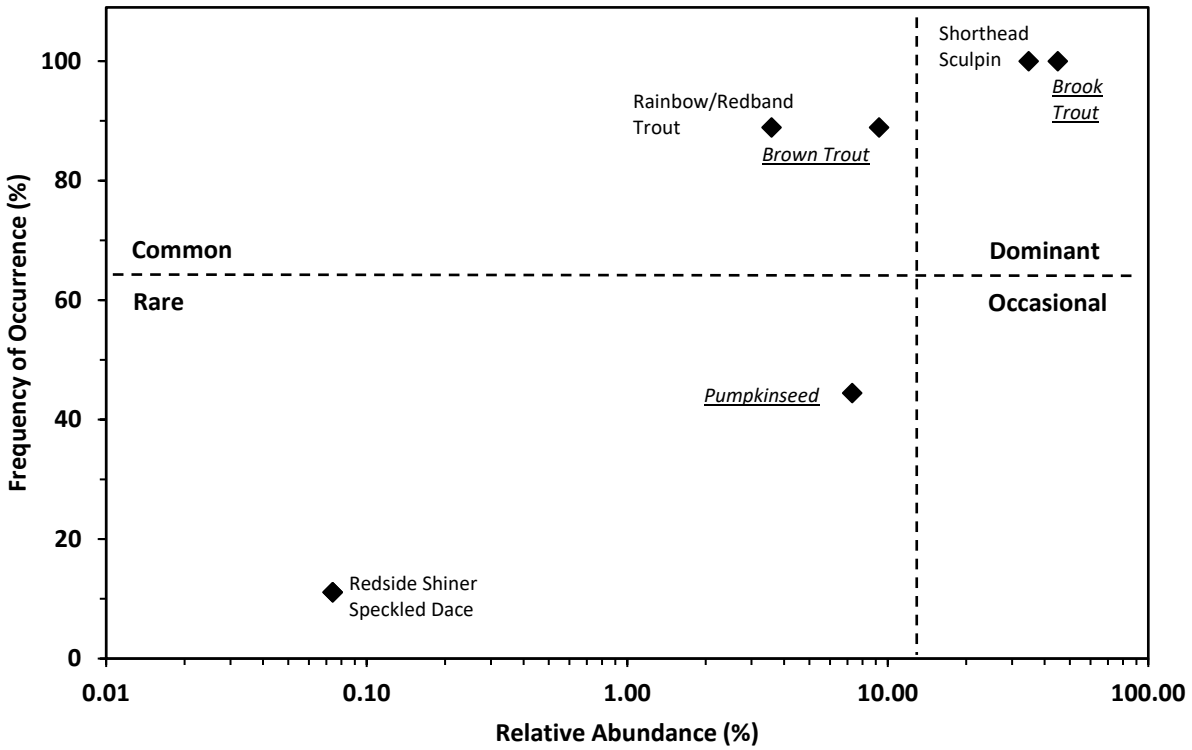

Figure 16. Ecological classification of seven species collected during nine fish surveys in the Little Pend Oreille River during 2015–2017 (non-native in underlined italics).

Pumpkinseed were initially collected during the second survey in 2016, and had presumably moved downstream from McDowell Lake (about 8.5 km upstream of the survey reach), which was treated with rotenone in 2015. Pumpkinseed abundance was highest during the second survey in August 2016 (n=71, 43.6%), and was lower during the third survey in September (n=29, 20.1%). A total of two individuals were collected during all surveys in 2017. Presence of Pumpkinseed, the only warmwater species collected at the site, was reflected in both the temperature class and assemblage tolerance indices (Figure 17). Multiple annual surveys during the pilot project allowed us to observe the presence of Pumpkinseed, likely within weeks of when they moved into the reach.

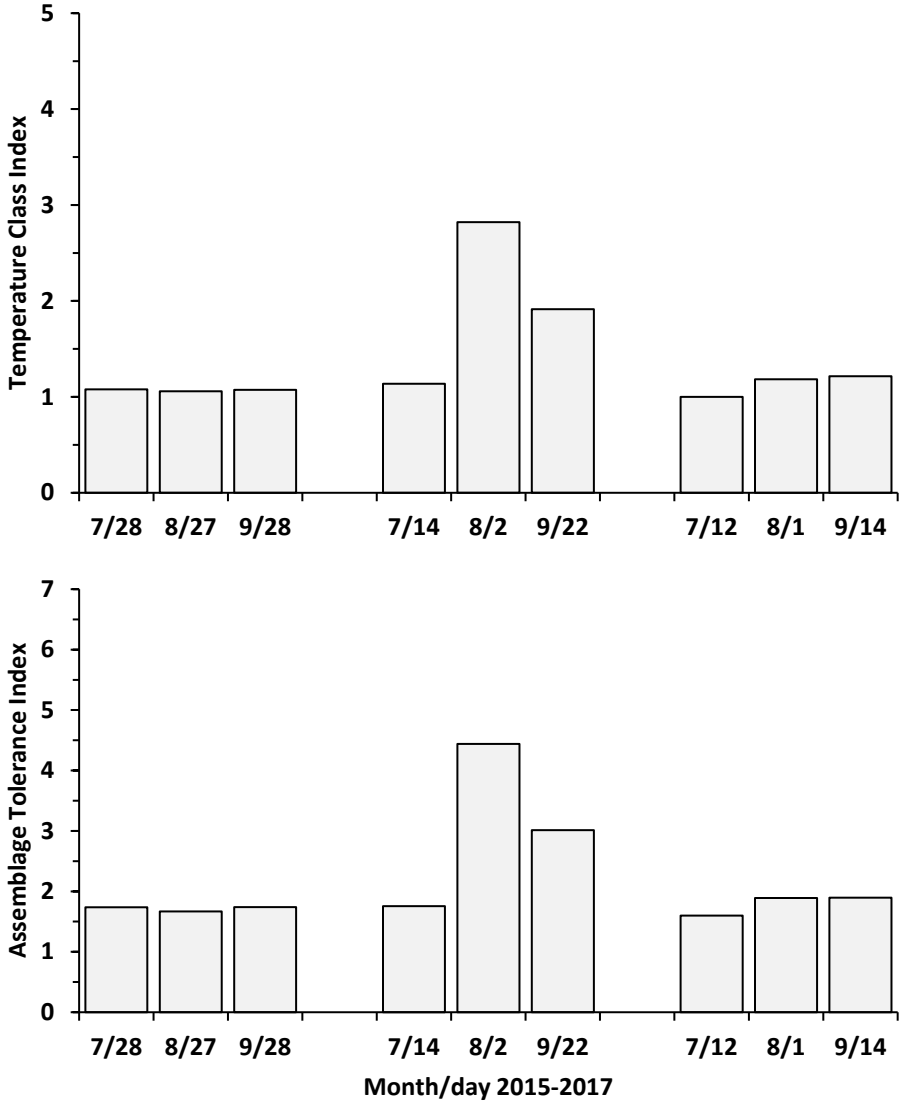

Figure 17. Temperature class index and assemblage tolerance index for surveys in the Little Pend Oreille River 2015–2017.

Myrtle Creek

Myrtle Creek was inspected along an 800-m reach within Kootenai NWR, from the waterfall at the NWR boundary downstream to the slack-water influence from the Kootenai River, during a reconnaissance trip in September 2014. Mean wetted width of the reach was 7 m. The upper limit of the survey reach (transect K) was located adjacent to the NWR's screened water diversion near the Myrtle Falls Trail footbridge, and the reach extended 280 m downstream (transect A; Figure 18), ending at a point immediately upstream from a large pool adjacent to a bedrock outcrop. The Westside Road Bridge crossed the reach approximately at its mid-point. The bridge was equipped with a U.S. Forest Service staff gauge on an abutment, and a pressure/temperature logger was installed on a different bridge abutment. Temperature loggers were installed at the diversion and along the west shore of the lowermost transect. Additional loggers (both a pressure/temperature logger and temperature logger) were installed in a solar radiation shield attached to the NWR shop building, located within 300 m from Myrtle Creek, in summer 2015 to record air temperature and barometric pressure.

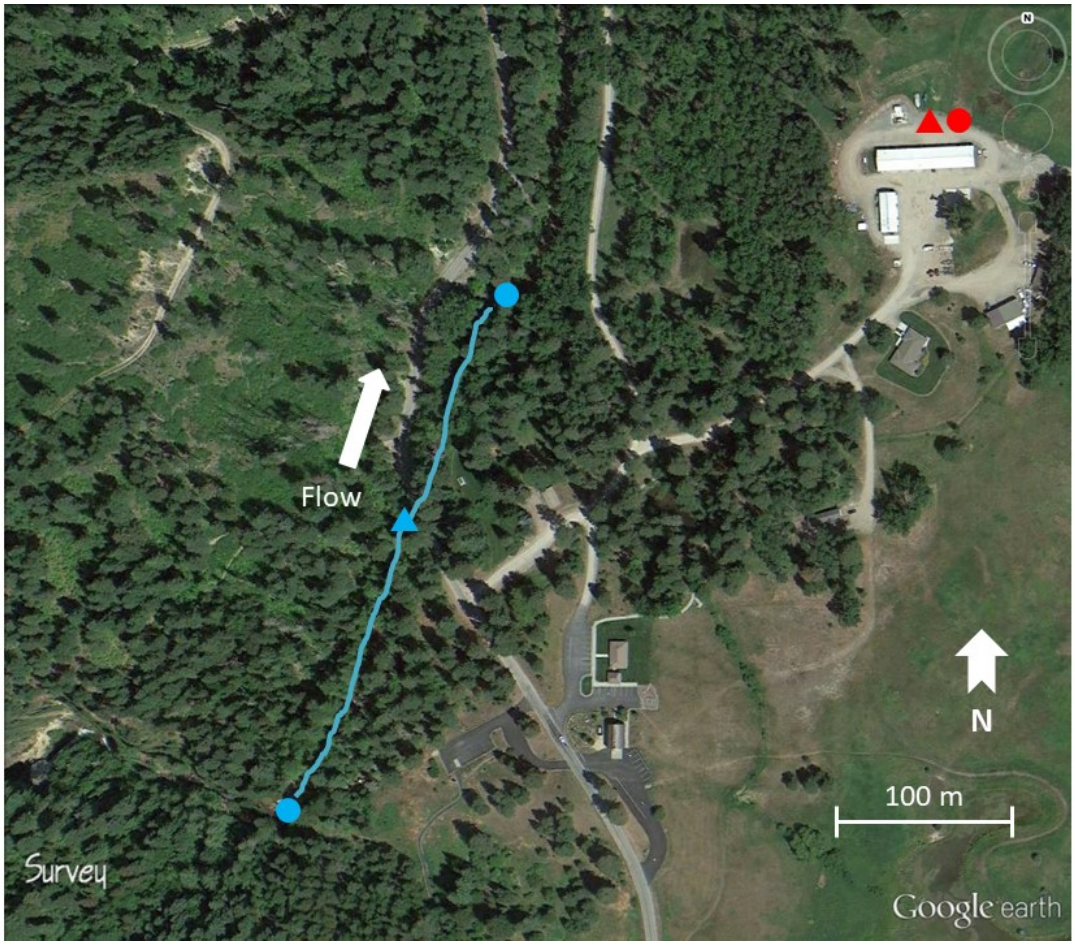

Figure 18. Aerial photograph of Myrtle Creek survey reach (blue line) showing locations of loggers (temperature logger (circle) and pressure/temperature logger (triangle) in water (blue shading) and air (red shading)).

Continuous air temperature data were collected during June 2015–October 2016 and August–September 2017, and continuous water temperature data were collected for January 2015–June 2017 and August–September 2017. Some temperature loggers were lost and replaced during the pilot project, and some had malfunctioned. Ranges in monthly mean, maximum, and minimum temperatures for air were -1.4–22.0˚C, 5.0–39.1˚C, and -17.0–8.3˚C, respectively, and for water were 0.7–16.5˚C, 1.7–20.7˚C, and 0.0–12.4˚C, respectively (Figure 19). The warmest summer month (June–August) at Myrtle Creek was variable (see Appendix B and Appendix C).

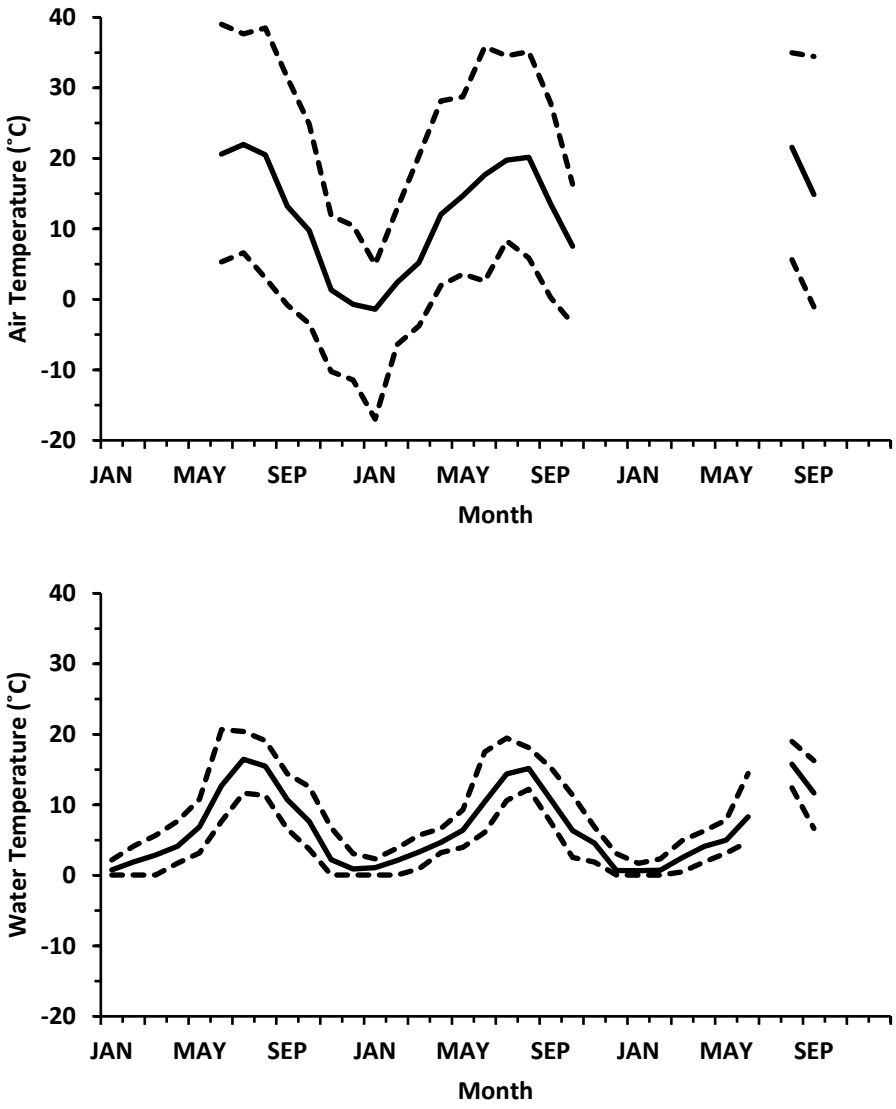

Figure 19. Monthly mean (solid line), maximum, and minimum (dashed lines) air temperatures at Myrtle Creek, June 2015–October 2016 and August–September 2017, and water temperatures, January 2015–June 2017 and August–September 2017. (Data loggers 10563306 and 10562373 for air temperature, loggers 10563330 and 10563318 for water temperature)

Difficulties with maintaining the pressure/temperature logger in Myrtle Creek precluded collection of data for estimating stream flow. Myrtle Creek was subject to anchor ice formation and substantial substrate movement, which resulted in the pressure/temperature logger being buried by substrate in one instance and failure of mounts in another instance. Problems persisted after reinstallation of the logger with modifications to its location within the stream and mounting technique. Stream flow of 6.5–24.7 cfs was estimated using a current meter during June–July 2015.

Habitat was assessed once annually in August during each of the three years of the pilot project. Overall characteristics for the four categories of habitat variables (i.e., channel, substrate, fish cover, and riparian vegetation) at Myrtle Creek included: channel widths up to 8 m and heights up to 1 m; substrate dominated by cobble, coarse gravel, and sand; fish cover consisting primarily of boulders and undercut banks; substantial mid-channel canopy cover (~80%); and riparian area dominated by bare ground and canopy of large trees (see Appendix E). Stream channel characteristics and riparian vegetation were the least variable habitat categories, and were followed by substrate and fish cover (Appendix F).

A total of nine fish surveys were conducted in Myrtle Creek during 2015–2017 (Appendix G). Number of species collected during each survey was 6–8 (Appendix H), which represented a total of 11 species (9 native and 2 non-native) for all surveys combined. Electrofishing effort in the 280-m survey reach appeared adequate for application of EMAP methods based on values of Jaccard Index comparing species collected in even- to odd-numbered subreaches for seven of the nine surveys (i.e., values ≥ 0.70; Peck et al. 2006). Species represented by 1–2 individuals were prevalent in surveys with low values of Jaccard Index.

For fish assemblage indices, there was substantial similarity in species presence-absence for comparisons made between surveys within years and all pairwise comparisons made among years (i.e., all Jaccard Index values > 0.60; Figure 20; Appendix I). In addition, similarity was high for species relative abundance for comparisons made within years and pairwise comparisons made among years (i.e., the majority of Morisita Index values ≥ 0.75). Three pairs of comparisons made among years exhibited moderate similarity (Morisita Index values 0.50–0.75) in species relative abundance (Figure 20).

All surveys and species were combined to conduct ecological classification of species. A total of 3,577 individuals were collected in Myrtle Creek (Appendix H). Mean (SD) relative abundance and mean (SD) frequency of occurrence were 9.1% (17.0) and 64.6% (41.5), respectively (Figure 21). Three species were classified as dominant (Longnose Dace (*R. cataractae*), Rainbow/Redband Trout[4], and Slimy Sculpin (*C. cognatus*)); three as common (Brook Trout, Mountain Whitefish (*Prosopium williamsoni*), and Torrent Sculpin (*C. rhotheus*)); and five as rare (Bullhead (*Ameiurus* sp.), Bull Trout (*S. confluentus*), Lake Chub (*Couesius plumbeus*), Longnose Sucker (*Catostomus catostomus*), and Westslope Cutthroat Trout (*O. clarki lewisi*)).

[4] Individuals likely resulting from introgression between coastal Rainbow Trout and inland Redband Trout (see USFWS 2011).

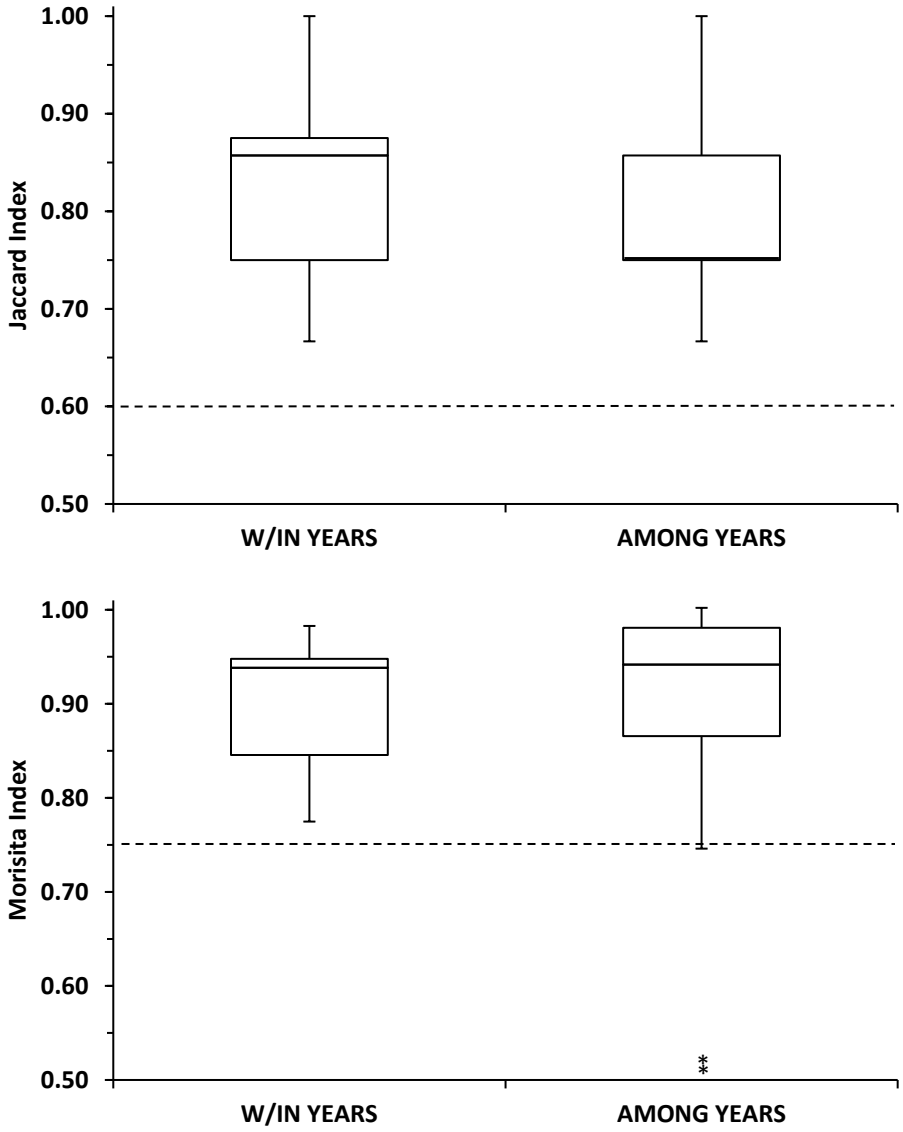

Figure 20. Indices of similarity between surveys conducted within years and all pairwise comparisons among years in Myrtle Creek during 2015–2017, based on species presence-absence (Jaccard Index) and species relative abundance (Morisita Index). Horizontal dashed line indicate threshold (see Methods).

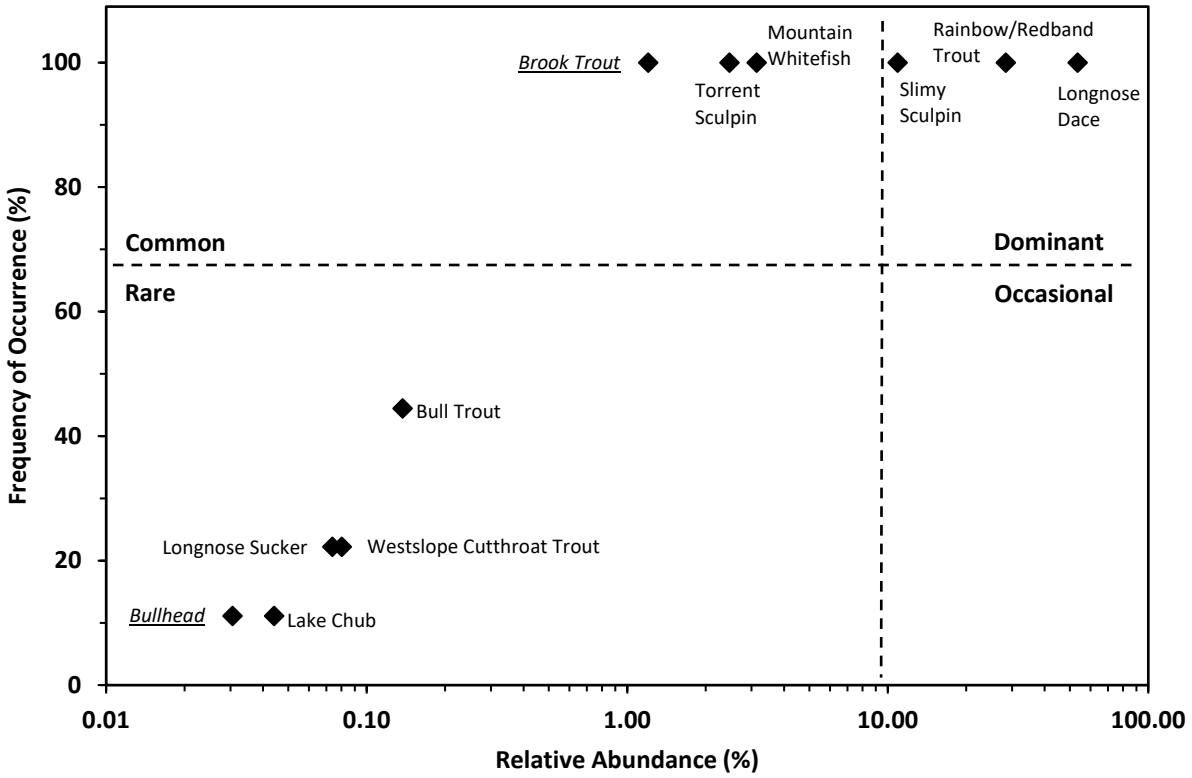

Figure 21. Ecological classification of 11 species collected during 9 fish surveys in Myrtle Creek during 2015–2017 (non-natives in underlined italics).

Fish species collected in Myrtle Creek represented three of five temperature classes, cold, cool, and warm (assigned ordinal values of 1, 3, and 5, respectively, Appendix I). Bullhead, a non-native represented by one individual, is the only species in the warm temperature class, and Longnose Dace and Longnose Sucker are the only species in the cool temperature class. The remaining eight species are in the cold temperature class. Range in temperature class index was 1.5–2.5 due primarily to Longnose Dace composing about half the individuals collected among the surveys and members of the cold temperature class composing most of the remaining individuals (Figure 22). Although differing in scale, the relative pattern of the temperature class index through time was similar to that of the assemblage tolerance index.

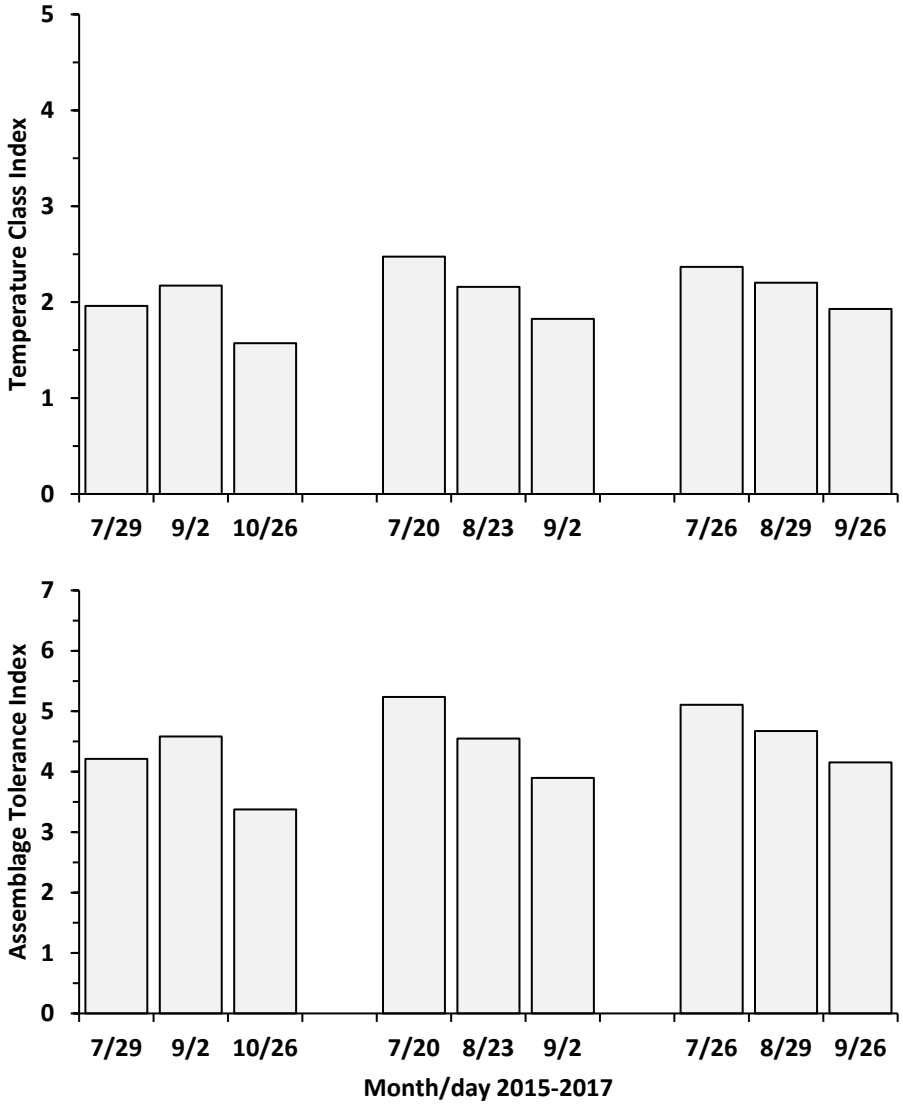

Figure 22. Temperature class index and assemblage tolerance index for surveys in Myrtle Creek 2015–2017.

Bridge Creek

Bridge Creek, within Malheur NWR, was inspected from the FWS Water Resources gauge station to about 1 km upstream during a reconnaissance trip in September 2014. Mean wetted widths were 6 m, and the area was considered suitable for establishing a survey reach for the sentinel site. Temperature loggers were installed in the stream about 150 m downstream of the gauge station and 500 m upstream. The survey reach was established during the initial field survey in August 2015. The lower limit of the reach (transect A; Figure 23) was 200 m above the gauge station and extended 240 m upstream (transect K). Temperature loggers were installed in a solar radiation shield and attached to a tree about 70 m upstream of the survey reach during the initial survey to record air temperature, and an additional temperature logger was placed in the stream about 80 m downstream of the survey reach in September 2016.

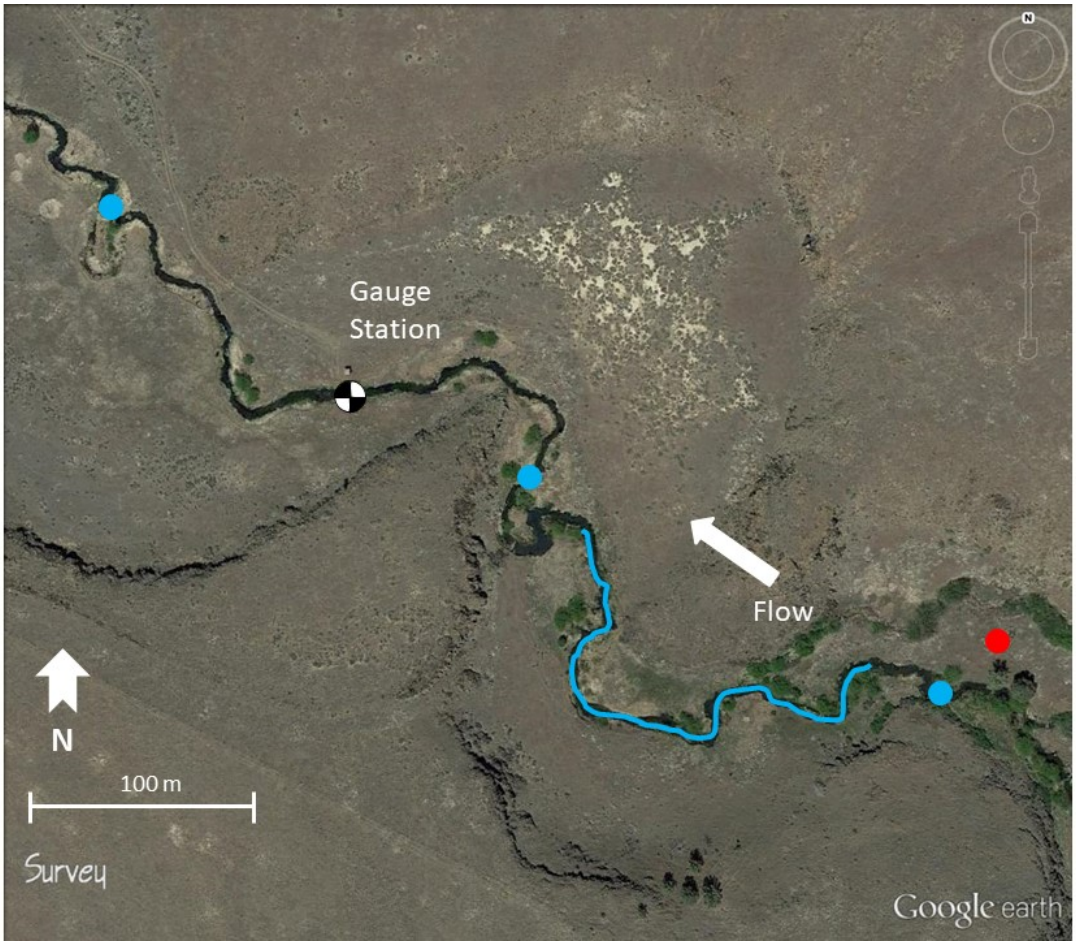

Figure 23. Aerial photograph of Bridge Creek survey reach (blue line) showing locations of loggers (temperature logger (circle) in water (blue shading) and air (red shading)) and Water Resources gauge station.

Continuous air temperature data were collected during September 2015–August 2017 and continuous water temperature data presented here were collected during January 2015–August 2017. Ranges in monthly mean, maximum, and minimum temperatures for air were -4.5–22.9˚C, 9.8–37.0˚C, and -27.4–6.7˚C, respectively, and for water were 8.4–14.7˚C, 10.0–18.5˚C, and 5.3–12.0˚C, respectively (Figure 24). June or July were the warmest summer months (June–August) at Bridge Creek(see Appendix B and Appendix C).

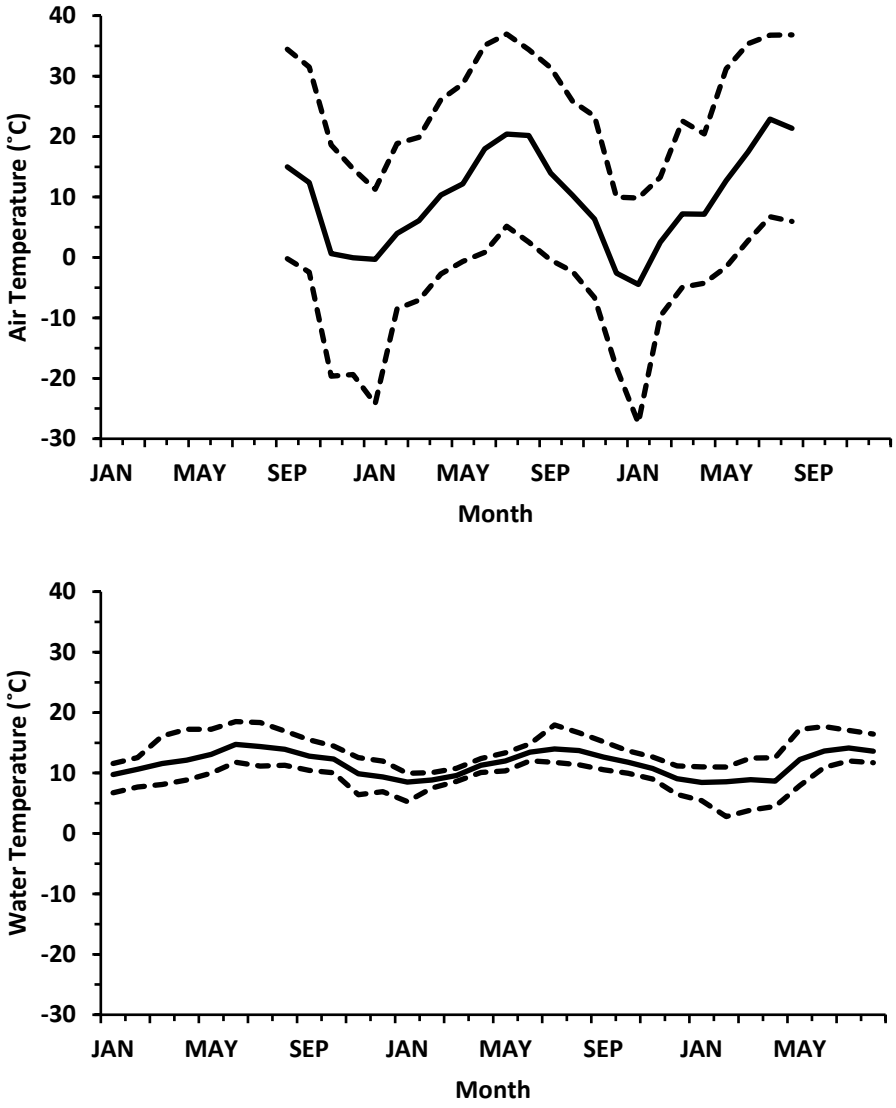

Figure 24. Monthly mean (solid line), maximum, and minimum (dashed lines) air temperatures at Bridge, September 2015–August 2017, and water temperatures, January 2015–August 2017. (Data loggers 10563311 and 10563328 for air and water temperatures, respectively).

Stream flow was continuously recorded at the FWS Water Resources gauge station during January 2015–December 2017. Range in monthly mean, maximum, and minimum flow was 9–

34 cfs, 9–64 cfs, and 9–21 cfs, respectively (Figure 25). Range in daily flow was 9–14 cfs for dates on which habitat and fish surveys were conducted. Range in flow measured upstream and downstream of the survey reach during habitat and fish surveys was 8–14 cfs.

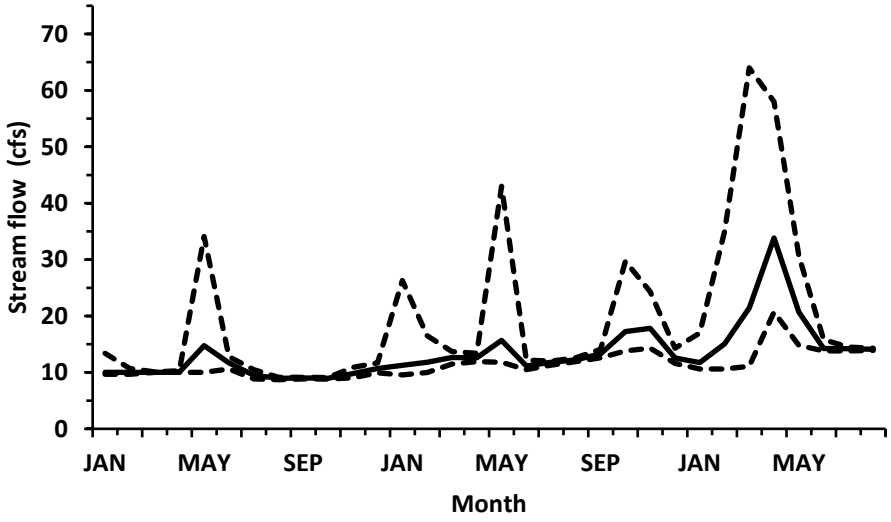

Figure 25. Monthly mean (solid line), maximum, and minimum (dashed lines) stream flow at Bridge Creek during 2015–2017. (Data provided by FWS Water Resources).

Habitat was assessed once annually in August during each of the three years of the pilot project. Overall characteristics for the four categories of habitat variables (i.e., channel, substrate, fish cover, and riparian vegetation) in Bridge Creek included: channel widths up to 6 m and heights less than 1 m; substrate dominated by fines, sand, and fine and coarse gravel; fish cover consisting primarily of overhanging vegetation and macrophytes rooted along the stream margins; and low mid-channel canopy cover (~25%) provided by understory vegetation and absence of riparian canopy (trees > 5 m in height; see Appendix E). Stream channel and riparian vegetation characteristics were the least variable habitat categories among surveys, and were followed by substrate and fish cover (Appendix F).

A total of nine fish surveys were conducted in Bridge Creek during 2015–2017 (Appendix G). Number of species collected during each survey was 2–4 (Appendix H), which represented a total of four species for all surveys combined. All species were native. Electrofishing effort in the 240-m survey reach appeared adequate for application of EMAP methods based on values of Jaccard Index comparing species collected in even- to odd-numbered subreaches for six of the nine surveys (i.e., values ≥ 0.70; Peck et al. 2006). Species represented by 1–2 individuals were present in surveys with low values of Jaccard Index (i.e., values < 0.70).

For fish assemblage indices, there was substantial similarity in species presence-absence for comparisons made between surveys within years and all pairwise comparisons made among years (i.e., majority of Jaccard Index > 0.60; Figure 26; Appendix I). Patterns in Jaccard Index values were identical for comparisons both within year and among years. All values < 0.60 were comparisons that involved a single survey in which only two species were collected. For

assemblage structure based on species relative abundance, overall similarity was high for both comparisons within years and all pairwise comparisons among years (i.e., majority of Morisita Index > 0.75), indicating consistency of the most abundant species among surveys. A small number of among year comparisons indicated moderate similarity (i.e., values > 0.50 but < 0.75), and involved comparisons with surveys for which the most abundant species varied.

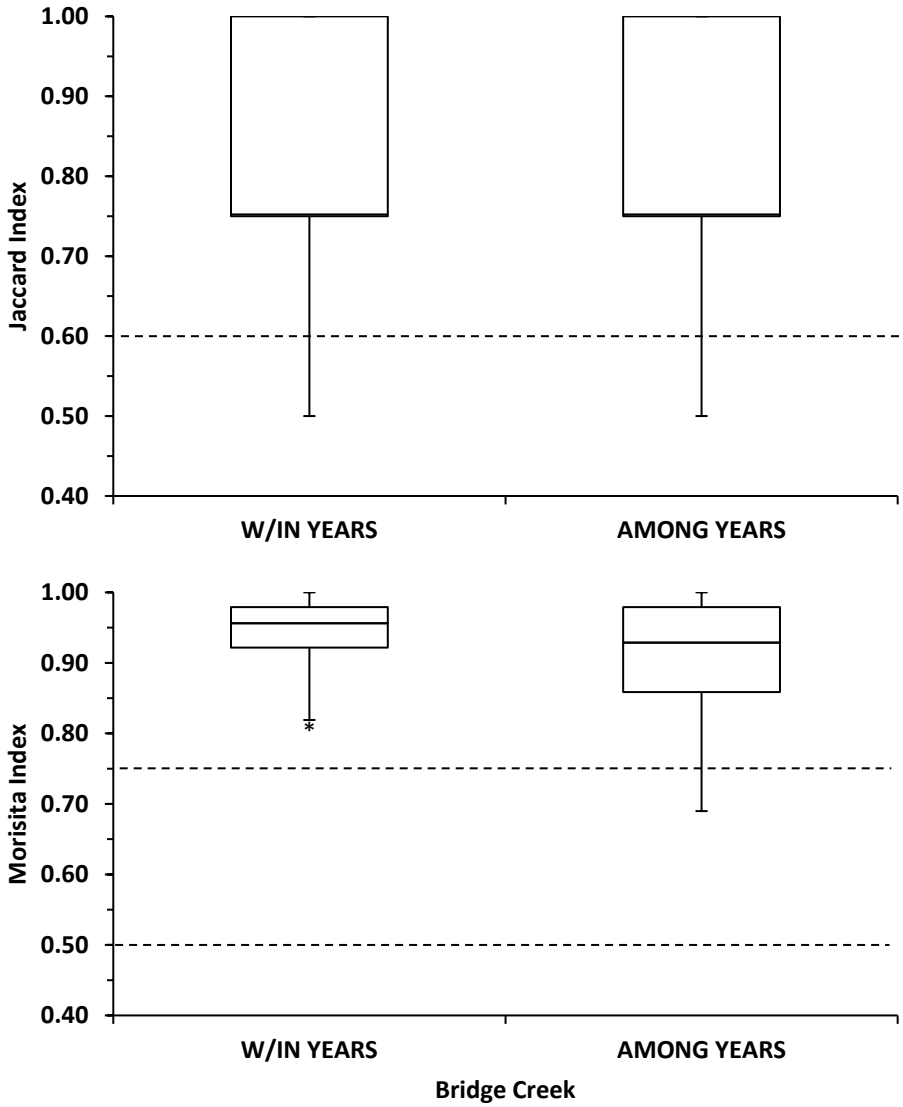

Figure 26. Indices of similarity between surveys conducted within years and all pairwise comparisons among years in Bridge Creek during 2015–2017, based on species presence-absence (Jaccard Index) and species relative abundance (Morisita Index). Horizontal dashed line indicate threshold (see Methods).

All surveys and species were combined to conduct ecological classification of species. A total of 3,063 individuals were collected in Bridge Creek (Appendix H). Mean (SD) relative abundance and mean (SD) frequency of occurrence were 25.0% (28.3) and 83.3% (26.4), respectively

(Figure 27). Two species were classified as dominant (Speckled Dace and Malheur Sculpin (C. bendirei)), one as common (Redband Trout[5]), and one as rare (Longnose Dace).

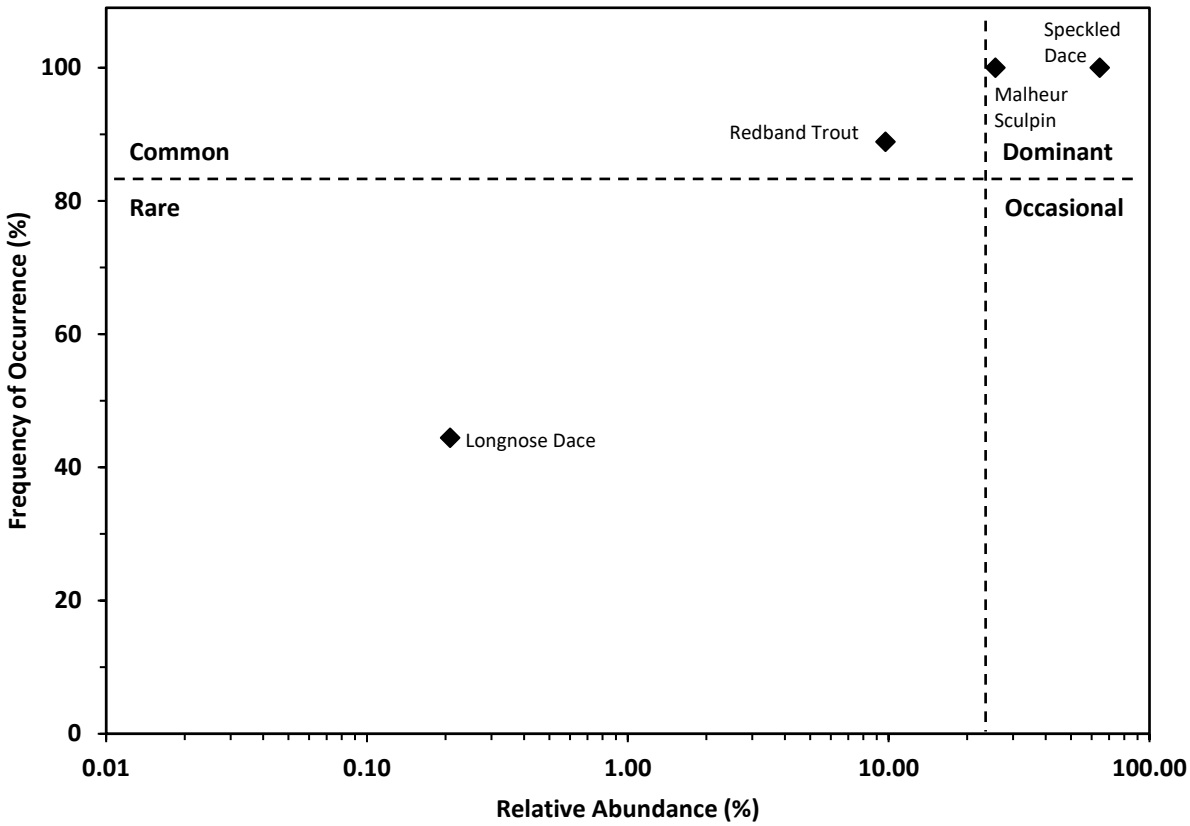

Figure 27. Ecological classification of four fish species collected during nine fish surveys in Bridge Creek during 2015–2017.

Fish species collected in Bridge Creek represents three of five temperature classes, cold, cold/cool, and cool (assigned ordinal values 1, 2, and 3, respectively, Appendix I). Malheur Sculpin and Redband Trout are in the cold temperature class, Speckled Dace is in the cold/cool temperature class, and Longnose Dace is in the cool temperature class. The lowest values of the temperature class index were for surveys in September 2016 and 2017 (Figure 28), which were the only instances when Speckled Dace relative abundance was not the highest among surveys (see Appendix F). Malheur Sculpin had the highest relative abundance for the two surveys. This pattern was similar to that for the assemblage tolerance index.

Among all sentinel sites combined, temperature class index and ATI were significantly correlated ($r_s = 0.87$; n = 42; $p < 0.001$).

[5] Individuals likely with relatively low levels of introgression between coastal Rainbow Trout and inland Redband Trout (see Dehaan et al. 2015, ODFW 2018).

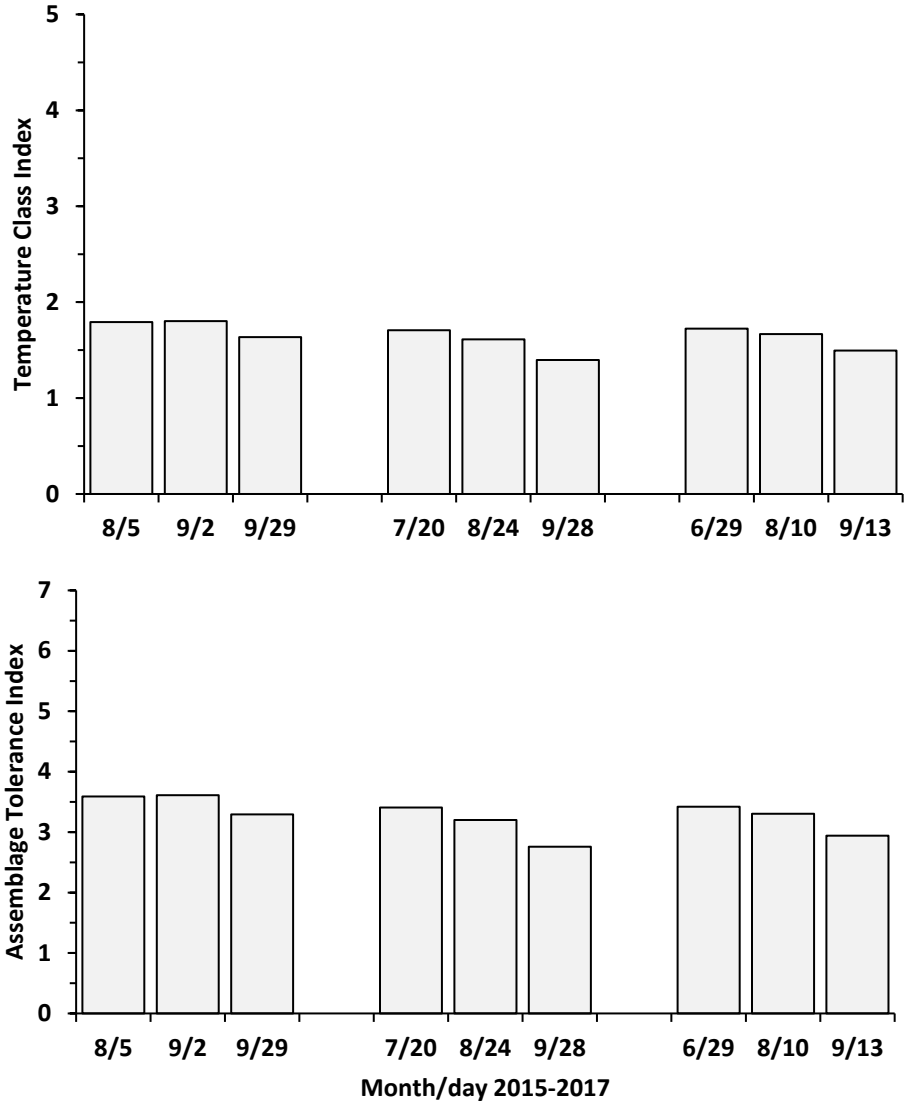

Figure 28. Temperature class index and assemblage tolerance index for fish surveys in Bridge Creek 2015–2017

Habitat Attributes Among Sentinel Sites

Each category of habitat variables (i.e., channel, substrate, fish cover, and riparian) describing characteristics of survey reaches consisted of 9–11 individual variables (Table 1). The order of categories based on lowest to highest median CV for sentinel sites combined was channel, riparian, substrate, and fish cover (Figure 29). Variability of habitat variables were significantly different among categories ($p < 0.05$, $df = 3$, Kruskal-Wallis test). The medial variability in measures of channel characteristics was significantly less than the substrate and fish cover categories, and the riparian category was significantly less than the fish cover category (nonparametric multiple range test of ranks; Figure 29).

Table 1. Habitat variables assessed at each sentinel site, by category—channel, substrate, fish cover, and riparian.

Channel	Substrate	Fish cover	Riparian
Mean wetted width	Proportion bedrock	Mean % filamentous algae	Mean % mid-channel canopy cover
Mean bankfull width	Proportion boulder	Mean % macrophytes	Mean % banks canopy cover
Mean bankfull height	Proportion cobble	Mean % woody debris	Mean % canopy large trees
Mean incised height	Proportion coarse gravel	Mean % brushy/woody debris	Mean % canopy small trees
Mean thalweg depth	Proportion fine gravel	Mean % live trees/roots	Mean % understory woody vegetation
Mean residual pool depth	Proportion sand	Mean % overhanging vegetation	Mean % understory non-woody vegetation
Water surface slope	Proportion fines	Mean % undercut banks	Mean % ground cover woody vegetation
Channel sinuosity	Mean % embeddedness	Mean % boulders	Mean % ground cover non-woody vegetation
Mean left bank angle	Geometric mean particle size	Mean % artificial structures	Mean % bare ground
Mean right bank angle	$\log_{10}$ erodible substrate diameter	Total volume woody debris	
	$\log_{10}$ relative bed stability	Volume woody debris per m^2	

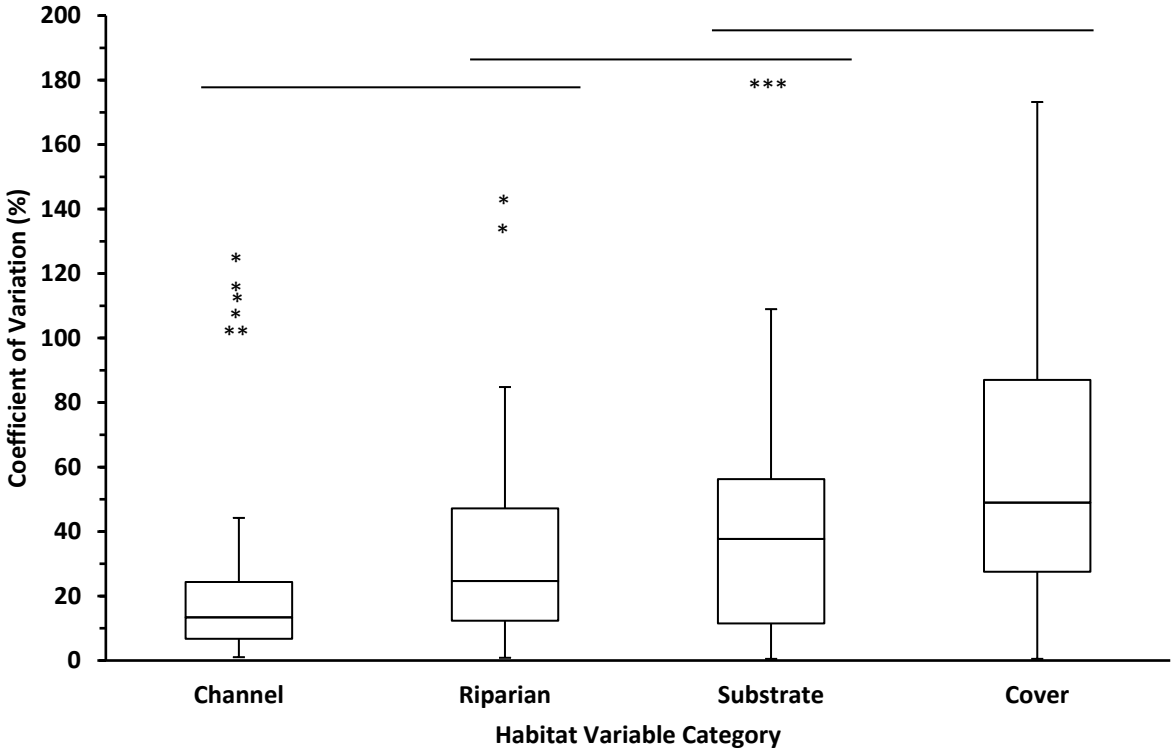

Figure 29. Coefficients of variation for categories of habitat variables among sentinel sites (n=50, 44, 44, and 43, respectively, for channel, riparian, substrate, and cover categories). Horizontal bars indicate categories that were not significantly different.

Each class of measurement for habitat variables (i.e., quantitative measurement of stable features, quantitative measurement of flow-dependent features, semi-quantitative measurement of presence-absence, and visual estimates of areal cover) describing characteristics of survey reaches consisted of 5–17 individual variables (Table 2). The order of classes based on lowest to highest median CV for sentinel sites combined was quantitative, flow-dependent quantitative, semi-quantitative, and visual estimates (Figure 30). The median variability in measures of habitat variables were significantly different among classes ($p < 0.05$, $df = 3$, Kruskal-Wallis test). The quantitative and flow-dependent quantitative classes were significantly less than the semi-quantitative and visual estimates classes (nonparametric multiple range test of ranks; Figure 30).

Table 2. Habitat variables assessed at each sentinel site, by classes of measurements—quantitative, flow-dependent quantitative, semi-quantitative, and visual estimates.

Quantitative	Flow-dependent quantitative	Semi-quantitative	Visual estimates
Mean residual pool depth	Mean wetted width	Proportion bedrock	Mean % embeddedness
Water surface slope	Mean bankfull width	Proportion boulder	Mean % filamentous algae
Channel sinuosity	Mean bankfull height	Proportion cobble	Mean % macrophytes
Mean % mid-channel canopy cover	Mean incised height	Proportion coarse gravel	Mean % woody debris
Mean % banks canopy cover	Mean thalweg depth	Proportion fine gravel	Mean % brushy/woody debris
	Mean left bank angle	Proportion sand	Mean % live trees/roots
	Mean right bank angle	Proportion fines	Mean % overhanging vegetation
		Geometric mean particle size	Mean % undercut banks
		$\log_{10}$ erodible substrate diameter	Mean % boulders
		$\log_{10}$ relative bed stability	Mean % artificial structures
		Total volume woody debris	Mean % canopy large trees
		Volume woody debris per m^2	Mean % canopy small trees
			Mean % understory woody vegetation
			Mean % understory non-woody vegetation
			Mean % ground cover woody vegetation
			Mean % ground cover non-woody vegetation
			Mean % bare ground

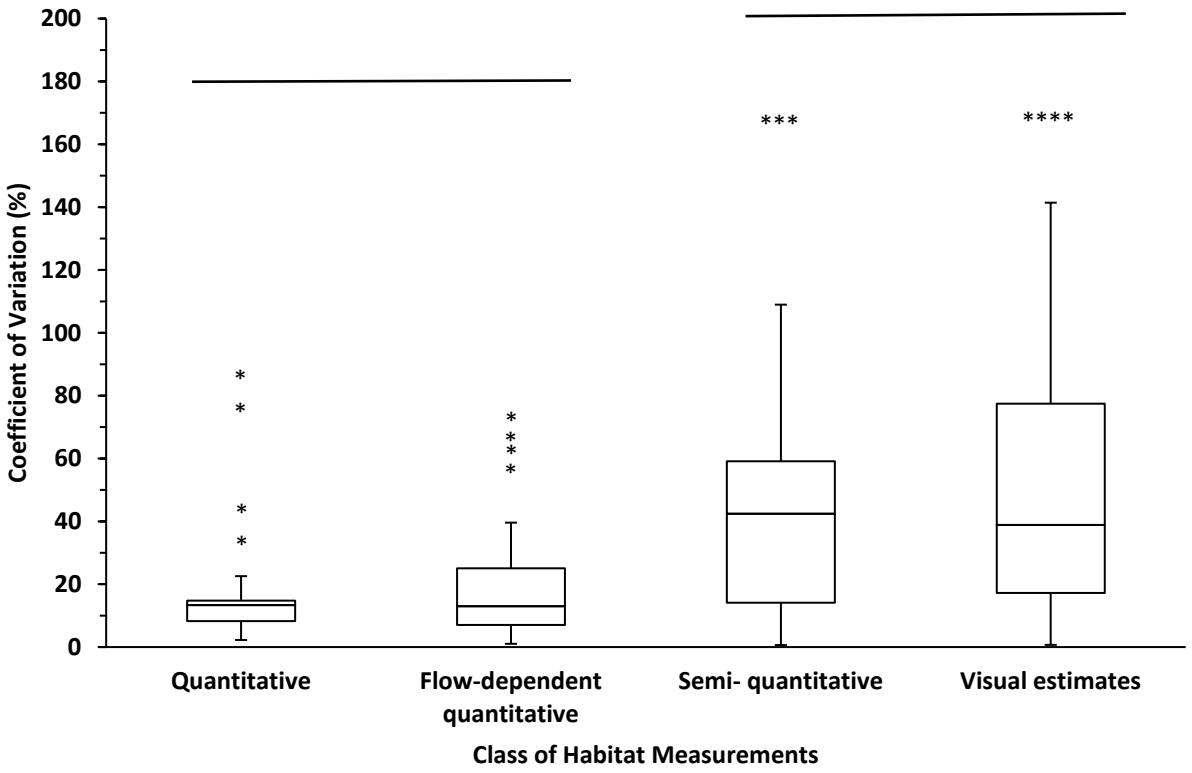

Figure 30. Coefficients of variation for classes of habitat measurements among sentinel sites (n=25, 35, 49, and 72, respectively; for classes of measurements—quantitative, flow-dependent quantitative, semi-quantitative, and visual estimates). Horizontal bars indicate classes that were not significantly different.

Discussion

The pilot project consisted of four major components characterizing physical, habitat, and biological attributes of the five sentinel sites: air and water temperatures, stream flow, habitat, and fish assemblages. The performance, logistical constraints, and likely sustainability of each major component are discussed relative to the goal and applicable objectives of the monitoring program, and form the rationale of our recommendations for long-term implementation of the program.

Water and Air Temperatures

Temperature loggers were deployed at various locations at each sentinel site to record air and water temperatures during the pilot project. Complete time series of temperatures for the time of deployment (i.e., continuous time series produced by a single logger) exist for both air and water temperatures at four sites, Muddy Creek, Omeara Creek, Little Pend Oreille River, and Bridge Creek, with air temperature at Little Pend Oreille River generated by a logger maintained by Water Resources. Incomplete time series of air and water time series at Myrtle Creek were caused by several factors: loss of loggers likely due to being buried, displacement, attachment failure, or suspected vandalism; and failure of logger to record temperature due likely to malfunction or error in properly programming loggers. Performance can be considered moderate given that complete time series were generated for four of five sentinel sites and partial time series were generated at the remaining site. Overall, these data initiate the generation of long-term time series necessary to address the objective to describe how physical attributes vary through time. Performance in the future can be improved by: adjusting logger deployment techniques according to published guidance (i.e., EPA 2014) where problems were previously encountered; testing that loggers are properly programmed prior to deployment; immediately backing up all data files; and deploying multiple loggers at each sentinel site.

Temperature loggers recording at 30-minute intervals have a storage capacity of slightly more than two years and a battery life of five years. Thus, a logistical constraint is that loggers should be downloaded before storage capacity is exceeded and replaced every five years, assuming that they are operating correctly. To ensure continuity of a time series of temperatures, a preference would be to download and inspect the integrity of loggers on an annual basis. The effort to maintain temperature loggers on such a schedule is assumed to be less than a day of personnel time per sentinel site, and thus appears reasonable to be sustainable if performed by NWR personnel located at each site. Such an arrangement would eliminate travel expenses if annual downloads were conducted by FAC personnel.

Stream Flow

Pressure/temperature loggers and staff gauges were installed to facilitate generating a time series for stream flow at three sentinel sites (Muddy, Omeara, and Myrtle creeks), and Water Resources provided stream flow data from gauge stations operated at two sentinel sites (Little Pend Oreille River and Bridge Creek). Complete or partial time series of stream flow exist during the duration of the pilot project for Little Pend Oreille River, Bridge Creek, and Muddy Creek. However, the Muddy Creek data is of limited utility. Stream flow was extremely low during

summer–fall months in Muddy Creek, and the pressure/temperature logger was dewatered for extended periods. Moreover, most flow observations used to generate the rating curve were conducted during the low-flow period and only limited measurements taken at higher flows when the stream could be safely waded. Based on the time series, stage exceeded the upper limit for which stream flow was appropriate to extrapolate (i.e., twice the highest flow measured; EPA 2014) for almost half of the time series. Considerably more effort and alternatives to wading were needed to measure a broader range of flows for the rating curve at Muddy Creek.

Maintaining pressure/temperature loggers at Omeara and Myrtle creeks were especially challenging. Flows in Omeara Creek were extremely low during surveys and exhibit considerable range during winter based on movement of large wood and substrate, whereas Myrtle Creek was subject to anchor ice and presumed bedload movement. Loggers at both sentinel sites were buried during winter–spring flows and had to be relocated within the streams. No usable files were retrieved from the loggers and few estimates of stream flow were made.

Pressure/temperature loggers recording both variables at 15-minute intervals (EPA 2014) have a storage capacity of slightly more than seven months and a battery life of five years. Thus, a logistical constraint is that loggers should be downloaded before storage capacity is exceeded and replaced every five years, assuming that they are operating correctly. In addition, stream flows would need to be estimated over a broad range to develop an adequate rating curve, and locations monitored for changes in the stream channel that could affect the rating curve. Because the effort necessary to maintain pressure/temperature loggers and safely develop a rating curve is assumed to be substantial, the resources required to generate stream flow time series at the three sentinel sites that do not have existing gauge stations are assumed to be unsustainable. In addition, resources necessary for the installation and operation of gauge stations at the three sites are also assumed to be unsustainable, especially given challenging conditions at some sites (e.g., small stream size, high substrate movement, and anchor ice). Although methods to estimate flow statistics for unregulated sites (e.g., Risley et al. 2008) could be applied to the three sentinel sites that lack gauge stations, estimated stream flow statistics would not address potential changes in seasonal flows (e.g., overall quantity, peaks, minima, timing, duration) that are anticipated responses to climate change (Dalton et al. 2013). Therefore, a preferred approach is to conduct analyses of data generated by multiple established gauge stations in the vicinity of sentinel sites to assess potential changes in how stream flow varies through time. This may allow inferences about how stream flow likely varies through time at the un-gauged sentinel sites.

Habitat

Habitat at sentinel sites consisted of four categories of variables (i.e., channel, riparian, substrate, and fish cover characteristics) that represented various classes of measurements (i.e., variables based on quantitative stable, quantitative flow-dependent, semi-quantitative or presence-absence, and visually estimated measurements). Habitat variables were assessed during each of the three years of the pilot project at all sentinel sites with the exception of Omeara Creek, which was assessed for only two years because riparian vegetation was removed from much of the original reach during the third year of the project. Performance of the habitat assessment, and likely ability to detect potential changes through time, was based on the variability (CVs) of the variables measured during the pilot project and their relevance to anticipated effects of climate change.

The least variable category of habitat variables among sentinel sites was stream channel characteristics, which was followed by the riparian vegetation, substrate, and fish cover categories. Each category consisted of 9–11 individual variables. For classes of habitat measurements, the quantitative and flow-dependent quantitative classes were significantly less variable than variables based on semi-quantitative and visually estimated classes of variables. The quantitative and flow-dependent quantitative classes were primarily represented by variables within the stream channel category, whereas the semi-quantitative class consisted of variables in the substrate category; and the visually estimated class primarily consisted of variables in both the riparian and fish cover categories. Each class consisted of 5–17 individual variables, and variability of habitat measurement class inversely varied with the number of variables composing each class. Several factors may have affected estimates of variation during the pilot project (e.g., actual changes in habitat variables, variability among different field crew characterizing habitat at a sentinel site) for which we did not address. However, our overall observations of variability are similar to findings by Kaufmann et al. (1999) for which signal-to-noise ratios were analyzed as a measure of variability for habitat data from an extensive EMAP data set. Channel morphology variables were the least variable and fish cover variables were the most variable for categories of habitat variables; and quantitative measurements were the most precise and visually estimated measurements were imprecise for classes of habitat measurement (Kaufmann et al. 1999).

The importance of the habitat variables included in EMAP methods have been noted for assessing associations with fish assemblages as well as a variety of other aquatic taxa (Kaufmann et al. 1999). However, specific variables likely differ in their sensitivities to anticipated responses to climate change. In general, climate influences such factors as temperature, precipitation, and vegetation, which may be major determinants of flow regime and sediment dynamics. Relatively small fluctuations in climate affecting these variables have been found to strongly influence habitat in rivers (Knighton 1998). Buffington (2012) noted a broad range of spatial and temporal responses possible in streams to changes in climate, ranging from substrate composition at a point within a stream over the course of minutes to changes in gradient and sinuosity at stream reaches over longer time periods (e.g., up to centuries). Changes in channel dimensions at cross sections may occur at intermediate spatial and temporal scales, which may be detectable at the scale of our sentinel sites. In addition, relatively rapid responses in riparian forests to climate change have been hypothesized (e.g., reductions in recruitment, shifts in species composition) with various implications for stream systems (Davis et al. 2013). Of the four categories of habitat variables assessed, channel and riparian characteristics performed well relative to variability and also are thought to be sensitive to likely effects of climate change.

Time required to conduct the habitat survey at sentinel sites ranged from a matter of hours to more than a day. Thus, a logistical constraint is availability of personnel, ideally 2–4 individuals, able to conduct surveys. Time required can be reduced by focusing on the most precise habitat variables that are sensitive to likely effects of climate change (i.e., channel and riparian habitat variable categories) and eliminating the imprecise variable categories (i.e., substrate and fish cover categories), which would improve sustainability of habitat surveys. Also, additions or modifications can be made to the channel and riparian variables to improve their utility (e.g., expressing channel dimensions relative to mean thalweg depth of the reach to

eliminate flow dependency on some variables, incorporating stem counts for woody vegetation in canopy and understory layers of riparian plots to gauge recruitment through time).

Fish Assemblages

Adequacy of effort for the fish surveys were assessed using EMAP guidance (i.e., Jaccard Index ≥ 0.70 comparing species similarity between even– to odd–numbered subreaches; Peck et al. 2006), and fish assemblages were described using four approaches (i.e., descriptors of species, indices of similarity, ecological classification, and temperature class index and ATI). Effort was adequate for EMAP application for the majority of fish surveys, with Jaccard Index below the threshold value during 1–3 surveys at each sentinel site. Recommendations for applying EMAP methods include surveying additional pairs of subreaches until Jaccard Index values surpass the threshold, if possible, which would increase sample size and habitat sampled, thus improving the likelihood of encountering additional species (Cao et al. 2001). Additional areas were not sampled during the pilot project due to constraints in time and limited availability of suitable stream habitat at some sentinel sites. Low Jaccard Index values primarily were due to encountering rare species that were often represented by single individuals.

The four approaches used to describe fish assemblages encompassed various aspects of the fish assemblage at each sentinel site, including: descriptors documenting species composition and their origin, native or nonnative; similarity indices compared pairs of surveys based on species presence-absence and species relative abundance; ecological classification assigned species to categories based on their relative abundance and frequency of occurrence for all surveys at each site; and indices of temperature class and tolerance characterized fish assemblages relative to temperature preference and sensitivity to overall habitat degradation for each survey. These assemblage metrics ranged from taxonomic richness to ecological traits of species, for which some have be used individually to assess variability of fish assemblages (Lohr and Fausch 1997) or in multimetric indices to assess anthropogenic degradation of aquatic systems (Karr et al. 1986; Fausch et al. 1990; Roset et al. 2007). All assemblage metrics assisted in describing various aspects of biological attributes. Moreover, the results of multiple annual surveys performed during the pilot project can be considered a baseline, for which a time series of surveys generated during long-term implementation of the monitoring program can be compared to assess evidence of climate change.

Performance of the fish assemblage metrics was site specific for general descriptors, species composition and origin. Because the available species pool is associated with stream size and zoogeographic history (Fausch et al. 1984), as well as access by nonnative species, site specificity was expected given that sentinel sites represent streams of various sizes occurring in three ecoregions. Performance of similarity indices were consistent overall, both for within years and all pairwise comparisons among years, with median values indicating substantial similarity for species presence-absence and high similarity for species relative abundance. An exception was that the Muddy Creek fish assemblage exhibited substantial difference in species presence-absence for all pairwise comparisons among years, which was likely due to the sporadic occurrence of rare species. Overall, range in values for both similarity indices was typically lower for within year comparisons than all pairwise comparisons among years. Differences in range could be affected by sample size (i.e., fewer pairs of surveys contributing to within year versus comparisons among years) as well as greater similarity of species presence-

absence and relative abundance during a season, indicating that a single fish survey per field season would be adequate for long-term implementation of the monitoring program. Ecological classification provided a characterization of species composing assemblages relative to results of all surveys at each sentinel site. Ecological classification should be updated with additional surveys in the future and any changes in the classification of species assessed. Both temperature class and tolerance indices characterized prevalent traits of the assemblage for each survey (i.e., temperature preference and tolerance to habitat degradation). A time series of indices should be generated so that potential changes in index values through time can be analyzed. Even though both indices were highly correlated, the temperature class index is likely more appropriate for long-term implementation because it specifically focuses on temperature and not habitat degradation in general.

Stream flow and water temperatures affected our ability to efficiently conduct surveys during the pilot project. For instance, high water temperatures exceeded collection permit limits to safely electrofish during mid-summer at Muddy Creek; early rains increased flows in Omeara Creek precluding a survey during early fall; high flows and low water temperatures due to late runoff reduced survey efficiency during the early portion of the field season at the Little Pend Oreille River; and low water temperatures likely reduced survey efficiency at Myrtle Creek during the latter portion of the field season. Thus, site conditions can be a logistic constraint for surveys. Site-specific information generated by conducting multiple fish surveys during the pilot project should be considered with current conditions at each sentinel site when selecting timing of surveys for long-term implementation of the monitoring program.

Four people with electrofishing experience was needed to complete a fish survey within one to two days. Additional personnel to assist with capture and processing fish could increase efficiency and reduce time on site. Given travel to and from a sentinel site of up to two days, a crew could perform both habitat and fish surveys within one work week.

Conclusions and Recommendations for Long-term Implementation

Based on the three-year pilot project, overall conclusions for the various components of the monitoring program are that assessing air and water temperature using temperature loggers is an efficient and sustainable approach to generate time series of temperature. Careful deployment and diligent maintenance of multiple loggers, to provide redundancy in case of failures, are required for long-term implementation. Generating an adequate time series of stream flow using pressure/temperature loggers and rating curves was not successful at the three sentinel sites that did not have established stream gauge stations. Resources necessary for the installation and maintenance of gauge stations at these sites are likely not sustainable. Categories of habitat variables were relatively consistent with respect to variability, with stream channel and riparian vegetation categories the least variable. In addition, the stream channel and riparian vegetation categories of variables are responsive to precipitation, stream flow, and temperature over decadal time scales, which makes them the best of the four categories we evaluated for assessing potential effects of climate change. Using various metrics to describe fish assemblages highlighted multiple aspects of assemblage structure. Overall, similarity in species presence-absence and relative abundance was substantial at all but one site during the pilot project, so that a single fish survey conducted once over the course of multiple years should be sufficient to establish a time series. Fish assemblage data generated during the pilot project, based on multiple surveys conducted during three consecutive years, can be considered a baseline to which results of future surveys can be compared. To achieve the goal of the monitoring program, we consider the priorities of data generated by the four components of the program to be: first–air and water temperature; second–stream flow; third–fish assemblage characteristics; and fourth–habitat.

Recommendations for long-term implementation of the monitoring program include:

- Maintain at least two loggers for air temperature and two loggers for water temperature at each sentinel site. Establish procedures with NWR personnel to at least annually inspect and download loggers.
- Continue collecting stream flow data at Water Resources gauge stations (Little Pend Oreille River and Bridge Creek).
- Discontinue efforts to collect stream flow data at sentinel sites without gauge stations. Identify existing gauge stations in the vicinity of these sites and assess whether data are appropriate to make inferences with respect to temporal analyses of stream flow for the sentinel sites.
- Conduct a fish survey at least at one sentinel site per year with timing based on site conditions that optimize sampling efficiency.
- In conjunction with fish surveys, continue habitat surveys for stream channel and riparian vegetation categories of variables. Explore modifications to assess channel variables to account for flow-dependency (e.g., calculate channel heights relative to streambed as opposed to water level) and additional riparian vegetation variables specific to potential effects of climate change (e.g., incorporate indicators of tree recruitment).
- Establish rotating schedule for fish and habitat surveys so that each sentinel site is surveyed at least once per a 5-year interval, and conduct surveys as soon as possible

following major watershed events (e.g., fire, 20-year flood). Identify additional conditions that would necessitate surveying more frequently (e.g., values of similarity indices for a fish survey fall outside the range observed during the pilot project).

- Conduct all surveys with a composite crew representing personnel from all FAC offices to enhance sustainability of the effort and encourage continuity in the application of program protocols over time. Personnel from each office would annually update databases and perform analyses.
- As the workforce turns over through time, designate and train new staff at each FAC office to be responsible for program activities at respective sentinel sites, and a lead person to ensure coordination among activities, Service programs, reporting, and data management.
- Develop operating manuals for the monitoring program establishing the roles/responsibilities of each NWR and FAC office, protocols for field work, data management, and reporting.
- Develop comprehensive progress reports at intervals of no more than 10 years. Reports should include temporal analyses of air and water temperature, stream flow, fish assemblages, and habitat; assessments of potential changes in landscape attributes used in the selection of sentinel sites (e.g., land cover, ownership); review of relevant studies (e.g., broad-scale assessments or predictions relative to climate change); and evaluation of adequacy in addressing program goal and objectives.
- Secure commitments from Service programs for personnel and resources, including the ability to accommodate inflation and changes in program costs, necessary for long-term implementation of the monitoring program (see Appendix K for anticipated initial budget per office).

Acknowledgements

We would like to thank the numerous individuals who have contributed to and supported collaborative work described in this report, namely personnel of the Columbia-Pacific Northwest Region National Wildlife Refuge System, Branch of Refuge Biology, Inventory and Monitoring Initiative, NWR complexes and individual units in Washington, Oregon, and Idaho; Columbia-Pacific Northwest Region Fish and Aquatic Conservation, CRFWCO, IFWCO, MRFWCO, and WWFWCO; Columbia-Pacific Northwest Region Water Resources; and many others. Funding was provided by the U.S. Fish and Wildlife Service, Natural Resource Program Center, the Columbia-Pacific Northwest Region Inventory and Monitoring Initiative, and FAC.

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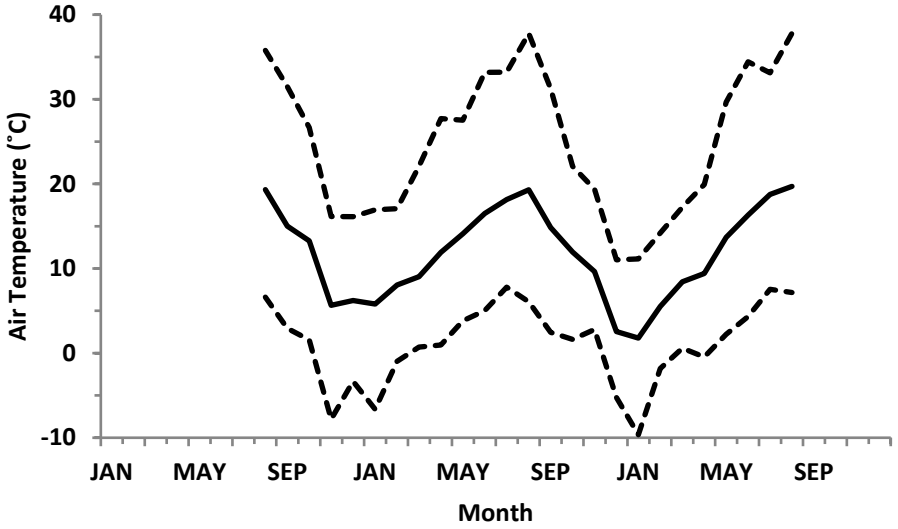
Appendix A. Results of the two-phased assessment to select sentinel sites at R1 NWRs (X under phase 1 screening indicates that the NWR was excluded from further consideration).

NWR	Areas of Interest	Phase 1-Screening	Phase 2-Geospatial Assessment Comments concerning selections
Marine West Coast Forest Ecoregion			
Bandon Marsh	Fahys Creek		Not selected—short stream reach on NWR, high proportion of private ownership in watershed
Grays Harbor		X	
Julia Butler Hansen		X	
Lewis and Clark		X	
Nestucca Bay		X	
Siletz Bay		X	
Willapa	Streams east of 101, Porters Point and Bear River Units		Selected to represent Marine West Coast Forest Ecoregion—two streams (Headquaters and Omeara) had the highest proportion of federal ownership in the ecoregion (66% and 45%, respectively), Omeara Creek selected after reconnaissance field visit
Cape Meares		X	
Copalis		X	
Flattery Rocks		X	
Oregon Island		X	
Quillayute Needle		X	
Three Arch Rocks		X	
Dungeness	Dean Creek		Not selected—short stream reach on NWR, concerns with passage and development in watershed
Nisqually	Nisqually River	X	
Protection Island		X	
San Juan Island		X	
Ankeny		X	
Baskett Slough		X	
Ridgefield	Gee Creek	X	
Steigerwald Lake		X	
Tualatin River	Chicken Creek	X	
William L.Finley	Muddy Creek, others on main unit		Selected to represent Marine West Coast Forest Ecoregion—extensive reach (13.6 km) of Muddy Creek occurs on NWR, third highest proportion of federal ownership in ecoregion (18%), contains ODEQ survey site (considered "least disturbed" relative to similar valley streams), represents interior portion of ecoregion compared to Willapa NWR
Northwestern Forested Mountains Ecoregion			
Franz Lake	Indian Mary Creek		Not selected—concerns with passage to watershed
Pierce	Hardy Creek		Not selected—short stream reach on NWR
Conboy Lake		X	
Kootenai	Myrtle Creek		Selected to represent Northwestern Forested Mountains Ecoregion—Myrtle Creek had a high proportion of federal ownership in the watershed (82%), history of work by Idaho FRO, fish species considered sensitive to climate change

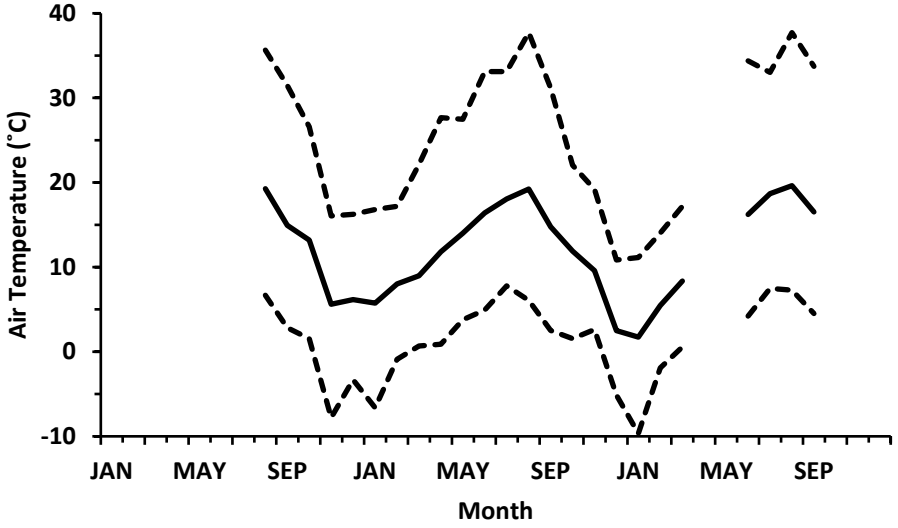
Appendix A. Continued.

NWR	Areas of Interest	Phase 1-Screening	Phase 2-Geospatial Assessment Comments concerning selections
Little Pend Oreille	Bear Creek, Little Pend Oreille River		Selected to represent Northwestern Forested Mountains Ecoregion—extensive reach (10 km) of Little Pend Oreille River occurs on NWR, relatively high proportion of federal ownership in watershed (43-56% depending on reach, West or at Blacktail Road), FWS Water Resources gauge station operated in the West reach, West reach selected after reconnaissance field visits
Grays Lake		X	
North American Deserts Ecoregion			
Cold Springs		X	
Columbia		X	
McKay Creek		X	
McNary		X	
Saddle Mountain		X	
Toppenish	Toppenish Creek		Not selected—substantial water diversions and management activities in watershed upstream
Turnbull	Pine Creek		Not selected—concerns with effects of water impounds on the NWR
Umatilla		X	
Camas	Camas Creek	X	
Deer Flat		X	
Minidoka		X	
Hart Mountain	Willow, Rock, and Guano creeks		Not selected—low fish diversity (1 or 2 species present) in each stream
Malheur	Blitzen River, Bridge Creek		Selected to represent North American Deserts Ecoregion—Bridge Creek possesses high proportion of federal ownership (76%) and a relatively diverse fish fauna compared to other NWR in the ecoregion, FWS Water Resources gauge station operated in the reach
Sheldon	Virgin and Fish creeks		Not selected—low fish diversity (1 or 2 species present) in each stream
Oxford Slough		X	
Bear Lake		X	

Appendix B. Monthly mean (solid line), maximum, and minimum (dashed lines) temperatures from loggers at various locations at sentinel sites during 2015–2017.

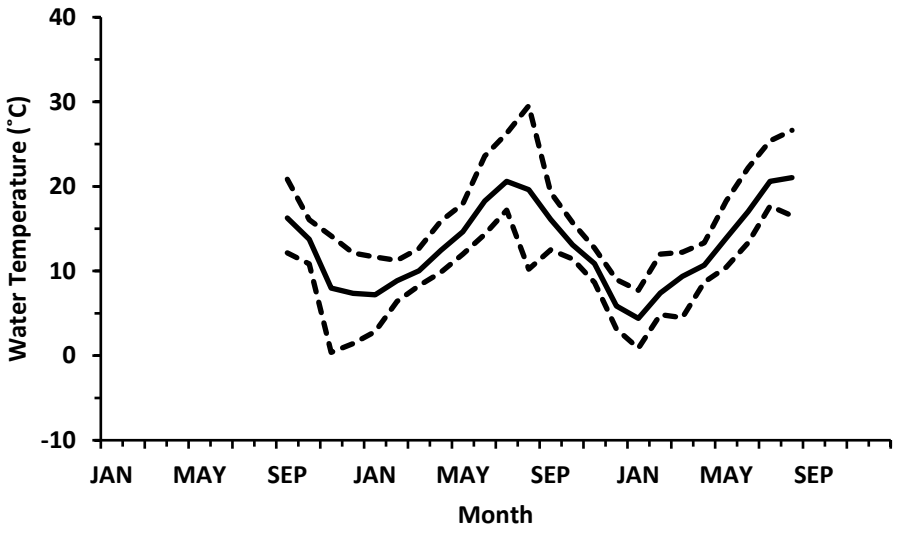


Muddy Creek: Temperature logger 10563308 upstream of survey reach.

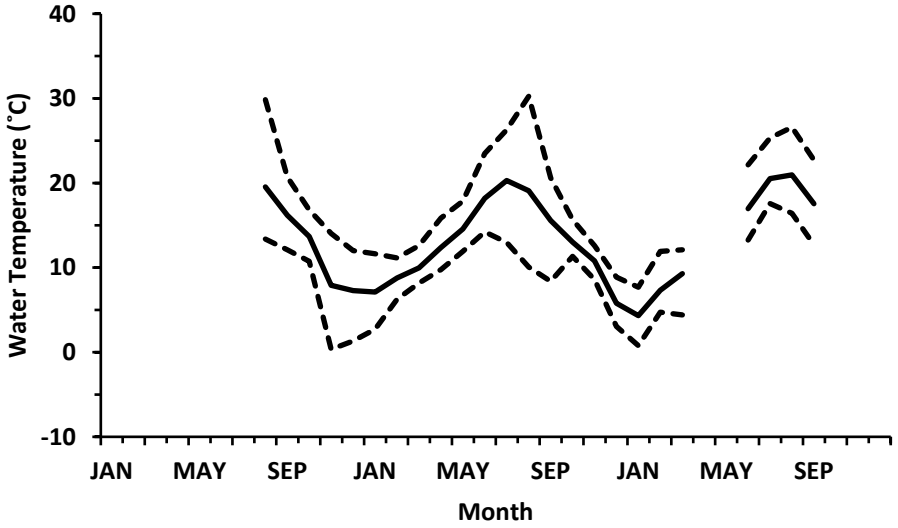


Muddy Creek: Pressure/temperature logger 10548558 upstream of survey reach.

Appendix B. Continued.

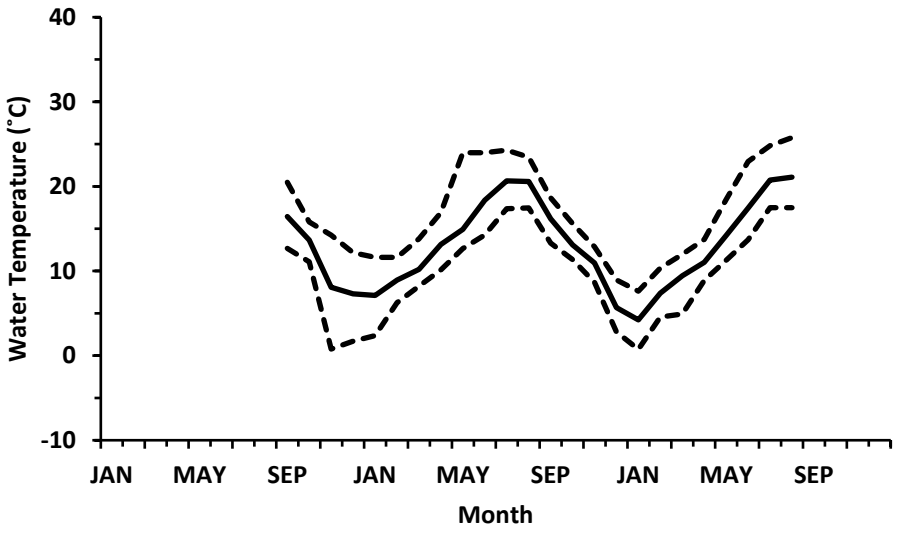


Muddy Creek: Temperature logger 1563310 upstream of survey reach.

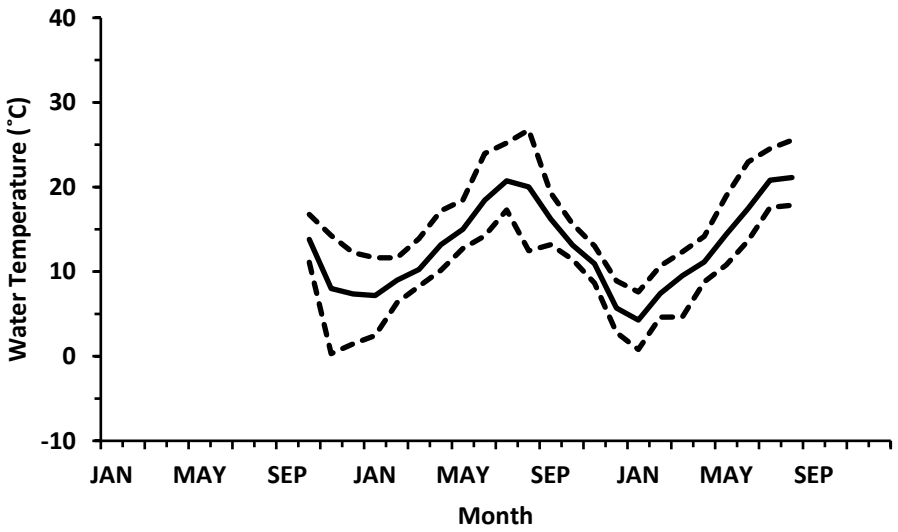


Muddy Creek: Pressure/temperature logger 10523252 upstream of survey reach.

Appendix B. Continued.

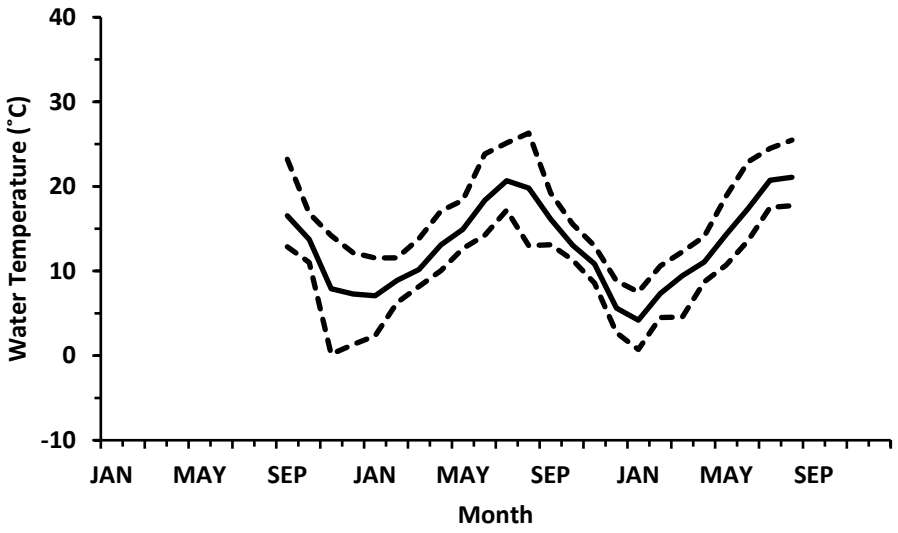


Muddy Creek: Temperature logger 10563304 at Transect K.

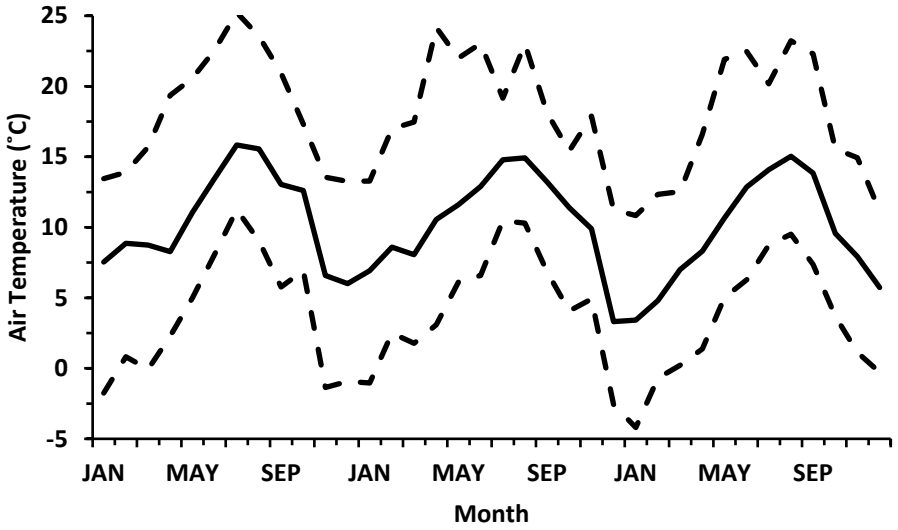


Muddy Creek: Temperature logger 10563324 at Transect A.

Appendix B. Continued.

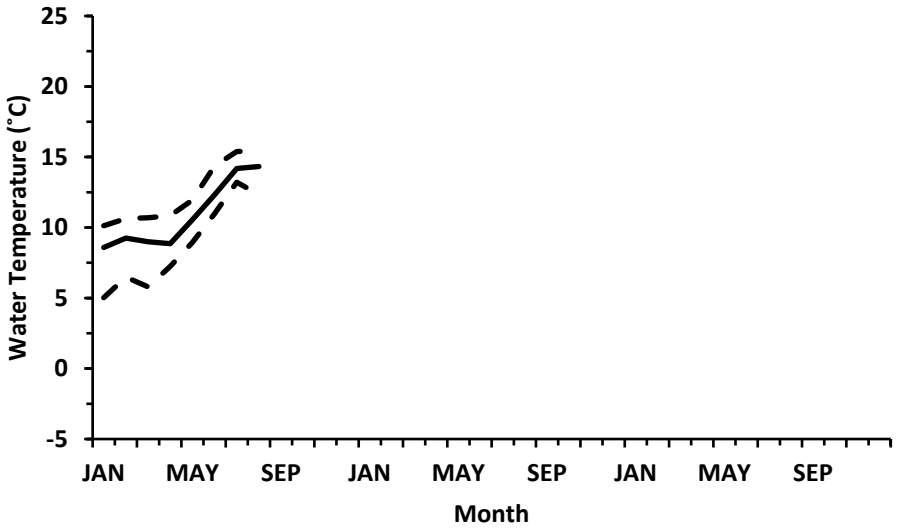


Muddy Creek: Temperature logger 10563325 at Transect A.

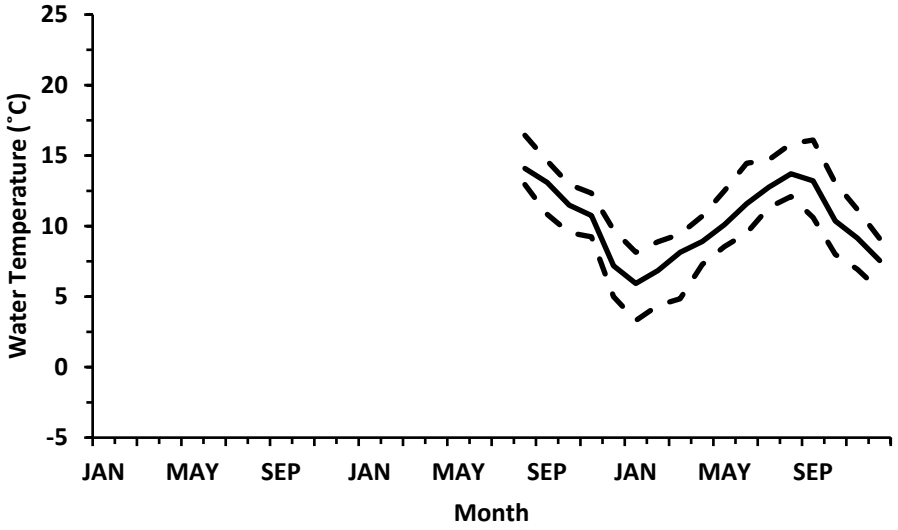


Omeara Creek: Temperature logger 10563312 upstream of survey reach (#1).

Appendix B. Continued.

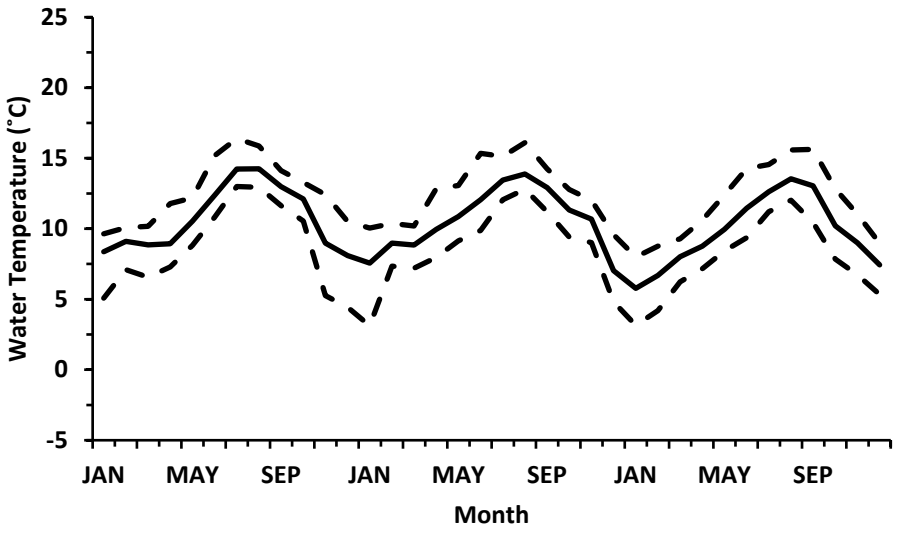


Omeara Creek: Temperature logger 10563319 upstream of survey reach (#1).

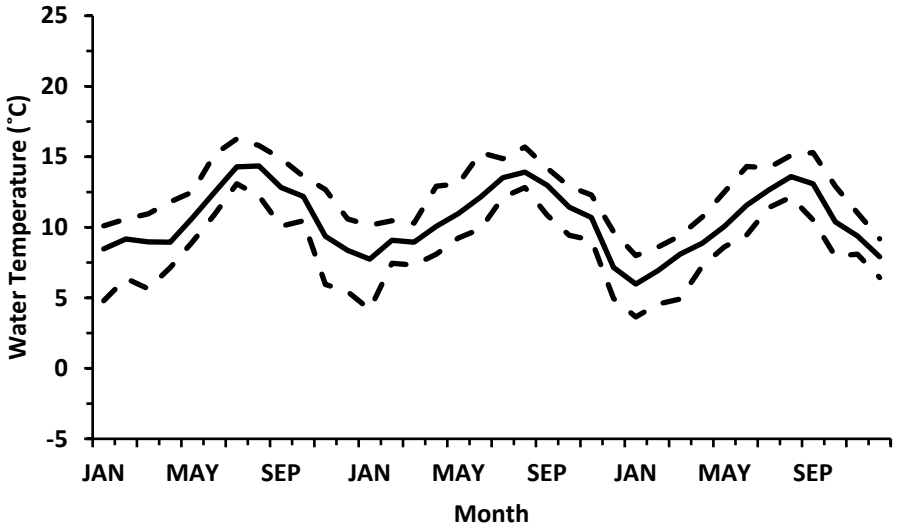


Omeara Creek: Temperature logger 10561778 at transect C of survey reach (#1).

Appendix B. Continued.

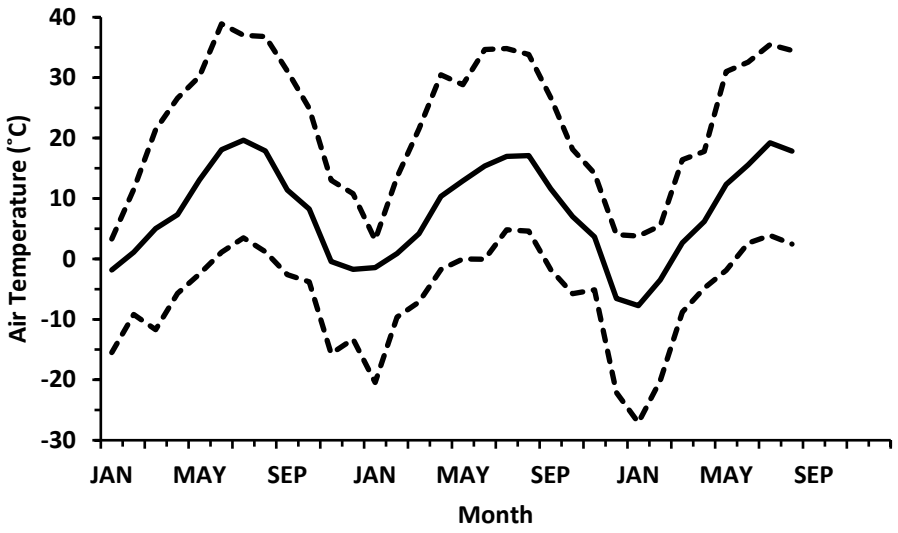


Omeara Creek: Temperature logger 10563327 downstream of survey reach (#1).

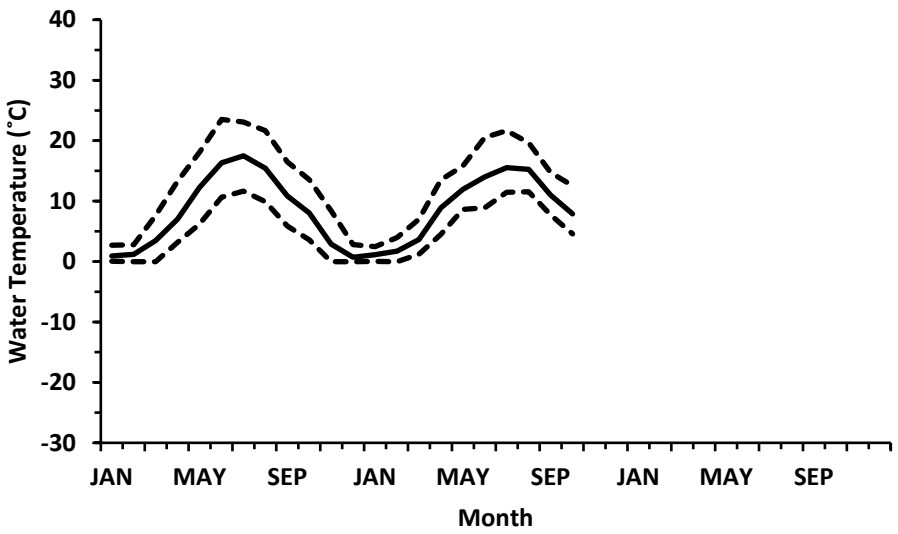


Omeara Creek: Temperature logger 10563329 downstream of survey reach (#1).

Appendix B. Continued.

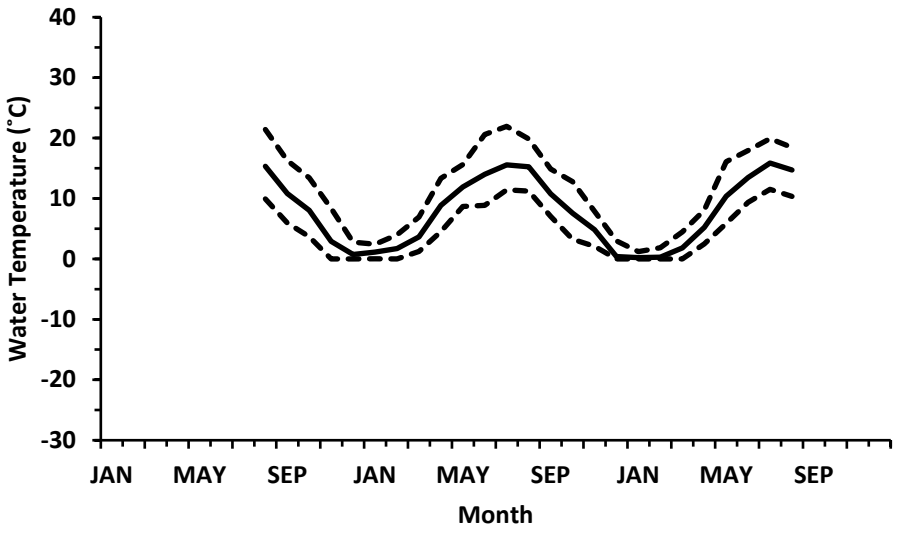


Little Pend Oreille River: FWS Water Resources temperature logger.

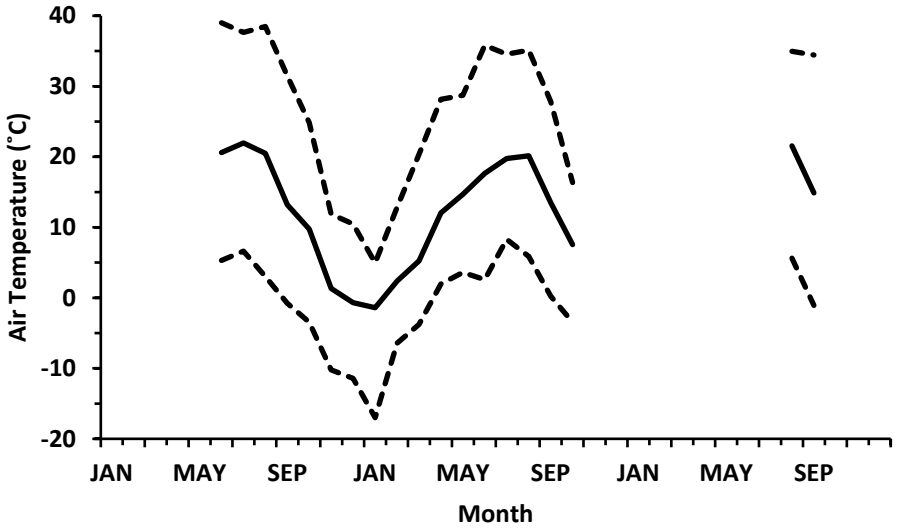


Little Pend Oreille River: FWS Water Resources temperature logger.

Appendix B. Continued.

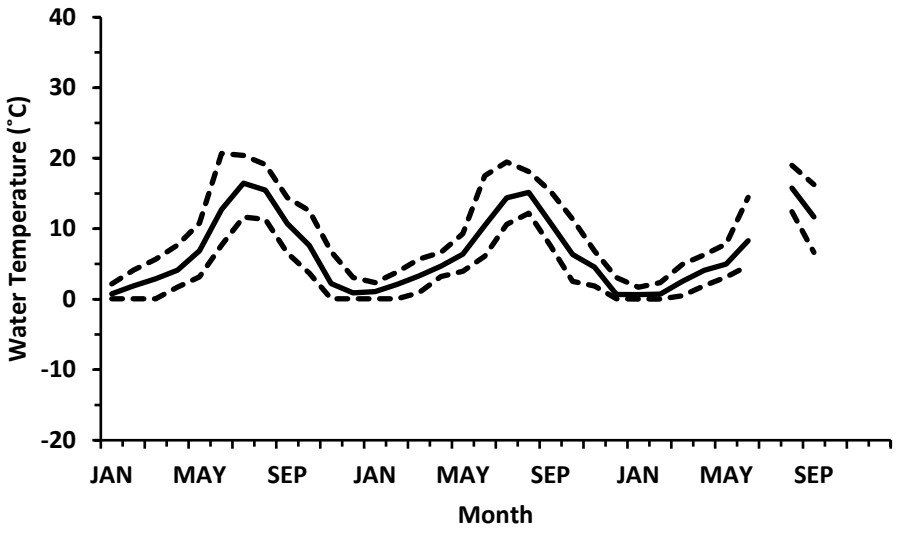


Little Pend Oreille River: Temperature logger 10563317 upstream Transect K.

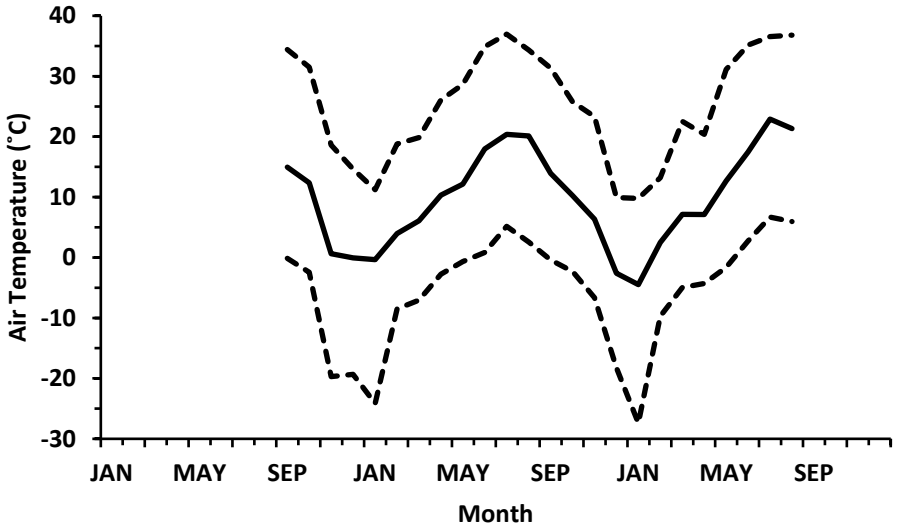


Myrtle Creek: Multiple loggers at FWS shop.

Appendix B. Continued.

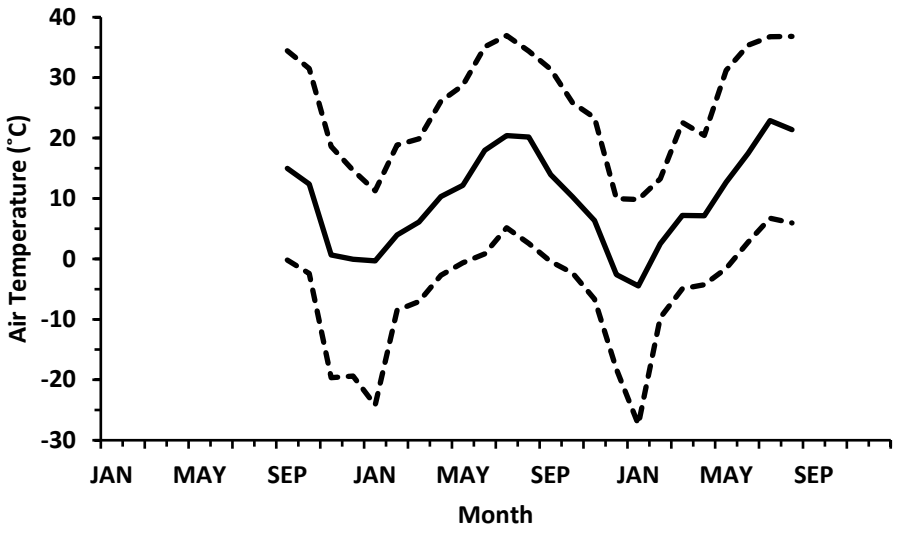


Myrtle Creek: Temperature logger 10563330 at Transect A.

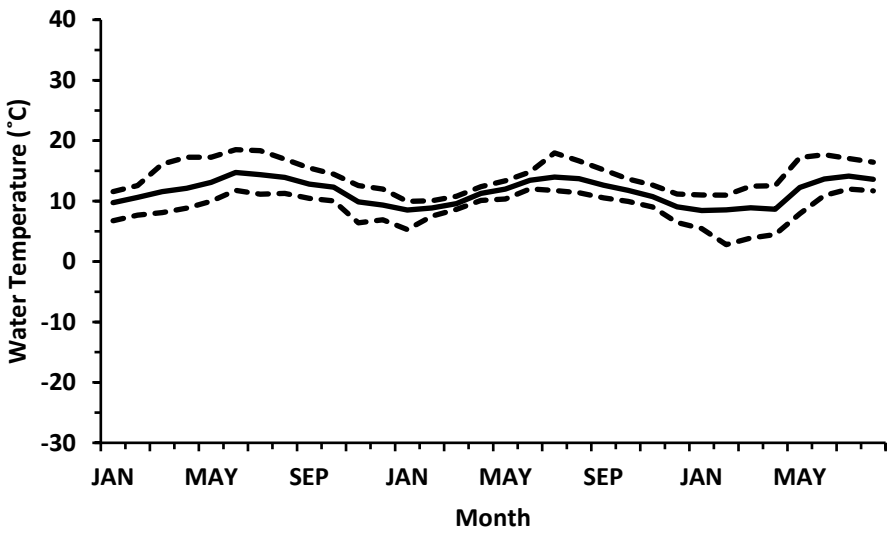


Bridge Creek: Temperature logger 10563309 upstream of survey reach.

Appendix B. Continued.

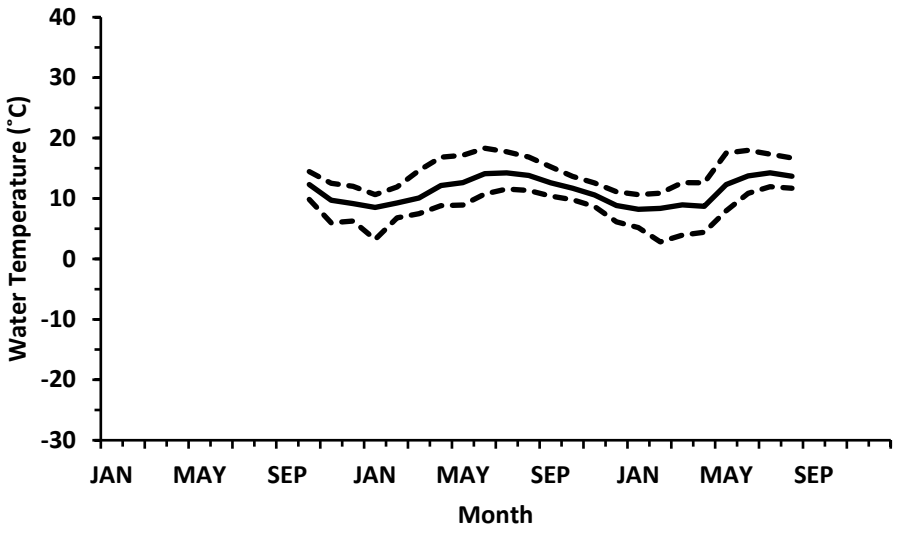


Bridge Creek: Temperature logger 10563311 upstream of survey reach.

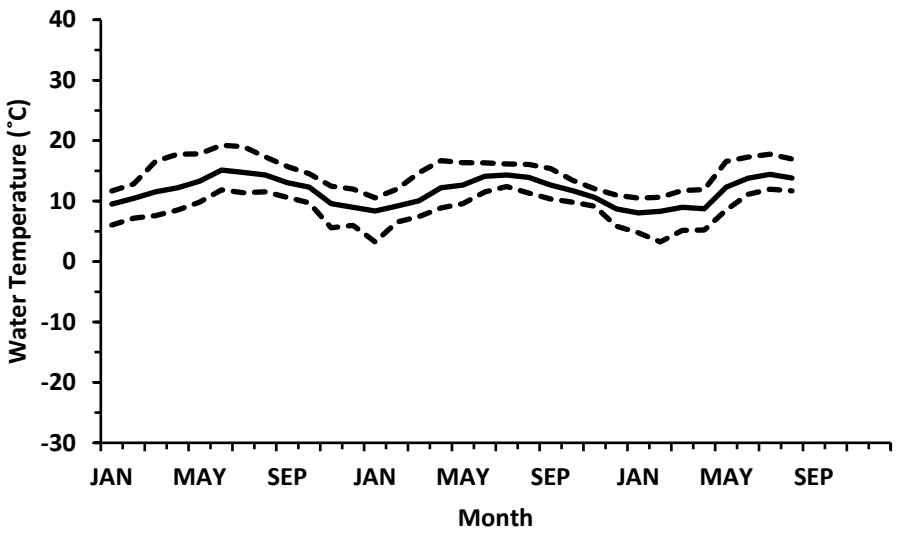


Bridge Creek: Temperature logger 10563328 upstream of survey reach.

Appendix B. Continued.



Bridge Creek: Temperature logger 10635054 downstream of survey reach.



Bridge Creek: Temperature logger 10563313 downstream of survey reach.

Appendix C. Mean and maximum temperatures (°C) for daily temperature, average weekly average temperature (AWAT, 7-day moving average), and average weekly maximum temperature (AWMT, 7-day moving average) by month during June–August at locations associated with each sentinel site for the period of record (logger serial number).

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Muddy Creek: Water temperature 5 m downstream survey reach (10563324) [a]						
June 2016	18.437	23.954	17.912	20.526	19.461	22.233
July 2016	20.738	25.210	20.539	22.640	21.885	24.024
August 2016	20.018	26.744	20.508	22.507	22.923	25.240
June 2017	17.462	22.968	17.115	20.304	18.280	21.943
July 2017	20.798	24.532	20.573	22.092	22.400	23.854
August 2017	21.119	25.525	21.344	23.035	22.651	24.647
Muddy Creek: Water temperature 5 m downstream survey reach (10563325) [a]						
June 2016	18.351	23.833	17.823	20.433	19.324	22.120
July 2016	20.675	25.137	20.477	22.580	21.844	23.958
August 2016	19.799	26.304	20.306	22.447	22.423	24.894
June 2017	17.388	22.896	17.041	20.234	18.207	21.878
July 2017	20.734	24.484	20.506	22.048	22.336	23.823
August 2017	21.081	25.477	21.307	22.988	22.638	24.582
Muddy Creek: Water temperature 1 m upstream survey reach (10563304) [a]						
June 2016	18.364	23.978	17.830	20.448	19.351	22.168
July 2016	20.645	24.291	20.456	22.445	21.750	23.391
August 2016	20.586	23.448	20.868	22.336	21.892	23.264
June 2017	17.443	22.944	17.097	20.244	18.306	21.991
July 2017	20.752	24.823	20.522	22.088	22.532	24.212
August 2017	21.094	25.768	21.334	23.005	22.793	24.958
Muddy Creek: Water temperature 800 m upstream survey reach (10563310) [a]						
June 2016	18.274	23.593	17.736	20.343	19.111	21.998
July 2016	20.602	26.208	20.424	22.510	22.629	25.204
August 2016 [b]	20.061	25.890	-	-	-	-
June 2017	17.020	22.178	16.675	19.970	17.516	21.141
July 2017	20.603	25.380	20.365	21.977	22.161	24.643
August 2017	21.038	26.622	21.262	22.914	23.463	25.659

[a] Temperature logger, 30-minute interval.
[b] Logger intermittently dewatered.

Appendix C. Continued.

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Muddy Creek: Water temperature 800 m upstream survey reach (10523252) [c]						
August 2015 [b]	19.484	24.158	-	-	-	-
June 2016	18.205	23.484	17.669	20.282	19.052	21.941
July 2016	20.303	26.292	20.216	22.079	22.670	25.168
August 2016 [b]	19.468	26.097	-	-	-	-
June 2017	16.957	22.142	16.612	19.910	17.456	21.078
July 2017	20.518	25.319	20.286	21.845	22.097	24.559
August 2017	20.959	26.585	21.474	25.857	23.390	25.584
Muddy Creek: Air temperature 800 m upstream survey reach (10563308) [a]						
August 2015	19.330	35.770	-	-	-	-
June 2016	16.507	33.183	16.179	20.660	22.874	28.572
July 2016	18.143	33.209	17.979	20.818	24.854	29.873
August 2016	19.311	37.783	19.585	21.750	28.909	32.616
June 2017	16.316	34.440	16.136	20.530	21.976	28.669
July 2017	18.757	33.131	18.362	20.485	26.730	29.451
August 2017	19.711	37.811	19.940	23.153	29.141	33.940
Muddy Creek: Air temperature 800 m upstream survey reach (10523258) [c]						
August 2015	19.265	35.649	-	-	-	-
June 2016	16.419	33.118	16.089	20.573	22.760	28.478
July 2016	18.061	33.118	17.898	20.747	24.736	29.792
August 2016	19.233	37.714	19.509	21.684	28.816	32.544
June 2017	16.221	34.374	16.043	20.422	21.887	28.610
July 2017	18.683	33.014	18.285	20.419	26.633	29.374
August 2017	19.627	37.714	20.114	25.669	29.049	33.850

[a] Temperature logger, 30-minute interval.
[b] Logger intermittently dewatered.
[c] Pressure/temperature logger, 15- minute interval.

Appendix C. Continued.

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Omeara Creek: Air temperature upstream survey reach (#1) (10563312) [a]						
June 2015	13.461	22.561	13.144	15.362	16.082	19.108
July 2015	15.838	25.234	15.768	16.387	18.852	19.908
August 2015	15.559	23.545	15.612	16.502	19.250	20.705
June 2016	12.890	23.040	12.719	14.897	15.925	19.170
July 2016	14.787	19.151	14.665	15.530	16.854	18.176
August 2016	14.927	23.016	14.951	15.374	17.869	19.341
June 2017	12.860	22.465	12.637	14.758	15.320	18.322
July 2017	14.082	20.174	14.004	15.104	16.830	17.962
August 2017	15.036	23.232	14.949	16.404	17.985	20.756
Omeara Creek: Water temperature upstream survey reach (#1) (10563319) [a]						
June 2015	12.310	14.361	12.091	13.299	12.603	13.837
July 2015	14.185	15.390	14.111	14.515	14.561	14.973
August 2015	14.327	15.438	14.342	14.835	14.778	15.192
Omeara Creek: Water temperature at transect C of survey reach (#1) (10561778) [a]						
July 2016 [d]	13.943	15.414	-	-	-	-
August 2016	14.087	16.439	14.092	14.378	14.894	15.386
June 2017	11.584	14.457	11.404	12.770	12.011	13.517
July 2017	12.755	14.697	12.691	13.449	13.445	14.272
August 2017	13.704	15.843	13.620	14.280	14.302	15.065
Omeara Creek: Water temperature downstream survey reach (#1) (10563327) [a]						
June 2015	12.360	15.175	12.133	13.390	13.065	14.491
July 2015	14.235	16.392	14.152	14.543	15.092	15.557
August 2015	14.250	15.867	14.299	14.672	14.903	15.659
June 2016	12.058	15.342	11.913	13.069	12.711	14.072
July 2016	13.445	15.127	13.317	14.000	13.892	14.748
August 2016	13.878	16.106	13.883	14.143	14.591	15.000
June 2017	11.452	14.266	11.272	12.636	11.882	13.370
July 2017	12.619	14.553	12.555	13.306	13.284	14.077
August 2017	13.545	15.581	13.466	14.127	14.073	14.850

[a] Temperature logger, 30-minute interval.
[d] July 14–31.

Appendix C. Continued.

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Omeara Creek: Water temperature downstream survey reach (#1) (10563329) [a]						
June 2015	12.480	15.175	12.261	13.479	13.183	14.512
July 2015	14.292	16.272	14.215	14.596	15.036	15.458
August 2015	14.349	15.796	14.374	14.838	15.151	15.547
June 2016	12.146	15.294	12.005	13.176	12.762	14.079
July 2016	13.518	14.864	13.390	14.061	13.913	14.614
August 2016	13.920	15.700	13.927	14.148	14.453	14.775
June 2017	11.564	14.314	11.384	12.737	11.991	13.438
July 2017	12.643	14.218	12.583	13.218	13.101	13.793
August 2018	13.600	15.103	13.520	14.124	13.995	14.597

[a] Temperature logger, 30-minute interval.

Appendix C. Continued.

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Little Pend Oreille River: Water temperature at upstream transect of survey reach (10563317) [a]						
August 2015	15.325	21.413	-	-	-	-
June 2016	13.990	20.603	13.569	15.896	15.694	18.485
July 2016	15.567	21.939	15.364	18.230	17.607	20.706
August 2016	15.251	19.865	15.672	18.121	17.873	20.560
June 2017	13.474	17.938	13.364	14.940	15.067	17.361
July 2017	15.864	19.912	15.784	16.736	18.178	19.236
August 2017	14.722	18.438	14.924	15.971	16.825	18.179
Little Pend Oreille River: Water temperature at downstream transect of survey reach (10563316) [a]						
August 2015	15.445	21.604	-	-	-	-
Little Pend Oreille River: Water temperature at downstream transect of survey reach (10563307) [a]						
August 2016	15.066	19.865	-	-	-	-
Little Pend Oreille River: Water temperature downstream of survey reach (FWS Water Resources) [f]						
June 2015	16.330	23.510	15.851	18.77	18.552	21.726
July 2015	17.493	23.080	17.851	19.903	20.787	22.956
August 2015	15.419	21.660	15.670	17.373	18.352	20.229
June 2016	14.012	20.540	13.592	15.932	15.731	18.550
July 2016	15.540	21.660	15.345	18.130	17.488	20.450
August 2016	15.247	19.650	15.658	18.031	17.771	20.321
July 2017 [f]	15.990	20.000	-	-	-	-
August 2017	14.761	18.570	14.971	15.983	16.946	18.274
Little Pend Oreille River: Air temperature downstream of survey reach (FWS Water Resources) [f]						
June 2015	18.072	38.900	17.346	22.455	27.076	33.743
July 2015	19.646	37.000	20.100	23.338	30.294	35.114
August 2015	17.861	36.800	18.208	21.418	29.733	33.186
June 2016	15.380	34.650	14.713	18.840	23.119	29.737
July 2016	16.955	34.810	16.841	20.717	26.093	32.197
August 2016	17.097	33.840	17.478	20.200	28.427	32.643
June 2017	15.552	32.560	15.546	18.040	24.313	29.144
July 2017	19.229	35.480	19.043	20.458	30.240	32.416
August 2017	17.840	34.490	18.105	19.903	30.018	32.883

[a] Temperature logger, 30-minute interval.
[f] Temperature logger, 1-hour interval.
[g] July 5–31.

Appendix C. Continued.

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Myrtle Creek: Water temperature at upstream transect of survey reach (10563318) [a]						
August 2017	15.761	18.985	-	-	-	-
Myrtle Creek: Water temperature at bridge near survey reach midpoint (10523250) [c]						
June 2015	12.626	20.615	11.779	16.301	13.482	18.370
July 2015	16.366	20.329	16.584	17.802	18.290	19.839
August 2015	15.383	18.996	15.711	18.498	16.649	18.059
Myrtle Creek: Water temperature at bridge near survey reach midpoint (10548575) [c]						
July 2017 [h]	15.503	18.711	-	-	-	-
August 2017	15.678	18.806	16.053	19.051	17.226	18.535
Myrtle Creek: Water temperature at downstream transect of survey reach (10563330) [a]						
June 2015	12.719	20.674	11.870	16.404	13.578	18.477
July 2015	16.457	20.388	16.677	17.903	18.375	19.926
August 2015	15.463	19.103	15.600	17.049	16.719	18.139
June 2016	10.446	17.510	9.774	12.724	11.137	14.667
July 2016	14.378	19.460	14.072	16.827	15.816	18.696
August 2016	15.146	18.105	15.355	16.718	16.728	18.502
June 2017	8.291	14.457	7.709	11.308	9.053	12.891
July 2017 [i]	14.450	17.701	-	-	-	-
Myrtle Creek: Air temperature downstream survey reach site at shop (10548568) [c]						
June 2015	20.381	38.602	-	-	-	-
July 2015	21.770	37.494	22.176	25.077	30.130	34.307
August 2015	20.297	38.379	20.933	25.920	30.157	34.116
Myrtle Creek: Air temperature downstream survey reach at shop (10563306) [a]						
June 2015	20.593	39.008	-	-	-	-
July 2015	21.963	37.645	22.369	25.307	30.347	34.534
August 2015	20.483	38.476	20.895	23.755	30.333	24.306
June 2016	17.647	35.797	16.800	21.717	23.532	29.730
July 2016	19.751	34.545	19.650	22.889	27.146	31.835
August 2016	20.144	35.128	20.408	22.687	29.196	32.828
Myrtle Creek: Air temperature downstream survey reach at shop (10523251) [c]						
July 2017 [h]	22.983	35.115	-	-	-	-
August 2017	21.317	34.691	22.021	27.967	30.991	34.437
Myrtle Creek: Air temperature downstream survey reach at shop (10962373) [j]						
July 2017 [h]	23.190	35.422	-	-	-	-
August 2017	21.551	34.969	22.258	28.245	31.357	34.771

[a] Temperature logger, 30-minute interval.
[c] Pressure/temperature logger, 15- minute interval.
[h] July 13–31.
[i] July 1–12.
[j] Temperature logger, 15-minute interval.

Appendix C. Continued.

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Bridge Creek: Water temperature 40 m upstream survey reach (10563328) [a]						
June 2015	14.736	18.509	14.662	15.068	17.203	17.915
July 2015	14.378	18.343	14.499	15.340	16.657	17.704
August 2015	13.917	16.939	13.951	14.413	16.200	16.786
June 2016	13.448	14.816	13.283	13.900	13.797	14.423
July 2016	13.977	17.962	13.929	14.467	15.363	17.027
August 2016	13.706	16.654	13.806	14.427	16.023	16.973
June 2017	13.644	17.677	13.638	14.299	15.859	17.004
July 2017	14.136	17.058	14.120	14.375	16.551	17.001
August 2017	13.600	16.439	13.647	14.090	15.546	16.354
Bridge Creek: Water temperature 80 m downstream survey reach (10635054) [a]						
June 2016	14.113	18.319	13.970	14.934	16.574	17.731
July 2016	14.243	17.724	14.253	14.768	16.893	17.690
August 2016	13.816	16.868	13.927	14.607	16.201	17.235
June 2017	13.725	17.986	13.719	14.432	16.086	17.289
July 2017	14.248	17.344	14.231	14.500	16.795	17.283
August 2017	13.684	16.701	13.734	14.195	15.710	16.582
Bridge Creek: Water temperature 350m downstream survey reach (10563313) [a]						
June 2015	15.130	19.246	15.040	15.501	17.817	18.604
July 2015	14.754	19.008	14.877	15.791	17.132	18.271
August 2015	14.315	17.320	14.354	14.859	16.483	17.130
June 2016	14.106	16.320	13.943	14.845	15.147	16.054
July 2016	14.306	16.153	14.307	14.778	15.458	16.041
August 2016	13.915	16.058	14.024	14.660	15.199	15.721
June 2017	13.796	17.296	13.775	14.471	15.406	16.381
July 2017	14.415	17.748	14.400	14.686	17.065	17.643
August 2017	13.803	16.963	13.856	14.351	15.925	16.851
Bridge Creek: Air temperature 70 m upstream survey reach (10563309) [a]						
August 2015 [k]	21.056	35.182	-	-	-	-
June 2016	17.964	34.889	17.107	21.363	26.134	31.296
July 2016	20.391	36.960	20.257	24.119	30.185	35.395
August 2016	20.127	34.334	20.509	23.819	31.228	35.080
June 2017	17.467	35.155	17.279	21.069	25.670	31.386
July 2017	22.903	36.552	22.550	24.275	32.499	34.695
August 2017	21.344	36.796	21.400	23.970	31.730	35.496

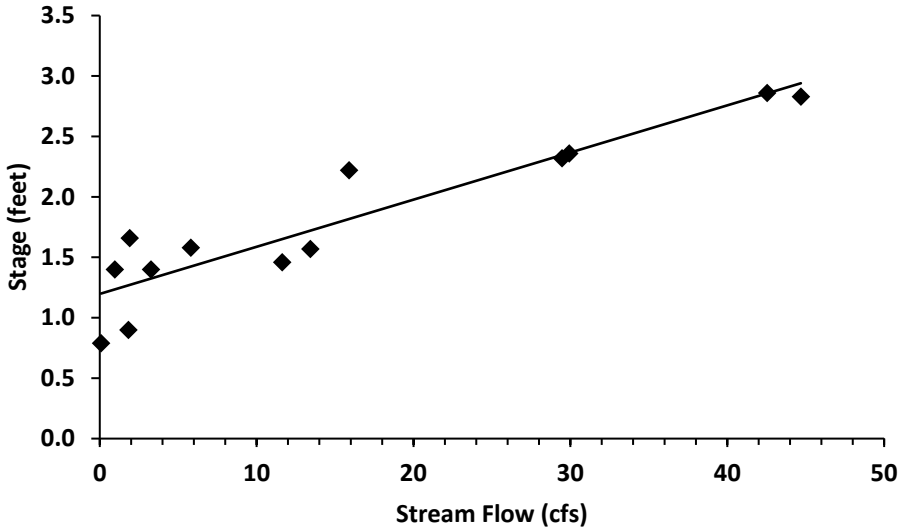
[a] Temperature logger, 30-minute interval.
[k] August 7–31.

Appendix C. Continued.

Month year	Daily		AWAT		AWMT	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Bridge Creek: Air temperature 70 m upstream survey reach (10563311) [a]						
August 2015 [k]	21.092	35.342	-	-	-	-
June 2016	17.969	35.102	17.112	21.371	26.222	31.426
July 2016	20.402	36.960	20.265	24.151	30.261	35.426
August 2016	20.168	34.387	20.548	23.852	31.289	35.106
June 2017	17.481	35.368	17.293	21.078	25.764	31.507
July 2017	22.890	36.769	22.536	24.257	32.565	34.737
August 2017	21.379	36.824	21.429	23.973	31.803	35.554

[a] Temperature logger, 30-minute interval.
[k] August 7–31.

Appendix D. Stage–stream flow relationship for Muddy Creek.



$y = 1.20 + 0.04\ x$; $R^2 = 0.86$

Appendix E. Results of habitat surveys by categories of habitat variables (stream channel, substrate, fish cover, and riparian vegetation) for each sentinel site during 2015–2017.

Table E1. Mean stream channel characteristics (SD) of survey reaches in Bridge Creek, Muddy Creek, Little Pend Oreille River, Myrtle Creek, and Omeara Creek during each 2015—2017, and mean, (SD), and CV among years (in respective rows).

Length (m)	Mean width (m)		Mean height (m)		Mean depth (cm)		Water surface slope (%)	Sinuosity	Mean bank angle (degrees)	
	Wetted	Bankfull	Bankfull	Incised	Thalweg	Residual pool*			Left	Right
					Muddy Creek					
					2015					
320	6.82	9.98	1.06	1.06	32.7	11.1	0.02	1.99	15.7	21.8
	(2.07)	(1.82)	(0.16)	(0.16)	(9.5)				(6.1)	(10.8)
					2016					
320	8.67	11.04	0.99	0.99	64.4	11.9	0.97	1.73	49.5	48.6
	(1.38)	(1.76)	(0.41)	(0.41)	(15.0)				(35.9)	(33.5)
					2017					
320	9.05	10.55	0.65	0.65	68.6	23.3	0.79	2.30	62.0	50.0
	(1.45)	(1.66)	(0.41)	(0.41)	(22.1)				(29.0)	(27.7)
					Muddy Creek among years					
320	8.18	1.52	0.90	0.90	55.23	15.43	0.59	2.01	42.4	40.1
	(1.19)	(0.53)	(0.22)	(0.22)	(19.63)	(6.82)	(0.50)	(0.29)	(24.0)	(15.9)
	14.6	5.0	24.4	24.4	35.5	44.2	85.1	14.2	56.5	39.6
					Omeara Creek #1					
					2015					
150	1.91	2.98	0.36	0.72	14.5	6.5	1.92	2.28	72.5	57.7
	(1.14)	(1.27)	(0.07)	(0.12)	(11.3)				(47.1)	(53.1)
					2016					
150	2.09	3.20	0.52	1.01	15.8	7.6	1.67	1.88	45.9	54.5
	(1.02)	(1.08)	(0.28)	(0.33)	(9.7)				(38.5)	38.8)
					Omeara Creek #1 among years					
150	2.00	3.09	0.44	0.87	15.15	7.05	1.80	2.08	59.2	56.1
	(0.13)	(0.16)	(0.11)	(0.21)	(0.92)	(0.78)	(0.18)	(0.28)	(18.8)	(2.3)
	6.4	5.0	25.7	23.7	6.1	11.0	9.9	13.6	31.8	4.0
					Omeara Creek #2					
					2017					
150	2.91	5.94	0.22	0.23	16.2	7.3	3.33	1.89	38.9	37.5
	(1.58)	(2.74)	(0.08)	(0.08)	(12.8)				(40.0)	(41.1)

Table E1. Continued.

Length (m)	Mean width (m)		Mean height (m)		Mean depth (cm)		Water surface slope (%)	Sinuosity	Mean bank angle (degrees)	
	Wetted	Bankfull	Bankfull	Incised	Thalweg	Residual pool*			Left	Right
					Little Pend Oreille River					
					2015					
280	7.09	10.57	0.63	0.84	46.7	24.4	0.03	2.36	60.4	40.1
	(2.22)	(2.56)	(0.94)	(0.39)	(20.3)				(38.9)	(28.7)
					2016					
280	9.06	11.40	0.46	0.78	59.5	27.0	0.13	2.19	44.2	35.2
	(2.82)	(2.51)	(0.15)	(0.14)	(20.9)				(19.8)	(18.3)
					2017					
280	8.81	11.19	0.52	0.99	53.6	24.8	0.06	2.16	34.2	30.9
	(3.93)	(2.17)	(0.12)	(0.84)	(19.4)				(18.1)	(9.8)
					Little Pend Oreille River among years					
280	8.32	11.05	0.54	0.87	53.27	25.40	0.07	2.24	46.3	35.4
	(1.07)	(0.43)	(0.09)	(0.11)	(6.41)	(1.40)	(0.05)	(0.11)	(13.2)	(4.0)
	12.9	3.9	16.1	12.4	12.0	5.5	70.0	4.8	28.6	13.0
					Myrtle Creek					
					2015					
280	8.20	14.15	1.01	1.29	32.0	6.5	3.00	1.01	39.1	51.4
	(2.70)	(2.10)	(0.25)	(0.29)	(19.0)				(53.6)	(50.3)
					2016					
280	8.28	10.80	0.32	0.59	36.0	5.3	3.30	1.01	33.7	14.6
	(1.91)	(2.31)	(0.08)	(0.14)	(9.5)				(30.1)	(14.4)
					2017					
280	8.11	11.84	0.36	0.46	30.8	5.1	2.45	1.05	34.0	58.6
	(2.29)	(2.31	(0.09)	(0.23)	(8.7)				(38.6)	(52.6)
					Myrtle Creek among years					
280	8.20	12.26	0.56	0.78	32.93	5.63	2.92	1.02	35.6	41.5
	(0.09)	(1.71)	(0.39)	(0.45)	(2.72)	(0.76)	(0.43)	(0.02)	(3.0)	(23.6)
	1.0	14.0	68.8	57.2	8.3	13.4	14.8	2.3	8.5	56.8

Table E1. Continued.

Length (m)	Mean width (m)		Mean height (m)		Mean depth (cm)		Water surface slope (%)	Sinuosity	Mean bank angle (degrees)	
	Wetted	Bankfull	Bankfull	Incised	Thalweg	Residual pool*			Left	Right
					Bridge Creek					
					2015					
240	4.91 (1.52)	5.57 (1.43)	0.33 (0.15)	0.51 (0.36)	61.3 (19.6)	21.5	0.65	1.87	50.9 (34.3)	50.5 (34.0)
					2016					
240	4.38 (0.74)	6.25 (3.94)	0.34 (0.19)	0.75 (0.52)	61.1 (18.3)	17.4	0.82	1.71	40.9 (40.9)	42.7 (31.3)
					2017					
240	3.94 (0.95)	5.41 (1.77)	0.33 (0.17)	0.63 (0.37)	55.2 (16.7)	17.0	0.58	1.71	54.5 (40.6)	48.6 (33.3)
					Bridge Creek among years					
240	4.41 (0.49)	5.74 (0.45)	0.33 (0.01)	0.63 (0.12)	59.20 (3.47)	18.63 (2.49)	0.68 (0.12)	1.76 (0.09)	48.8 (7.1)	47.3 (4.1)
	11.0	7.8	1.7	19.1	5.9	13.4	18.1	5.2	14.5	8.6

*RP100 in Kaufmann et al. (1999)-equivalent to residual pool vertical profile area per 100 m of reach.

Table E2. Stream substrate characteristics (SD) of survey reaches in Bridge Creek, Muddy Creek, Little Pend Oreille River, Myrtle Creek, and Omeara Creek during 2015–2017, and mean, (SD), and CV among years (in respective rows).

Proportion substrate class*							Mean embeddedness (%)	Geometric mean particle size (mm)	Log_{10}	
Bedrock	Boulder	Cobble	Coarse gravel	Fine gravel	Sand	Fines			Erodible substrate diameter	Relative bed stability
					Muddy Creek					
					2015					
0.25	0	0	0	0	0	0.75	74.5 (44.0)	0.2	0.2	-0.9
					2016					
0.12	0	0	0	0	0.01	0.87	76.4 (42.9)	<0.1	2.0	-3.4
					2017					
0.16	0	0	0	0	0	0.84	92.7 (26.2)	0.1	1.8	-3.0
					Muddy Creek among years					
0.18					<0.01	0.82	81.2	0.1	1.3	-2.4
(0.07)					(0.01)	(0.06)	(10.0)	(0.1)	(1.0)	(1.3)
37.7					173.2	7.6	12.3	65.5	74.0	55.9
					Omeara Creek #1					
					2015					
0	0	0.04	0.44	0.22	0.19	0.11	60.3 (35.9)	3.8	1.6	-1.1
					2016					
0	0	0.07	0.36	0.25	0.11	0.21	54.6 (41.8)	2.4	1.8	-1.4
					Omeara Creek #1 among years					
		0.06	0.40	0.24	0.15	0.16	57.5	3.1	7.7	-1.3
		(0.02)	(0.06)	(0.02)	(0.06)	(0.07)	(4.0)	(1.0)	(0.1)	(0.2)
		38.6	14.1	9.0	37.7	44.2	7.0	31.9	8.3	17.0
					Omeara Creek #2					
					2017					
0	0	0.15	0.51	0.22	0.06	0.06	36.5 (33.1)	12.3	1.6	-0.5

Table E2. Continued.

Proportion substrate class*							Mean embeddedness (%)	Geometric mean particle size (mm)	Log_{10}	
Bedrock	Boulder	Cobble	Coarse gravel	Fine gravel	Sand	Fines			Erodible substrate diameter	Relative bed stability
					Little Pend Oreille River					
					2015					
0	0	0.01	0.24	0.27	0.37	0.12	71.9 (30.9)	1.5	0.3	-0.1
					2016					
0	0	0.01	0.20	0.27	0.33	0.19	66.6 (38.6)	0.9	0.8	-0.9
					2017					
0	0	0.01	0.25	0.26	0.46	0.02	54.0 (44.7)	2.2	0.5	-0.2
					Little Pend Oreille River among years					
		0.01	0.23	0.27	0.39	0.11	64.2	1.5	0.5	-0.4
		(0)	(0.03)	(0.01)	(0.07)	(0.09)	(9.2)	(0.7)	(0.3)	(0.4)
		0	11.5	2.2	17.2	77.7	14.3	42.4	47.2	109.0
					Myrtle Creek					
					2015					
0	0	0.72	0.13	0.01	0.11	0.03	20.8 (33.6)	41.6	2.4	-0.8
					2016					
0	0	0.47	0.15	0.11	0.27	0	29.9 (28.4)	15.0	2.5	-1.0
					2017					
0	0	0.69	0.15	0.11	0.05	0	47.9 (41.3)	55.8	2.0	-0.3
					Myrtle Creek among years					
		0.63	0.14	0.08	0.14	0.01	32.9	37.5	2.3	-0.7
		(0.14)	(0.01)	(0.06)	(0.11)	(0.02)	(13.8)	(20.7)	(0.3)	(0.4)
		21.8	8.1	75.3	79.3	173.2	42.0	55.3	11.5	51.5

Table E2. Continued.

Proportion substrate class*							Mean embeddedness (%)	Geometric mean particle size (mm)	Log_{10}	
Bedrock	Boulder	Cobble	Coarse gravel	Fine gravel	Sand	Fines			Erodible substrate diameter	Relative bed stability
					Bridge Creek					
					2015					
0	0	0.05	0.09	0.15	0.21	0.51	65.6 (43.7)	0.2	1.5	-2.4
					2016					
0.07	0	0.09	0.05	0.16	0.30	0.32	56.7 (45.6)	0.7	1.6	-1.8
					2017					
0	0	0.04	0.17	0.18	0.12	0.49	66.7 (42.0)	0.3	1.5	-2.1
					Bridge Creek among years					
0.02		0.06	0.10	0.16	0.21	0.44	63.0	0.4	1.5	-2.1
(0.04)		(0.03)	(0.06)	(0.02)	(0.09)	(0.10)	(5.5)	(0.3)	(0.1)	(0.3)
173.2		44.1	59.1	9.4	42.9	23.7	8.7	66.1	3.8	14.3

*Bedrock (>4000mm, including hard pan), Boulder (250-4000 mm), Cobble (64-250 mm), Coarse gravel (16-64 mm), Fine gravel (2-16 mm), Sand (0.6-2 mm), Fines (<0.6 mm, including silt/clay).

Table E3. Mean fish cover (SD) and large woody debris of survey reaches in Bridge Creek, Muddy Creek, Little Pend Oreille River, Myrtle Creek, and Omeara Creek during 2015–2017, and mean, (SD), and CV among years (in respective rows).

Fish cover categories (mean %)									Total volume (m^3/reach)	Volume per m^2 (m^3)
Filamentous algae	Macrophytes	Woody debris (>0.3m)	Brushy/woody debris	Live trees/roots	Overhanging vegetation	Undercut banks	Boulders	Artificial structures		
				Muddy Creek						
				2015						
0	0	2.7	11.4	0.5	20.7	0	0	0	21.72	0.00680
		(2.6)	(11.0)	(1.5)	(15.7)					
				2016						
0	0.5	1.4	4.6	0.9	13.0	0.9	0	0	48.02	0.01359
	(1.5)	(2.3)	(1.5)	(2.0)	(17.0)	(2.0)				
				2017						
0	0	2.7	11.1	2.3	18.9	0.5	0	0	19.93	0.00591
		(2.6)	(16.6)	(7.5)	(16.3)	1.5)				
				Muddy Creek among years						
	0.2	2.3	9.0	1.2	17.5	0.5			29.9	0.00877
	(0.3)	(0.8)	(3.8)	(1.0)	(4.0)	(0.5)			(15.7)	(0.00321)
	173.2	33.1	42.5	76.6	23.0	96.6			52.6	47.9
				Omeara Creek #1						
				2015						
0	0	6.4	4.5	3.2	12.0	4.5	0	0	24.8	0.05540
		(9.5)	(1.5)	(7.5)	(17.6)	(1.5)				
				2016						
0	3.2	7.3	4.5	1.8	9.5	20.7	0	0	27.0	0.05620
	(2.5	(9.0)	(1.5)	(2.5)	(10.1)	(15.7)				
				Omeara Creek #1 among years						
	1.6	6.9	4.6	2.5	10.9	12.7			25.9	0.05580
	(2.3)	(0.6)	(0)	(1.0)	(1.8)	(11.4)			(1.6)	(0.00051)
	141.4	9.3	0	39.6	16.3	90.0			6.0	0.9
				Omeara Creek #2						
				2017						
0	0	5.9	5.0	4.1	5.5	13.0	0	0	54.1	0.06080
		(6.6)	(0)	(7.4)	(6.9)	(17.0)				

Table E3. Continued.

Fish cover categories (mean %)									Total volume (m^3/reach)	Volume per m^2 (m^3)
Filamentous algae	Macrophytes	Woody debris (>0.3m)	Brushy/woody debris	Live trees/roots	Overhanging vegetation	Undercut banks	Boulders	Artificial structures		
				Little Pend Oreille River						
				2015						
0	0	0	10.9	10.0	8.9	3.2	0.9	0	4.04	0.00137
			(11.4)	(12.0)	(17.7)	(7.5)	(2.0)			
				2016						
0	0	0	15.5	16.1	13.2	7.7	0.5	0	3.76	0.00118
			(11.1)	(17.4)	(11.5)	(8.8)	(1.5)			
				2017						
0	0.5	2.7	15.9	1.8	15.9	2.3	0.5	0	5.99	0.00191
	(1.5)	(7.5)	(10.4)	(2.5)	(10.4)	(2.6)	(1.5)			
				Little Pend Oreille River among years						
	0.2	0.9	14.1	9.3	12.7	4.4	0.6		4.6	0..00149
	(0.3)	(1.6)	(2.8)	(7.2)	(3.5)	(2.9)	(0.2)		(3.8)	(0.00038)
	173.2	173.2	19.7	77.2	27.9	64.8	36.5		6.0	25.5
				Myrtle Creek						
				2015						
4.6	0	0	8.2	0.5	1.8	18.2	36.8	5.5	37.35	0.00942
(1.5)			(8.5)	(1.5)	(2.5)	(22.1)	(16.4)	(9.9)		
				2016						
0	0	1.4	6.4	0	0.9	2.3	27.1	13.0	9.70	0.00321
		(2.3)	(6.4)		(2.0)	(7.5)	(21.6)	(26.6)		
				2017						
0	0	3.6	5.9	0.4	1.4	3.2	57.3	2.7	10.98	0.00331
		(7.4)	(6.6)	(1.5)	(2.3)	(2.5)	(14.0)	(2.6)		
				Myrtle Creek among years						
1.5		1.7	6.8	0.3	1.4	7.9	40.4	7.1	19.3	0.00531
(2.7)		(1.8)	(1.2)	(0.3)	(0.5)	(8.9)	(15.4)	(5.3)	(15.6)	(0.00356)
173.2		108.9	17.7	88.2	33.0	113.1	38.2	75.4	80.7	66.9

Table E3. Continued.

Fish cover categories (mean %)									Total volume (m^3/reach)	Volume per m^2 (m^3)
Filamentous algae	Macrophytes	Woody debris (>0.3m)	Brushy/woody debris	Live trees/roots	Overhanging vegetation	Undercut banks	Boulders	Artificial structures		
					Bridge Creek					
					2015					
0	63.4	0	1.8	0.5	44.6	0.9	0.9	0	0.12	0.00009
	(28.2)		(2.5)	(1.5)	(29.4)	(2.0)	(2.0)			
					2016					
0	29.3	0.5	1.4	2.7	36.8	0.5	0.5	0	0.17	0.00012
	(27.2)	(1.5)	(2.3)	(7.5)	(16.4)	(1.5)	(1.5)			
					2017					
0	28.4	0.5	0.5	0.9	36.8	0	0.5	0	0.06	0.00004
	(28.2)	(1.5)	(1.5)	(2.0)	(31.0)		(1.5)			
					Bridge Creek among years					
	40.4	0.3	1.2	1.4	39.4	0.5	0.6		0.1	0.00008
	(20.0)	(0.3)	(0.7)	(1.2)	(4.5)	(0.5)	(0.2)		(0.1)	(0.00004)
	49.4	86.6	54.0	85.8	11.4	96.6	36.5		47.2	48.5

Table E4. Mean canopy cover (SD) and riparian vegetation structure of survey reaches in Bridge Creek, Muddy Creek, Little Pend Oreille River, Myrtle Creek, and Omeara Creek during 2015–2017, and mean, (SD), and CV among years (in respective rows).

Stream canopy cover (mean %)		Canopy (mean %)		Understory (mean %)		Ground cover (mean %)		
Mid channel	Banks	Big tree	Small tree	Woody	Non woody	Woody	Non-woody	Bare ground
				Muddy Creek				
				2015				
47.9	82.4	30.5	22.4	47.2	24.0	15.3	33.9	1.1
(30.7)	(28.8)	(32.1)	(21.5)	(27.1)	(21.0)	(26.7)	(26.8)	(2.1)
				2016				
57.1	84.2	51.1	26.1	33.8	20.6	0	16.9	3.0
(30.3)	(24.0)	(32.2)	(21.8)	(28.2)	(22.1)		(19.0)	(5.5)
				2017				
29.8	90.1	28.0	18.9	40.8	14.3	4.5	8.4	3.2
(23.6)	(21.6)	(30.8)	(16.6)	(21.6)	(16.3)	(5.1)	(8.1)	(5.5)
				Muddy Creek among years				
44.8	85.6	36.5	22.5	40.6	19.6	6.6	19.7	2.4
(13.9)	(4.0)	(12.7)	(3.6)	(6.7)	(4.9)	(7.9)	(13.0)	(1.2)
30.9	4.7	34.7	16.0	16.5	25.1	119.1	65.8	47.6
				Omeara Creek #1				
				2015				
76.7	84.0	6.5	36.1	12.4	3.2	0.7	87.5	0.9
(27.0)	(26.3)	(14.3)	(36.1)	(19.0)	(7.3)	(1.8)	(0.0)	(2.0)
				2016				
88.0	94.7	6.5	22.7	11.5	4.1	1.6	79.3	2.0
(17.3)	(11.3)	(14.3)	(23.7)	(18.8)	(7.2)	(2.4)	(13.7)	(2.5)
				Omeara Creek #1 among years				
82.4	89.4	6.5	29.4	12.0	3.7	1.2	83.4	1.5
(8.0)	(7.6)	(0)	(9.5)	(0.6)	(0.6)	(0.6)	(5.8)	(0.8)
9.7	8.5	0	32.2	5.3	17.4	55.3	7.0	53.6
				Omeara Creek #2				
				2017				
93.9	97.3	27.0	24.9	12.3	33.2	4.8	35.9	5.7
(12.6)	(6.2)	(24.7)	(20.4)	(9.8)	(20.2)	(1.1)	(17.2)	(4.4)

Table E4. Continued.

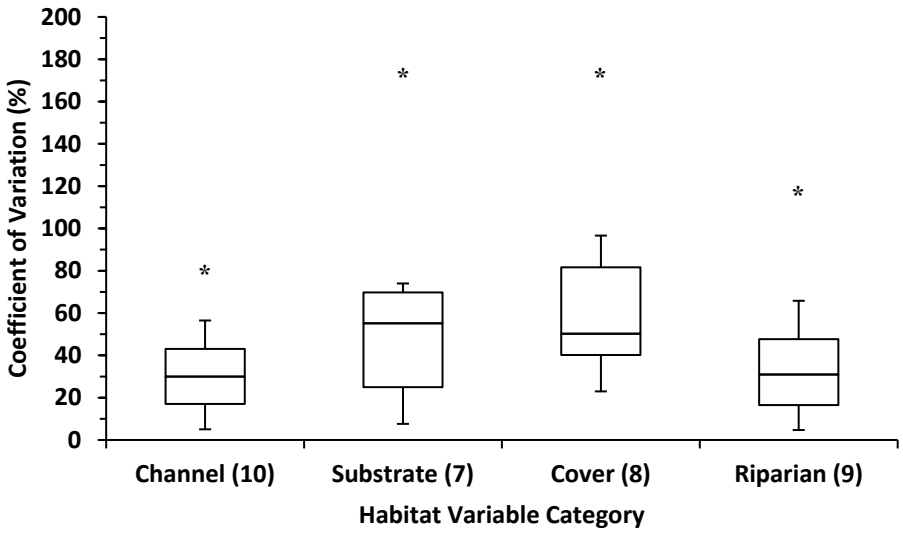
Stream canopy cover (mean %)		Canopy (mean %)		Understory (mean %)		Ground cover (mean %)		
Mid channel	Banks	Big tree	Small tree	Woody	Non woody	Woody	Non-woody	Bare ground
				Little Pend Oreille River				
				2015				
43.0	75.1	1.1	16.9	39.8	5.7	7.3	65.1	13.3
(30.5)	(33.2)	(5.3)	(13.9)	(21.0)	(6.6)	(8.8)	(25.7)	(14.8)
				2016				
33.4	88.0	0.2	21.7	29.7	24.0	16.7	81.9	8.5
(29.0)	(24.7)	(1.1)	(17.7)	(21.3)	(16.3)	(14.2)	(15.5)	(12.6)
				2017				
44.3	78.6	0.2	11.9	36.7	51.1	23.8	69.3	13.8
(32.6)	(32.8)	(1.1)	(15.0)	(26.1)	(32.2)	(16.6)	(24.7)	(14.4)
				Little Pend Oreille River among years				
40.2	80.6	0.5	16.8	35.4	26.9	15.9	72.1	11.9
(6.0)	(6.7)	(0.5)	(4.9)	(5.2)	(22.8)	(8.3)	(8.7)	(2.9)
14.8	8.3	103.9	29.1	14.6	84.8	52.0	12.1	24.7
				Myrtle Creek				
				2015				
70.5	73.3	44.1	23.8	18.5	8.2	8.6	13.8	65.7
(20.2)	(14.5)	(26.3)	(21.0)	(13.8)	(9.6)	(9.3)	(14.4)	(26.1)
				2016				
81.4	94.1	22.3	12.0	14.3	5.2	16.3	12.2	49.2
(17.4)	(7.5)	(19.7)	(10.1)	(12.1)	(8.4)	(23.0)	(14.0)	(37.7)
				2017				
90.8	94.1	14.8	11.8	14.8	4.8	7.0	8.9	23.3
(10.0)	(7.3)	(10.5)	(10.3)	(16.7)	(7.0)	(7.5)	(9.1)	(24.8)
				Myrtle Creek among years				
80.9	87.2	27.1	15.9	15.9	6.1	10.6	11.6	46.1
(10.2)	(12.0)	(15.2)	(6.9)	(2.3)	(1.9)	(5.0)	(2.5)	(21.4)
12.6	13.8	56.2	43.3	14.5	30.6	46.8	21.5	46.4

Table E4. Continued.

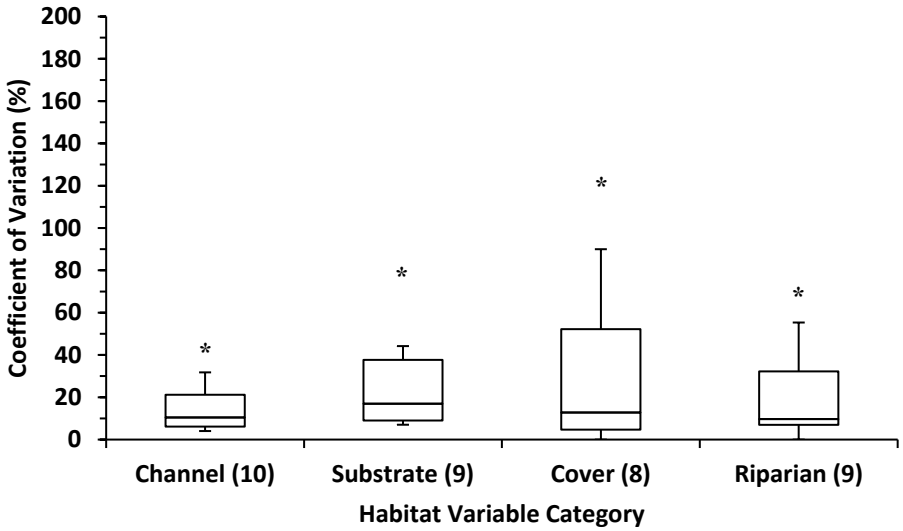
Stream canopy cover (mean %)		Canopy (mean %)		Understory (mean %)		Ground cover (mean %)		
Mid channel	Banks	Big tree	Small tree	Woody	Non woody	Woody	Non-woody	Bare ground
				Bridge Creek				
				2015				
18.6	77.3	0	0	30.0	22.7	8.3	59.7	10.5
(27.9)	(32.6)			(26.3)	(19.2)	(19.0)	(23.4)	(21.8)
				2016				
26.2	75.9	0	0	30.7	23.6	0.5	41.7	7.3
(34.6)	(27.0)			(36.7)	(22.8)	(1.5)	(30.2)	(10.1)
				2017				
29.5	86.4	0	0	32.4	24.8	5.3	74.4	0.9
(34.5)	(25.0)			(32.2)	(29.1)	(18.5(	(27.2)	(2.0)
				Bridge Creek among years				
24.8	79.9			31.0	23.7	4.7	58.6	6.2
(5.6)	(5.7)			(1.2)	(1.1)	(3.9)	(16.4)	(4.9)
22.6	7.1			4.0	4.5	83.7	28.0	78.4

*Heights of vegetation structure categories: canopy (>5 m), understory (0.5-5 m), and ground cover (<0.5 m).

Appendix F. Plots of coefficients of variation for categories of habitat variables (n) at each sentinel site.

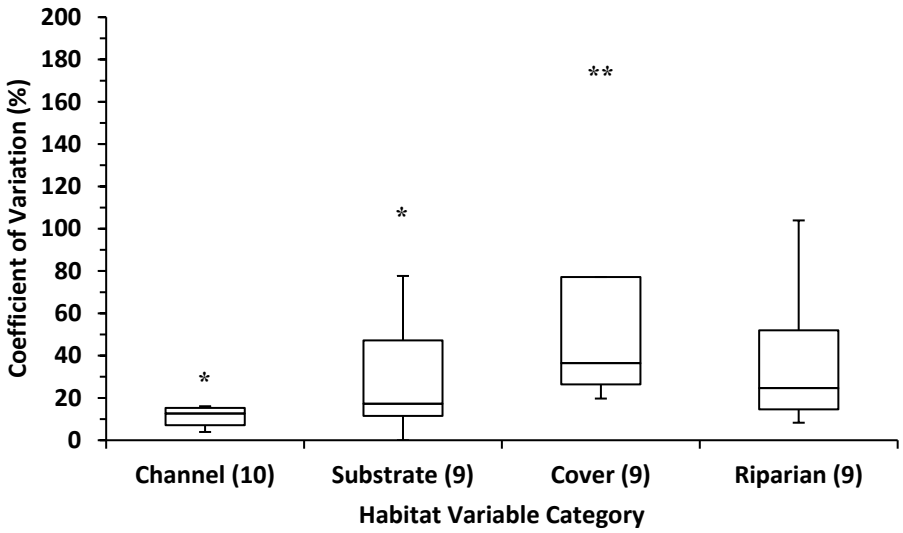


Muddy Creek 2015–2017.

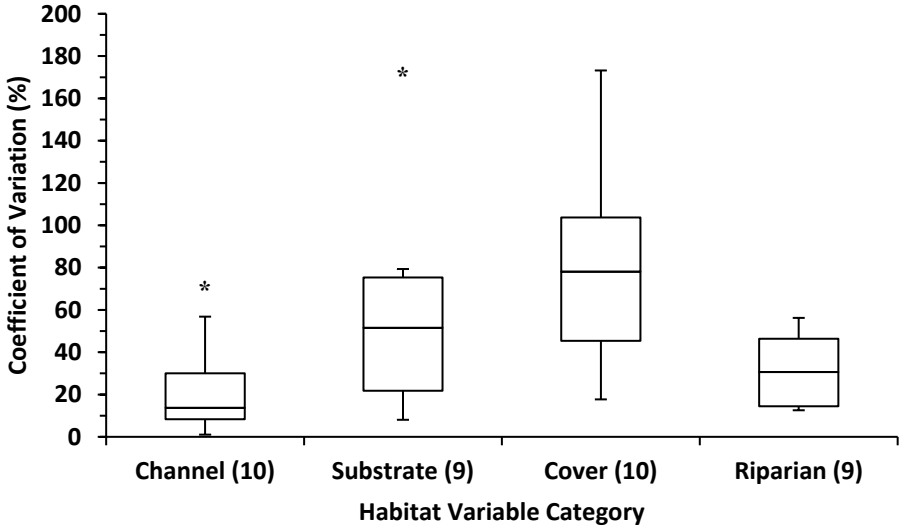


Omeara Creek #1 (original survey reach) 2015–2016.

Appendix F. Continued.

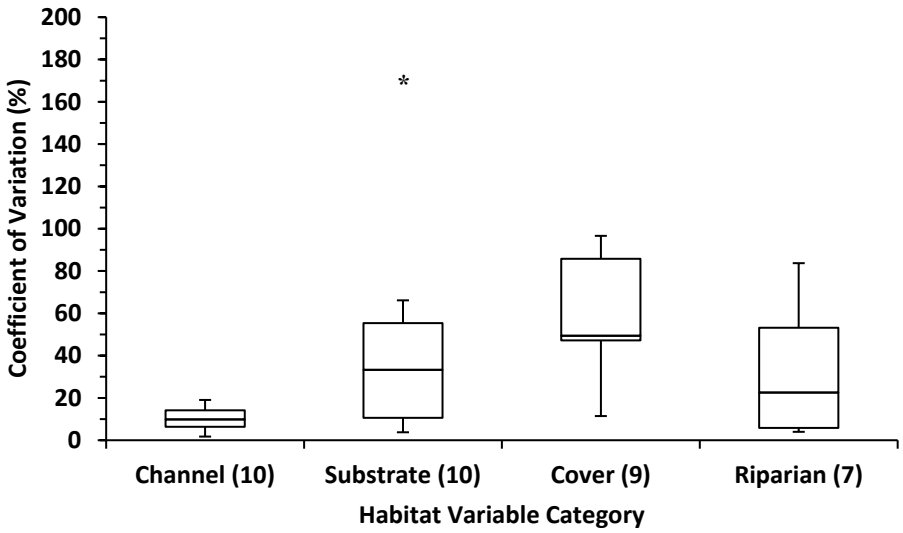


Little Pend Oreille River 2015–2017.



Myrtle Creek 2015–2017.

Appendix F. Continued.



Bridge Creek 2015–-2017.

Appendix G. Water chemistry characteristics and electrofisher settings during fish surveys at each sentinel site during 2015–2017.

Date	Time	Water temperature (°C)	Dissolved Oxygen		pH	Conductivity (µS)	Electrofisher settings			
			(mg/l)	(%)			Volts	Frequency (Hz)	Duty Cycle (%)	Time (sec.)
						Muddy Creek				
						2015				
Sept 15	1015	13.5	5.21	50.9	7.19	95	335	25	12	4,428
Oct 14	1030	13.0	6.50	63.7	6.98	80	335	25	12	3,384
						2016				
June 14	1040	14.5	7.65	101.2	7.85	65	300	20	15	4,878
July 12	1030	17.0	6.56	70.1	7.43	115	325	20	15	3,838
Sept 14	0830	14.0	6.67	64.8	-	-	325	20	15	4,259
						2017				
June 7	1020	15.5	6.30	69.5	8.50	75	325	30	12	2,518
Sept 27	0820	14.5	6.81	69.7	8.53	66	400	30	14	4,751
Oct 26	1015	12.0	8.41	78.4	7.96	104	400	30	14	3,461
						Omeara Creek #1				
						2015				
July 17	0945	17.0	8.9	95.3	8.3	55	300	30	12	1,861
Sept 2	1015	14.0	8.9	94.5	8.0	57	300	30	12	2,078
Oct 15	0915	11.9	9.3	91.9	7.5	55	300	30	12	1,741
						2016				
July 20	0930	13.9	9.0	93.0	6.9	55	300	30	12	1,616
Sept 9	1025	12.5	9.5	95.2	7.0	58	300	30	12	1,577
						2017				
July 26	1015	13.5	9.0	89.0	8.0	57	300	30	12	1,976
						Omeara Creek #2				
						2017				
Oct 4	1118	11.5	9.3	92.0	7.3	57	300	30	12	3,114

Appendix G. Continued.

Date	Time	Water temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	pH	Conductivity (µS)	Electrofisher settings: Volts	Electrofisher settings: Frequency (Hz)	Electrofisher settings: Duty Cycle (%)	Electrofisher settings: Time (sec.)
						Little Pend Oreille River				
						2015				
July 28	1130	14.50	8.7	89.0	-	185	500	45	12	4,711
Aug. 27	1130	13.0	-	-	-	-	600	60	-	2,845
Sept 28	0830	7.0	-	-	-	110	450	45	12	2,327
						2016				
July 14	1445	17.0	-	-	10.3	129	450	40	12	3,514
Aug 2	-	15.0	-	-	8.0	114	450	40	12	4,477
Sept 22	1010	9.3	-	-	9.0	91	450	38	-	5,017
						2017				
July 12	1030	16.0	-	-	-	130	250	30	12	3,250
Aug 1	1025	15.0	-	-	-	-	400	35	12	3,560
Sept 14	1050	10.0	-	-	-	-	400	35	12	3,569
						Myrtle Creek				
						2015				
July 29	1145	14.0	-	-	-	-	900	-	-	7,988
Sept 2	0915	13.0	-	-	-	-	879	-	-	8,840
Oct 26	0847	5.0	-	-	-	-	878	-	-	5,705
						2016				
July 20	1130	14.3	14.0	-	7.3	0	955	30	12	6,461
Aug 23	0900	13.5	13.6	-	7.8	0	710	30	12	4,229
Sept 21	0840	8.0	15.6	-	7.8	0	990	30	12	8,034
						2017				
July 26	0845	13.9	-	-	7.3	-	825	30	12	5,364
Aug 29	0825	14.0	-	-	-	-	969	30	12	4,813
Sept 26	0850	8.5	-	-	-	-	900	30	12	4,904

Appendix G. Continued.

Date	Time	Water temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	pH	Conductivity (µS)	Electrofisher settings: Volts	Electrofisher settings: Frequency (Hz)	Electrofisher settings: Duty Cycle (%)	Electrofisher settings: Time (sec.)
						Bridge Creek				
						2015				
Aug 5	0930	13.5	10.82	103.5	7.81	105	335	25	10	5,016
Sept 2	0830	12.9	10.82	99.7	8.11	110	335	25	10	4,536
Sept 29	0835	11.0	10.81	99.4	8.11	115	335	25	10	3,216
						2016				
July 20	0910	12.0	9.44	93.2	8.46	95	250	30	12	4,391
Aug 24	0825	10.5	8.28	87.2	8.51	95	250	30	12	4,633
Sept 28	0900	11.5	-	-	8.29	115	260	30	12	3,826
						2017				
June 29	0800	11.5	9.34	87.7	8.63	103	265	30	12	3,277
Aug 10	0900	13.0	9.65	90.7	8.45	93	265	30	12	3,376
Sept 13	0815	12.5	9.03	85.1	8.33	99	325	30	14	3,870

Appendix H. Abundance, percent composition, total length, and weight of fish collected during fish surveys of each sentinel site, 2015–2017 (non-natives in underlined italics).

Numbers of fish and species collected during each fish survey and all surveys combined in Muddy Creek during 2015 (percent of total individuals) and Jaccard Index for each survey*.

Species	Survey date		Total all surveys
	September 15	October 14	
Northern Pikeminnow	15 (10.0)	4 (6.7)	19 (9.0)
Redside Shiner	23 (15.3)	5 (8.3)	28 (13.8)
Reticulate Sculpin	69 (46.0)	15 (25.0)	84 (40.0)
Threespine Stickleback	1 (0.7)		1 (0.5)
Western Brook Lamprey		1 (1.7)	1 (0.5)
Western Mosquitofish	42 (28.0)	35 (58.3)	77 (36.7)
---total	150	60	210
---number species	5	5	6
---Jaccard Index	0.80	0.80	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Muddy Creek during 2016 (percent of total individuals) and Jaccard Index for each survey*.

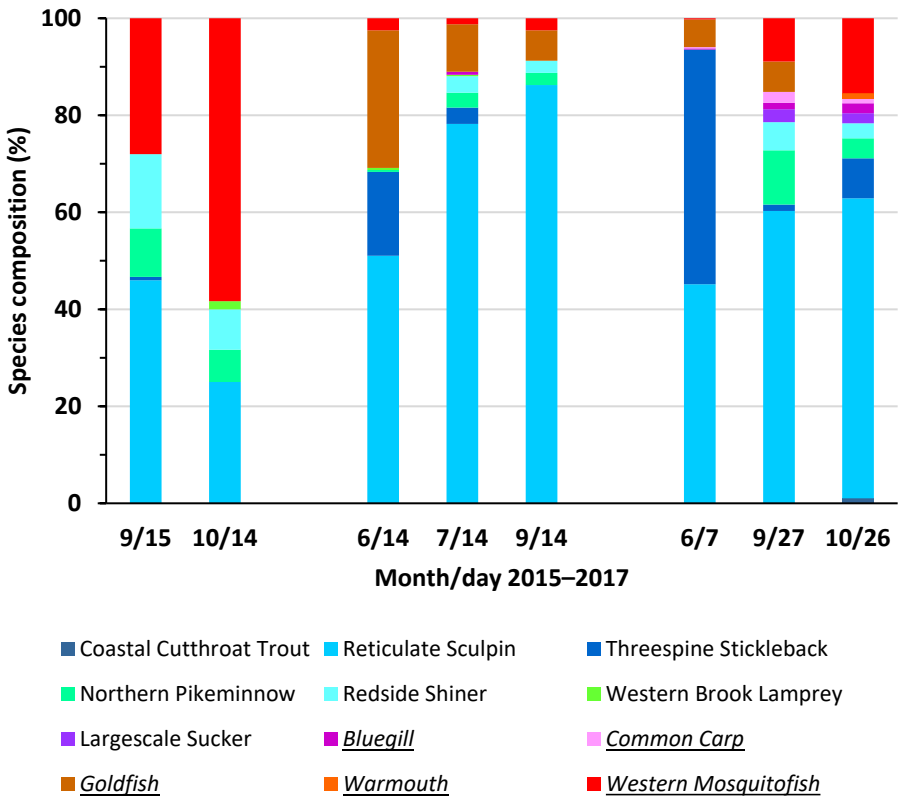
Species	Survey date			Total all surveys
	June 14	July 12	September 14	
Bluegill		2 (9.9)		2 (0.3)
Goldfish	69 (28.4)	32 (9.9)	10 (6.3)	111 (15.2)
Northern Pikeminnow	1 (0.4)	10 (3.1)	4 (2.5)	15 (2.1)
Redside Shiner		11 (3.4)	4 (2.5)	15 (2.1)
Reticulate Sculpin	124 (51.0)	255 (78.7)	138 (86.3)	517 (70.9)
Threespine Stickleback	42 (17.3)	11 (3.4)		53 (7.3)
Western Brook Lamprey	1 (0.4)	1 (0.3)		2 (0.3)
Western Mosquitofish	6 (2.5)	4 (1.2)	4 (2.5)	14 (1.9)
---total	243	326	160	729
---number species	6	8	5	8
---Jaccard Index	0.67	0.75	0.80	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Muddy Creek during 2017 (percent of total individuals) and Jaccard Index for each survey*.

Species	Survey date			Total all surveys
	June 7	September 27	October 26	
Bluegill	1 (0.2)	3 (1.3)	2 (3.1)	6 (0.8)
Coastal Cutthroat Trout			1 (1.0)	1 (0.1)
Common Carp	1 (0.2)	5 (2.2)	1 (1.0)	7 (1.0)
Goldfish	23 (5.7)	14 (6.3)		37 (5.1)
Largescale Sucker		6 (2.7)	2 (2.0)	8 (1.1)
Northern Pikeminnow		25 (11.2)	4 (4.1)	29 (4.0)
Redside Shiner		13 (5.8)	3 (3.1)	16 (2.2)
Reticulate Sculpin	182 (45.2)	135 (60.3)	60 (61.2)	377 (52.1)
Threespine Stickleback	195 (48.4)	3 (1.3)	8 (8.2)	206 (28.5)
Warmouth			1 (1.0)	1 (0.1)
Western Mosquitofish	1 (0.2)	20 (8.9)	15 (15.3)	36 (5.0)
---total	403	224	98	724
---number species	6	9	10	11
---Jaccard Index	0.50	0.89	0.50	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).



Fish species composition (percent of total individuals) for each fish survey in Muddy Creek 2015–2017.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Muddy Creek during 2015 (SD).

Species	September 15			October 14		
	n	Length	Weight	n	Length	Weight
Northern Pikeminnow	7	81.7 (21.5)	4.53 (3.04)	4	103.8 (34.3)	10.95 (8.74)
Redside Shiner	14	91.6 (21.7)	6.84 (3.89)	5	78.2 (25.2)	4.40 (3.98)
Reticulate Sculpin	33	57.2 (14.1)	2.22 (1.28)	14	56.2 (12.1)	2.04 (1.35)
Threespine Stickleback	1	39	0.5	0		
Western brook Lamprey	0			1	128	2.7
Western Mosquitofish	17	34.9 (5.5)	0.51 (0.38)	10	30.8 (7.4)	0.42 (0.55)

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Muddy Creek during 2016 (SD).

Species	June 14			July 12			September 14		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Bluegill				2	47.0 (5.7)	1.05 (0.35)			
Goldfish	24	61.0 (8.0)	3.35 (1.50)	32	64.1 (7.9)	4.45 (1.70)	10	86.7 (9.8)	11.04 (4.18)
Northern Pikeminnow	1	50	1.2	10	89.1 (19.1)	6.42 (4.00)	4	93.8 (8.0)	6.23 (1.30)
Redside Shiner	0			11	88.6 (14.7)	6.69 (3.09)	4	65.3 (20.6)	2.80 (2.45)
Reticulate Sculpin	49	66.5 (12.6)	4.52 (2.09)	50	68.7 (10.7)	4.60 (1.76)	50	66.7 (10.7)	3.82 (1.62)
Threespine Stickleback	23	32.7 (3.6)	0.41[a] (0.12)	11	31.3 (4.0)	0.34 (0.15)			
Western Brook Lamprey	1	97	1.5	1	137	4.5			
Western Mosquitofish	6	39.7 (5.2)	0.84[a] (0.15)	3	35.7 (6.8)	0.70 (0.50)	4	31.5 (11.8)	0.53 (0.66)

[a] n=19 and 5, respectively, for Threespine Stickleback and Western Mosquitofish.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Muddy Creek during 2017 (SD).

Species	June 7			September 27			October 26		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Bluegill	1	58	2.5	3	113.3 (2.9)	25.73 (4.28)	2	80.5 (6.4)	7.1[c]
Coastal Cutthroat Trout							1	155	24.6
Common Carp	1	172	87.5	5	155.0 (40.9)	62.36 (48.71)	1	97	14.3
Goldfish	20	59.7 (14.1)	3.79 (4.96)	14	82.9 (10.0)	8.78 (3.38)			
Largescale Sucker	0			6	191.5 (28.1)	66.97 (37.55)	2	137.0 (96.2)	43.65 (58.19)
Northern Pikeminnow	0			25	146.5 (35.7)	25.12 (16.72)	4	159.3 (73.0)	52.85 (79.96)
Redside Shiner	0			13	98.8 (15.8)	7.96 (3.64)	3	64.0 (24.4)	2.27 (2.71)
Reticulate Sculpin	50	71.4 (9.2)	5.64 (4.70)	45	69.7 (10.6)	5.47 (9.39)	31	71.2 (12.0)	4.52[c] (2.48)
Threespine Stickleback	36	26.6 (8.1)	0.27[a] (0.43)	3	32.3 (0.6)	0.20[b]	8	35.1 (5.1)	0.41 (0.12)
Warmouth							1	128	44.8
Western Mosquitofish	1	32	0.5	15	33.5 (3.8)	0.42[b] (0.08)	3	31.3 (1.2)	0.30[c]

[a] n=33.
[b] n=1 and 6, respectively, for Threespine Stickleback and Western Mosquitofish.
[c] n=1, 30, and 2, respectively for Bluegill, Reticulate Sculpin, and Western Mosquitofish.

Numbers of fish and species collected during each fish survey and all surveys combined in Omeara Creek during 2015 (percent of total individuals) and Jaccard Index for each survey*.

Species	Survey date			Total all surveys
	July 17	September 2	October 15	
Coastal Cutthroat Trout	15 (8.3)	15 (7.9)	14 (8.5)	44 (8.2)
Coho Salmon	29 (16.0)	29 (15.3)	13 (7.9)	71 (13.2)
Pacific Lamprey	1 (0.6)	0	0	1 (0.2)
Riffle Sculpin	135 (74.6)	146 (76.8)	138 (83.6)	409 (78.2)
Steelhead/Rainbow Trout	1 (0.6)	0	0	1 (0.2)
---total	181	190	165	536
---number species	5	3	3	5
---Jaccard Index	0.6	1.0	1.0	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Omeara Creek during 2016 (percent of total individuals) and Jaccard Index for each survey*.

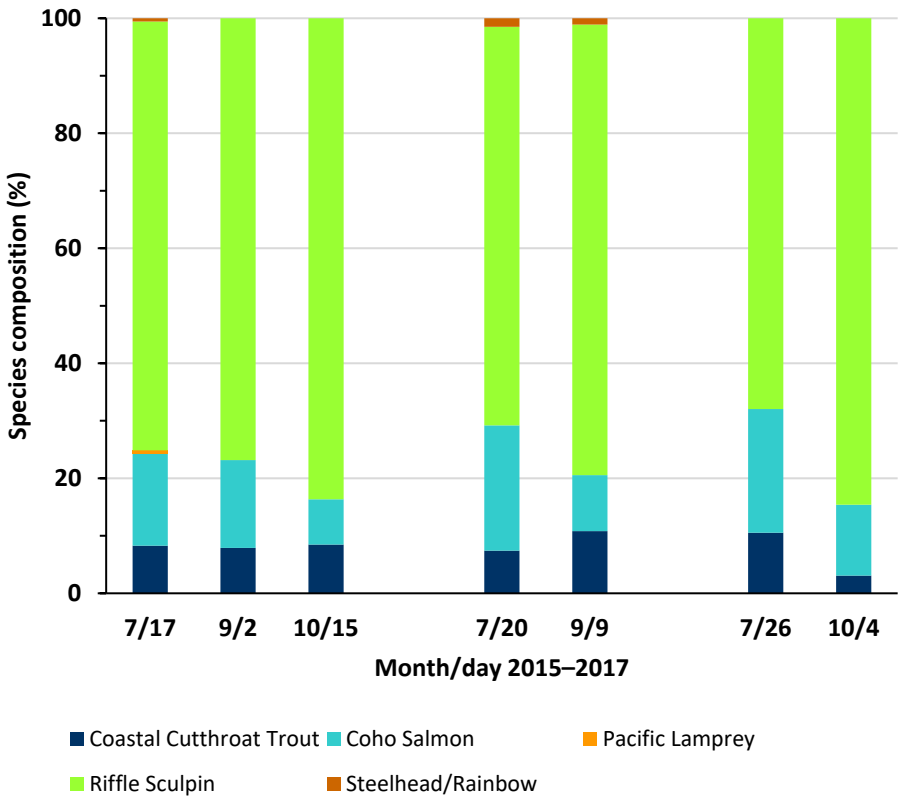
Species	Survey date		Total all surveys
	July 20	September 9	
Coastal Cutthroat Trout	15 (7.4)	20 (10.8)	35 (9.0)
Coho Salmon	44 (21.8)	18 (9.7)	62 (16.0)
Riffle Sculpin	140 (69.3)	145 (78.4)	285 (73.6)
Steelhead/Rainbow Trout	3 (1.5)	2 (1.1)	5 (1.3)
---total	202	185	387
---number species	4	4	4
---Jaccard Index	0.75	0.75	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey in Omeara Creek during 2017 (percent of total individuals) and Jaccard Index for each survey*.

Species	Omeara Creek	Omeara Creek #2
	July 26	October 4
Coastal Cutthroat Trout	22 (10.5)	7 (3.1)
Coho Salmon	45 (21.5)	28 (12.3)
Riffle Sculpin	142 (67.9)	192 (84.6)
---total	209	227
---number species	3	3
---Jaccard Index	1.0	1.0

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).



Fish species composition (percent of total individuals) for each fish survey in Omeara Creek 2015–2017. (Omeara #2 surveyed on 10/4/2017)

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Omeara Creek during 2015 (SD).

Species	July 17			September 2			October 15		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Coastal Cutthroat Trout	15	107.3 (42.2)	17.95 (21.40)	15	106.3 (45.7)	19.65[b] (23.72)	14	118.1 (43.1)	21.13 (21.81)
Coho Salmon	28	68.0 (17.5)	4.37[a] (4.57)	29	67.7 (6.9)	3.52 (1.03)	13	79.4 (8.2)	5.33 (1.52)
Pacific Lamprey	1	163	-						
Riffle Sculpin	35	55.3 (14.7)	2.6[a] (2.6)	80	47.7 (17.5)	1.72 (1.86)	134	50.8 (13.2)	1.87[c] (1.23)
Steelhead/Rainbow Trout	1	44	0.8						

[a] n=27 and 31, respectively, for Coho Salmon and Riffle Sculpin.
[b] n=14.
[c] n=129.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Omeara Creek during 2016 (SD).

Species	July 20			September 9		
	n	Length	Weight	n	Length	Weight
Coastal Cutthroat Trout	15	92.1 (35.9)	11.41 (12.41)	20	76.5 (23.2)	5.86 (9.13)
Coho Salmon	44	69.8 (8.7)	3.95 (1.50)	18	81.9 (7.3)	6.02 (1.57)
Riffle Sculpin	128	51.8 (16.8)	2.48[a] (1.16)	145	46.9 (17.4)	1.74[b] (1.45)
Steelhead	3	60.0 (7.6)	2.27 (0.81)	2	68.5 (2.1)	3.20 (0)

[a] n=109.
[b] n=134.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Omeara Creek during 2017 (SD).

Species	Omeara Creek July 26			Omeara Creek #2 October 4		
	n	Length	Weight	n	Length	Weight
Coastal Cutthroat Trout	22	112.0 (27.6)	15.96 (17.71)	7	128.1 (32.2)	24.29 (22.09)
Coho Salmon	45	66.8 (7.8)	3.43 (1.26)	28	73.6 (7.5)	4.70 (1.35)
Riffle Sculpin	142	53.4 (10.8)	2.08[a] (1.57)	186	58.8 (14.0)	2.81[b] (2.45)

[a] n=141.
[b] n=185.

Numbers of fish and species collected during each fish survey and all surveys combined in Little Pend Oreille River during 2015 (percent of total individuals) and Jaccard Index for each survey*.

Species	Survey date			Total all surveys
	July 28	August 27	September 28–29	
Brook Trout	70 (50.0)	64 (41.6)	55 (55.5)	189 (48.1)
Brown Trout	11 (7.9)	9 (5.8)	7 (7.1)	27 (6.9)
Rainbow/Redband Trout	10 (7.1)	4 (2.6)	9 (9.1)	23 (5.9)
Shorthead Sculpin	49 (35.0)	77 (50.0)	28 (28.3)	154 (39.2)
---total	140	154	99	393
---number species	4	4	4	4
---Jaccard Index	1.0	1.0	1.0	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Little Pend Oreille River during 2016 (percent of total individuals) and Jaccard Index for each survey*.

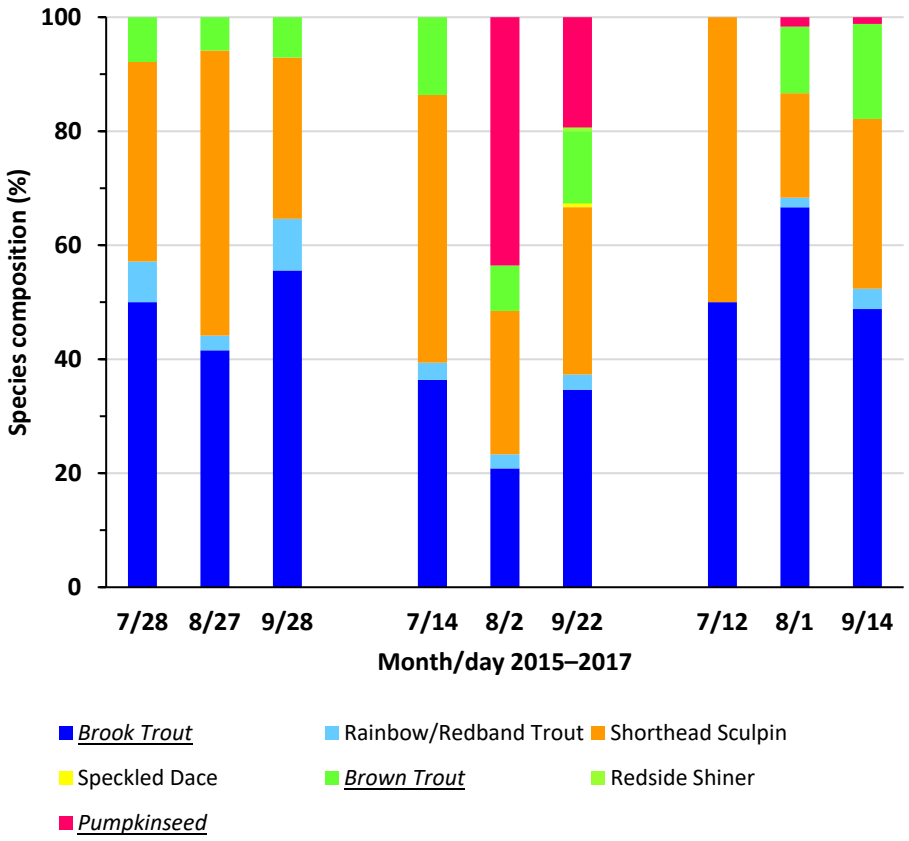
Species	Survey date			Total all surveys
	July 14	August 2	September 22	
Brook Trout	24 (36.4)	34 (20.9)	52 (34.7)	110 (29.0)
Brown Trout	9 (13.3)	13 (8.0)	19 (12.7)	41 (10.8)
Pumpkinseed		71 (43.6)	29 (19.3)	100 (26.4)
Rainbow/Redband Trout	2 (3.0)	4 (2.5)	4 (2.7)	10 (2.6)
Redside Shiner			1 (0.7)	1 (0.3)
Shorthead Sculpin	31 (47.0)	41 (25.2)	44 (29.3)	116 (30.6)
Speckled Dace			1 (0.7)	1 (0.3)
---total	66	163	150	379
---number species	4	5	7	7
---Jaccard Index	0.75	0.80	0.71	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Little Pend Oreille River during 2017 (percent of total individuals) and Jaccard Index for each survey*.

Species	Survey date			Total all surveys
	July 12	August 1	September 14	
Brook Trout	2 (50.0)	40 (66.7)	41 (48.8)	83 (56.1)
Brown Trout		7 (11.7)	14 (16.7)	21 (14.2)
Pumpkinseed		1 (1.7)	1 (1.2)	2 (1.4)
Rainbow/Redband Trout		1 (1.7)	3 (3.6)	4 (2.7)
Shorthead Sculpin	2 (50.0)	11 (18.3)	25 (29.8)	38 (25.7)
---total	4	60	84	148
---number species	2	5	5	5
---Jaccard Index	0.50	0.60	0.60	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).



Fish species composition (percent of total individuals) for each fish survey in Little Pend Oreille River 2015–2017.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Little Pend Oreille River during 2015 (SD).

Species	July 28			August 27			September 28–29		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Brook Trout	70	82.1 (31.2)	8.95 (12.67)	64	97.7 (35.8)	16.56[a] (20.24)	55	102.3 (29.9)	15.11[b] (17.81)
Brown Trout	11	124.0 (97.3)	63.05 (135.60)	9	141.8 (60.3)	55.6[a] (50.85)	7	151.0 (83.7)	72.14 (106.19)
Rainbow/Redband Trout	10	156.2 (69.6)	65.15 (66.81)	4	187.5 (62.0)	89.45 (91.64)	9	182.4 (45.2)	75.66 (46.43)
Shorthead Sculpin	49	49.5 (15.4)	2.07 (1.64)	69	53.6 (13.0)	2.17[a] (2.32)	28	58.9 (12.4)	2.46[b] (2.42)

[a] n=52, 7, and 56, respectively, for Brook Trout, Brown Trout, and Shorthead Sculpin.
[b] n=54 and 23, respectively, for Brook Trout and Shorthead Sculpin.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Little Pend Oreille River during 2016 (SD).

Species	July 14			August 2			September 22		
	n	Length	Weight[a]	n	Length	Weight[b]	n	Length	Weight
Brook Trout	24	94.4 (52.5)	31.51[a] (55.11)	34	116.2 (51.6)	25.03[b] (36.95)	52	119.5 (31.8)	18.99 (20.05)
Brown Trout	9	76.4 (40.9)	14.74[a] (27.99)	13	137.9 (111.3)	101.46 (250.40)	19	121.6 (44.8)	23.64 (30.89)
Pumpkinseed				71	77.5 (7.0)	8.71[b] (2.72)	29	78.7 (7.4)	8.24 (2.65
Rainbow/Redband Trout	2	54.5 (10.6)	2.8[a]	4	177.3 (84.2)	68.75 (55.54)	4	178.3 (46.7)	56.88 (50.60)
Redside Shiner							1	112	13.3
Shorthead Sculpin	31	63.2 (29.8)	3.85[a] (1.81)	41	62.4 (18.0)	3.08[b] (2.02)	44	63.4 (15.1)	3.11 (2.33)
Speckled Dace							1	28	1.0

[a] n=12, 5, 1, 11, respectively, for Brook Trout, Brown Trout, Rainbow Trout, and Shorthead Sculpin.
[b] n=30, 68, and 38, respecitively, for Brook Trout, Pumpkinseed, and Shorthead Sculpin.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Little Pend Oreille River during 2017 (SD).

Species	July 12			August 1			September 14		
	n	Length	Weight[a]	n	Length	Weight[b]	n	Length	Weight
Brook Trout	2	62.5 (9.2)	1.30 (0.14)	40	101.1 (49.8)	18.73 (26.23)	41	116.1 (45.7)	23.66 (38.72)
Brown Trout				7	85.7 (34.8)	8.70 (13.32)	14	152.9 (49.0)	43.01 (31.56)
Pumpkinseed				1	81	9.3	1	94	14.5
Rainbow/Redband Trout				1	160	40.4	3	209.3 (46.9)	90.37 (54.16)
Shorthead Sculpin	2	85.5 (21.9)	2.90 (2.12)	11	76.2 (16.4)	5.37 (2.45)	25	78.3 (16.2)	5.97 (3.10)

Numbers of fish and species collected during each fish survey and all surveys combined in Myrtle Creek during 2015 (percent of total individuals) and Jaccard Index for each survey*.

Species	Survey date			Total all surveys
	July 29–30	September 2–3	October 26–27	
Brook Trout	15 (2.3)	9 (1.3)	6 (2.5)	30 (1.9)
Bull Trout		1 (0.1)		1 (0.1)
Longnose Dace	318 (48.0)	394 (58.6)	67 (28.2)	779 (49.6)
Longnose Sucker			1 (0.4)	1 (0.1)
Mountain Whitefish	48 (7.3)	23 (3.4)	1 (0.4)	72 (4.6)
Ranbow/Redband Trout	183 (27.6)	188 (28.0)	128 (53.8)	499 (31.7)
Slimy Sculpin	74 (11.2)	48 (7.1)	27 (11.3)	149 (9.5)
Torrent Sculpin	22 (3.3)	9 (1.3)	7 (2.9)	38 (2.4)
Westslope Cutthroat Trout	2 (0.3)		1 (0.4)	3 (0.2)
---total	662	672	238	1,572
---number species	7	7	8	9
---Jaccard Index	0.86	0.86	0.63	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Myrtle Creek during 2016 (percent of total individuals) and Jaccard Index for each survey*.

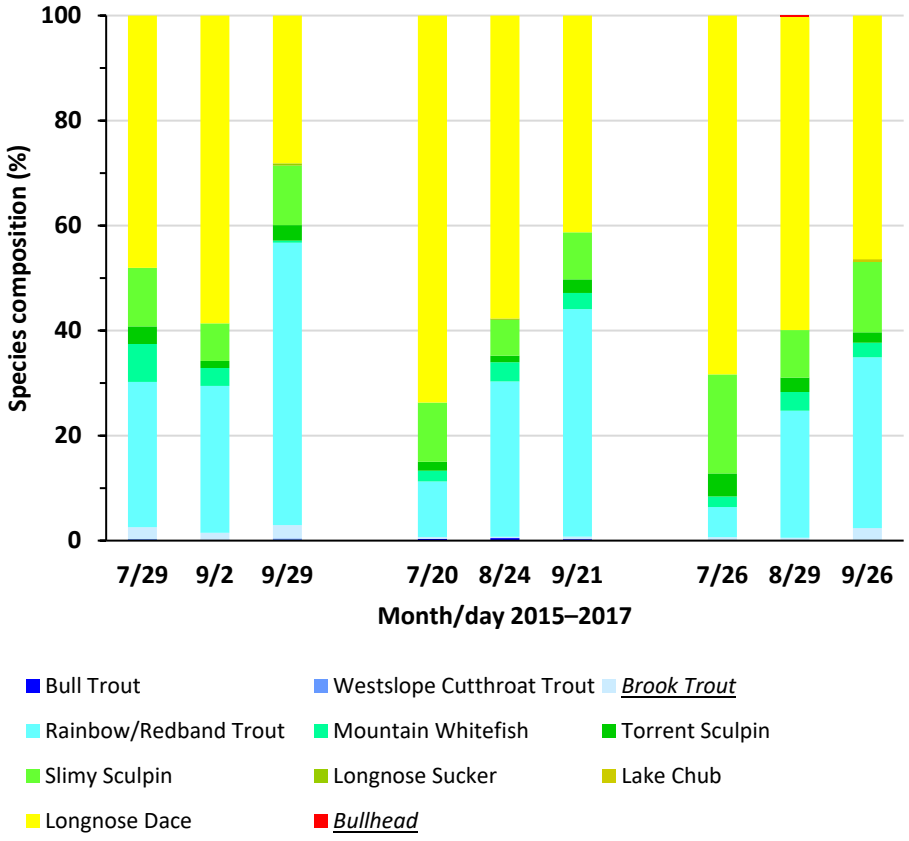
Species	Survey date			Total all surveys
	July 19--20	August 23--24	September 21--22	
Brook Trout	1 (0.3)	1 (0.2)	2 (0.5)	4 (0.4)
Bull Trout	1 (0.3)	2 (0.5)	1 (0.3)	4 (0.4)
Longnose Dace	216 (73.7)	236 (57.7)	161 (41.3)	613 (56.1)
Longnose Sucker		1 (0.2)		1 (0.1)
Mountain Whitefish	6 (2.0)	15 (3.7)	12 (3.1)	33 (3.0)
Rainbow/Redband Trout	31 (10.6)	121 (29.6)	169 (43.3)	321 (29.4)
Slimy Sculpin	33 (11.3)	28 (6.8)	35 (9.0)	96 (8.8)
Torrent Sculpin	5 (1.7)	5 (1.2)	10 (2.6)	20 (1.8)
---total	293	409	390	1,092
---number species	7	8	7	8
---Jaccard Index	0.71	0.63	0.86	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Myrtle Creek during 2017 (percent of total individuals) and Jaccard Indexfor each survey*.

Species	Survey date			Total all surveys
	July 26–27	August 29	September 26	
Brook Trout	2 (0.7)	2 (0.5)	6 (2.4)	10 (1.1)
Bullhead		1 (0.3)		1 (0.1)
Lake Chub			1 (0.4)	1 (0.1)
Longnose Dace	203 (68.4)	217 (59.6)	117 (46.4)	537 (58.8)
Mountain Whitefish	6 (2.0)	13 (3.6)	7 (2.8)	26 (2.8)
Rainbow/Redband Trout	17 (5.7)	88 (24.2)	82 (32.5)	187 (20.5)
Slimy Sculpin	56 (18.9)	33 (9.1)	34 (13.5)	123(13.5)
Torrent Sculpin	13 (4.4)	10 (2.7)	5 (2.0)	28 (3.1)
---total	297	364	252	913
---number species	6	7	7	8
---Jaccard Index	0.83	0.71	0.71	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).



Fish species composition (percent of total individuals) for each fish survey in Myrtle Creek 2015–2017.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Myrtle Creek during 2015 (SD).

Species	July 29—30			September 2—3			October 26—27		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Brook Trout	11	100.4 (28.2)	10.77 (9.05)	9	86.8 (29.9)	8.58 (9.52)	6	82.8 (5.1)	4.43[a] (1.93)
Bull Trout				1	170	49			
Longnose Dace	56	88.5 (26.4)	6.82 (5.18)	51	77.2 (27.8)	6.20 (6.21)	45	79.3 (24.6)	4.99[a] (4.19)
Longnose Sucker							1	84	5.9
Mountain Whitefish	37	82.0 (23.2)	4.67 (6.69)	23	78.8 (6.2)	3.88 (0.88)	1		158
Rainbow/RedbandTrout	62	107.0 (54.3)	19.32 (26.15)	52	87.3 (50.6)	14.68 (25.48)	50	86.9 (45.8)	11.36[a] (24.65)
Slimy Sculpin	61	71.1 (12.9)	3.51 (1.81)	42	70.1 (11.8)	3.37 (1.65)	25	76.1 (12.4)	4.31[a] (1.95)
Torrent Sculpin	22	84.3 (9.7)	7.27 (3.15)	9	87.1 (11.2)	7.43 (3.13)	7	80.6 (10.2)	5.62[a] (2.59)
Westslope Cutthroat Trout	2	239.0 (0.0)	130.95 (5.99)				1	244	124

[a] n=3, 35, 39, 23, and 6, respectively, for Brook Trout, Longnose Dace, Rainbow Trout, Slimy Sculpin, and Torrent Sculpin.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Myrtle Creek during 2016 (SD).

Species	July 19--20			August 23--24			September 21--22		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Brook Trout	1	75	3.6	1	85	5.0	2	87.5 (7.8)	4.45 (1.34)
Bull Trout	1	182	52.1	2	193.5 (23.3)	63.85 (26.52)	1	221	94.0
Longnose Dace	50	88.2 (23.0)	7.44 (10.49)	51	87.8 (24.3)	5.28[b] (3.76)	50	82.0 (22.3)	4.92 (4.03)
Longnose Sucker				1	130	18.2			
Mountain Whitefish	6	75.7 (4.4)	2.70 (0.35)	15	92.1 (6.8)	4.67[b] (1.23)	12	100.7 (7.5)	6.31 (1.30)
Rainbow/Redband Trout	22	50.1 (27.3)	2.54[a] (3.57)	50	73.4 (39.7)	5.68[b] (9.40)	50	78.3 (36.6)	7.33 (11.95)
Slimy Sculpin	31	77.5 (6.8)	4.09 (1.03)	27	80.4 (7.7)	4.54[b] (1.28)	26	82.5 (6.1)	4.74 (0.92)
Torrent Sculpin	5	90.6 (8.8)	8.70 (2.31)	5	96.2 (6.4)	9.62 (1.72)	10	91.2 (9.5)	8.06 (2.48)

[a] n=17.
[b] n=46, 14, 48, 24, respectively, for Longnose Dace, Mountain Whitefish, Rainbow Trout, Slimy Sculpin.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Myrtle Creek during 2017 (SD).

Species	July 26			August 29			September 26		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Brook Trout	2	68.0 (0.0)	2.50 (0.71)	2	108.5 (60.1)	15.50 (17.68)	6	102.3 (23.2)	8.67 (5.75)
Lake Chub							1	111	9.0
Longnose Dace	50	89.5 (25.5)	6.49[a] (5.31)	50	93.2 (21.6)	6.88 (6.06)	48	83.6 (19.3)	4.71 (3.35)
Mountain Whitefish	6	70.8 (7.2)	2.20[a] (0.84)	13	92.5 (13.8)	7.46 (8.92)	7	95.4 (5.9)	4.86 (0.90)
Rainbow/Redband Trout	17	116.0 (35.7)	15.47[a] (15.85)	48	104.0 (47.5)	14.94 (17.39)	52	103.4 (37.8)	11.85 (14.07)
Slimy Sculpin	44	78.7 (12.9)	4.88[a] (3.47)	31	83.0 (10.7)	4.77 (1.71)	32	80.8 (11.2)	4.34 (1.56)
Torrent Sculpin	13	84.2 (16.7)	7.08 (3.84)	9	72.7 (7.2)	3.78 (1.09)	5	79.6 (10.2)	4.40 (1.67)

[a] n=45, 5, 15, 40, respectively, for Longnose Dace, Mountain Whitefish, Rainbow Trout, Slimy Sculpin.

Numbers of fish and species collected during each fish survey and all surveys combined in Bridge Creek during 2015 (percent of total individuals) and Jaccard Indexfor each survey*.

Species	Survey date			Total all surveys
	August 5	September 2	September 29	
Longnose Dace	3 (0.5)			3 (0.2)
Malheur Sculpin	55 (8.8)	40 (6.3)	24 (7.3)	119 (7.5)
Redband Trout	78 (12.4)	85 (13.5)	96 (29.2)	259 (16.3)
Speckled Dace	491 (78.3)	507 (80.2)	209 (63.5)	1,207 (76.0)
---total	627	632	329	1,588
---number species	4	3	3	4
---Jaccard Index	1.0	1.0	1.0	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Bridge Creek during 2016 (percent of total individuals) and Jaccard Indexfor each survey*.

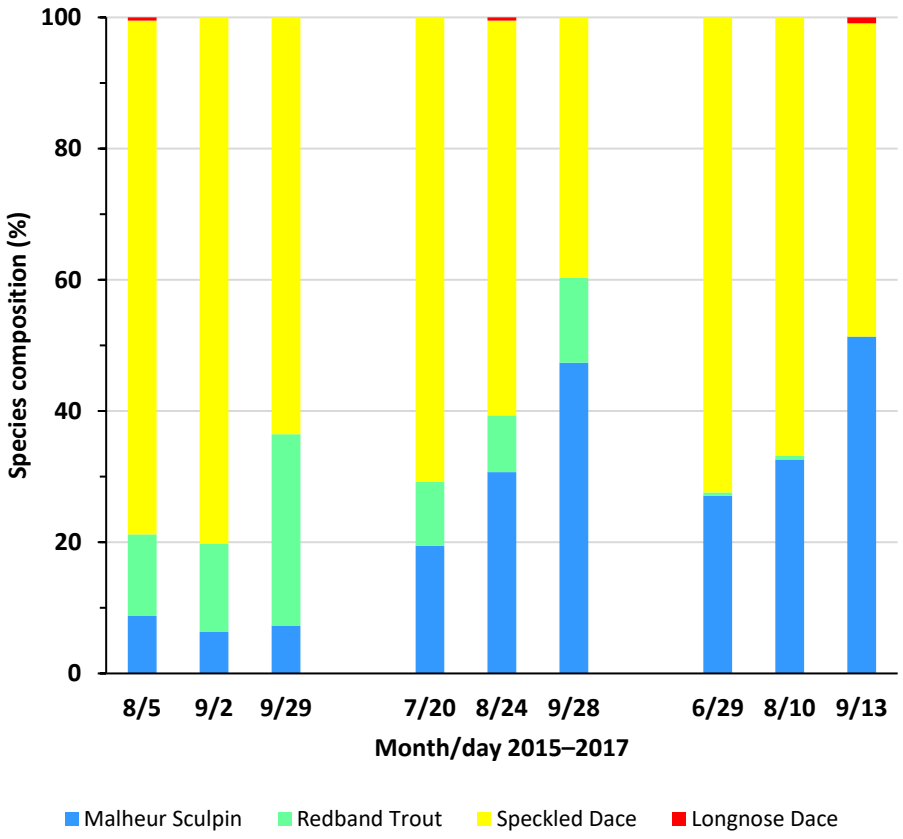
Species	Survey date			Total all surveys
	July 20	August 24	September 28	
Longnose Dace		2 (0.5)		2 (0.2)
Malheur Sculpin	44 (19.5)	124 (30.7)	99 (47.4)	267 (31.8)
Redband Trout	22 (9.7)	35 (8.7)	27 (12.9)	84 (10.0)
Speckled Dace	160 (70.8)	243 (60.1)	83 (39.7)	486 (57.9)
---total	226	404	209	839
---number species	3	4	3	4
---Jaccard Index	1.0	1.0	1.0	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).

Numbers of fish and species collected during each fish survey and all surveys combined in Bridge Creek during 2017 (percent of total individuals) and Jaccard Index for each survey*.

Species	Survey date			Total all surveys
	June 29	August 10	September 13	
Longnose Dace			1 (0.9)	1 (0.2)
Malheur Sculpin	55 (27.1)	105 (32.6)	57 (51.4)	217 (34.1)
Redband Trout	1 (0.5)	2 (0.6)		3 (0.5)
Speckled Dace	147 (72.4)	215 (66.8)	53 (47.7)	415 (65.3)
---total	203	322	111	636
---number species	3	3	3	4
---Jaccard Index	0.67	0.67	0.67	

*Used as an index to gauge adequacy of sampling by comparing species composition between even- to odd-numbered subreaches of a survey (Peck et al. 2006).



Fish species composition (percent of total individuals) for each fish survey in Bridge Creek 2015–2017.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Bridge Creek during 2015 (SD).

Species	August 5			September 2			September 29		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Longnose Dace	3	78.3 (16.5)	4.90 (2.70)	0			0		
Malheur Sculpin	39	72.6 (24.1)	6.41 (5.88)	26	82.5 (20.1)	15.55 (11.14)	24	72.8 (23.0)	13.25 (12.88)
Redband Trout	47	120.5 (42.2)	22.49 (22.08)	46	136.2 (49.6)	61.72 (82.89)	48	124.9 (42.7)	50.34 (50.71)
Speckled Dace	53	62.3 (9.1)	2.48[a] (0.94)	51	62.6 (5.5)	4.00[b] (1.47)	50	60.8 (5.5)	4.76 (1.32)

[a] n=52
[b] n=50

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Bridge Creek during 2016 (SD)

Species	July 20			August 24			September 28		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Longnose Dace				2	65.5 (2.1)	2.85 (0.07)			
Malheur Sculpin	36	58.6 (29.1)	5.70 (10.09)	50	57.8 (19.3)	3.67 (5.87)	43	60.2 (16.5)	3.75[a] (5.25)
Redband Trout	22	67.8 (13.5)	3.17 (2.10)	30	86.2 (28.1)	9.09[a] (17.21)	20	101.0 (49.0)	19.51 (39.94)
Speckled Dace	49	61.5 (5.7)	2.44 (0.74)	50	61.6 (6.2)	2.53 (0.94)	44	60.0 (7.8)	2.30 (0.81)

[a] n=29 and 42, respectively, for Redband Trout and Malheur Sculpin.

Number (n), mean total length (mm), and mean weight (g) of fish subsampled during each fish survey in Bridge Creek during 2017 (SD)

Species	June 29			August 10			September 13		
	n	Length	Weight	n	Length	Weight	n	Length	Weight
Longnose Dace							1	65	1.1
Malheur Sculpin	49	71.0 (15.2)	5.15 (2.74)	48	58.7 (20.7)	3.71 (5.19)	33	54.8 (12.7)	2.38 (3.07)
Redband Trout	1	188	65.7	2	175.5 (112.4)	79.00 (100.69)	0		
Speckled Dace	50	59.4 (7.9)	1.99 (0.83)	50	59.4 (8.2)	2.34 (0.97)	42	58.3 (6.7)	2.13 (0.83)

Appendix I. Values of similarity (Jaccard and Morisita indices), temperature class, and assemblage tolerance indices for each sentinel site.

Muddy Creek: Jaccard Index

	9/15/2015	10/14/2015	6/14/2016	7/12/2016	9/14/2016	6/7/2017	9/27/2017	10/26/2017
9/15/2015	1.000							
10/14/2015	0.667	1.000						
6/14/2016	0.571	0.571	1.000					
7/12/2016	0.625	0.625	0.750	1.000				
9/14/2016	0.667	0.667	0.571	0.625	1.000			
6/7/2017	0.375	0.222	0.500	0.556	0.375	1.000		
9/27/2017	0.556	0.400	0.500	0.700	0.556	0.667	1.000	
10/26/2017	0.500	0.364	0.333	0.500	0.364	0.455	0.727	1.000

Muddy Creek: Morisita Index

	9/15/2015	10/14/2015	6/14/2016	7/12/2016	9/14/2016	6/7/2017	9/27/2017	10/26/2017
9/15/2015	1.014							
10/14/2015	0.823	1.025						
6/14/2016	0.707	0.368	1.007					
7/12/2016	0.789	0.404	0.873	1.002				
9/14/2016	0.769	0.406	0.821	0.995	1.002			
6/7/2017	0.558	0.271	0.817	0.706	0.662	1.003		
9/27/2017	0.910	0.541	0.871	0.956	0.932	0.681	1.007	
10/26/2017	0.924	0.613	0.856	0.949	0.930	0.751	0.987	1.015

Muddy Creek: Temperature Class Index (TCI) and Assemblage Tolerance Index (ATI)

	9/15/2015	10/14/2015	6/14/2016	7/12/2016	9/14/2016	6/7/2017	9/27/2017	10/26/2017
TCI	2.373	3.500	2.243	1.534	1.400	1.258	1.973	1.897
ATI	5.161	6.647	5.391	4.205	4.004	4.433	4.575	4.627

Omeara Creek: Jaccard Index

	7/17/2015	9/2/2015	10/15/2015	7/20/2016	9/9/2016	7/26/2017	10/4/2017
7/17/2015	1.000						
9/2/2015	0.600	1.000					
10/15/2015	0.600	1.000	1.000				
7/20/2016	0.800	0.750	0.750	1.000			
9/9/2016	0.800	0.750	0.750	1.000	1.000		
7/26/2017	0.600	1.000	1.000	0.750	0.750	1.000	
10/4/2017	0.600	1.000	1.000	0.750	0.750	1.000	1.000

Omeara Creek: Morisita Index

	7/17/2015	9/2/2015	10/15/2015	7/20/2016	9/9/2016	7/26/2017	10/4/2017
7/17/2015	1.004						
9/2/2015	1.003	1.003					
10/15/2015	0.992	0.995	1.002				
7/20/2016	0.998	0.995	0.971	1.004			
9/9/2016	0.999	1.000	1.000	0.983	1.003		
7/26/2017	0.997	0.993	0.968	1.003	0.982	1.004	
10/4/2017	0.992	0.996	0.999	0.976	0.995	0.969	1.002

Omeara Creek: Temperature Class Index (TCI) and Assemblage Tolerance Index (ATI)

	7/17/2015	9/2/2015	10/15/2015	7/20/2016	9/9/2016	7/26/2017	10/4/2017
TCI	1.000	1.000	1.000	1.000	1.000	1.000	1.000
ATI	2.798	2.821	2.885	2.749	2.819	2.716	2.927

Little Pend Oreille River: Jaccard Index

	7/28/2015	8/27/2015	9/28/2015	7/14/2016	8/2/2016	9/22/2016	7/12/2017	8/1/2017	9/14/2017
7/28/2015	1.000								
8/27/2015	1.000	1.000							
9/28/2015	1.000	1.000	1.000						
7/14/2016	1.000	1.000	1.000	1.000					
8/2/2016	0.800	0.800	0.800	0.800	1.000				
9/22/2016	0.571	0.571	0.571	0.571	0.714	1.000			
7/12/2017	0.500	0.500	0.500	0.500	0.400	0.286	1.000		
8/1/2017	0.800	0.800	0.800	0.800	1.000	0.714	0.400	1.000	
9/14/2017	0.800	0.800	0.800	0.800	1.000	0.714	0.400	1.000	1.000

Little Pend Oreille River: Morisita Index

	7/28/2015	8/27/2015	9/28/2015	7/14/2016	8/2/2016	9/22/2016	7/12/2017	8/1/2017	9/14/2017
7/28/2015	1.012								
8/27/2015	0.970	1.009							
9/28/2015	1.003	0.925	1.015						
7/14/2016	0.968	1.005	0.916	1.027					
8/2/2016	0.591	0.603	0.561	0.621	1.014				
9/22/2016	0.907	0.881	0.881	0.912	0.869	1.019			
7/12/2017	1.193	1.210	1.150	1.197	0.727	1.087	1.500		
8/1/2017	0.945	0.829	0.982	0.815	0.516	0.821	1.040	1.018	
9/14/2017	1.000	0.940	0.996	0.960	0.606	0.930	1.153	0.962	1.022

Little Pend Oreille River: Temperature Class Index (TCI) and Assemblage Tolerance Index (ATI)

	7/28/2015	8/27/2015	9/28/2015	7/14/2016	8/2/2016	9/22/2016	7/12/2017	8/1/2017	9/14/2017
TCI	1.079	1.058	1.073	1.136	2.822	1.913	1.000	1.183	1.214
ATI	1.737	1.669	1.740	1.755	4.440	3.012	1.600	1.890	1.895

Myrtle Creek: Jaccard Index

	7/29/2015	9/2/2015	9/29/2015	7/20/2016	8/24/2016	9/21/2016	7/26/2017	8/29/2017	9/26/2017
7/29/2015	1.000								
9/2/2015	0.750	1.000							
9/29/2015	0.875	0.667	1.000						
7/20/2016	0.750	1.000	0.667	1.000					
8/24/2016	0.667	0.875	0.778	0.875	1.000				
9/21/2016	0.750	1.000	0.667	1.000	0.875	1.000			
7/26/2017	0.857	0.857	0.750	0.857	0.750	0.857	1.000		
8/29/2017	0.750	0.750	0.667	0.750	0.667	0.750	0.857	1.000	
9/26/2017	0.750	0.750	0.667	0.750	0.667	0.750	0.857	0.750	1.000

Myrtle Creek: Morisita Index

	7/29/2015	9/2/2015	9/29/2015	7/20/2016	8/24/2016	9/21/2016	7/26/2017	8/29/2017	9/26/2017
7/29/2015	1.003								
9/2/2015	0.983	1.002							
9/29/2015	0.846	0.803	1.007						
7/20/2016	0.892	0.947	0.587	1.003					
8/24/2016	0.985	1.002	0.819	0.938	1.003				
9/21/2016	0.958	0.935	0.966	0.775	0.945	1.004			
7/26/2017	0.885	0.924	0.555	0.992	0.913	0.746	1.003		
8/29/2017	0.981	1.000	0.770	0.963	0.999	0.915	0.948	1.004	
9/26/2017	0.997	0.977	0.896	0.868	0.981	0.982	0.859	0.970	1.008

Myrtle Creek: Temperature Class Index (TCI) and Assemblage Tolerance Index (ATI)

	7/29/2015	9/2/2015	9/29/2015	7/20/2016	8/24/2016	9/21/2016	7/26/2017	8/29/2017	9/26/2017
TCI	1.961	2.173	1.571	2.474	2.159	1.826	2.367	2.203	1.929
ATI	4.211	4.584	3.376	5.238	4.549	3.898	5.108	4.673	4.154

Bridge Creek: Jaccard Index

	8/5/2015	9/2/2015	9/29/2015	7/20/2016	8/24/2016	9/28/2016	6/29/2017	8/10/2017	9/13/2017
8/5/2015	1.000								
9/2/2015	0.750	1.000							
9/29/2015	0.750	1.000	1.000						
7/20/2016	0.750	1.000	1.000	1.000					
8/24/2016	1.000	0.750	0.750	0.750	1.000				
9/28/2016	0.750	1.000	1.000	1.000	0.750	1.000			
6/29/2017	0.750	1.000	1.000	1.000	0.750	1.000	1.000		
8/10/2017	0.750	1.000	1.000	1.000	0.750	1.000	1.000	1.000	
9/13/2017	0.750	0.500	0.500	0.500	0.750	0.500	0.500	0.500	1.000

Bridge Creek: Morisita Index

	8/5/2015	9/2/2015	9/29/2015	7/20/2016	8/24/2016	9/28/2016	6/29/2017	8/10/2017	9/13/2017
8/5/2015	1.001								
9/2/2015	1.000	1.001							
9/29/2015	0.957	0.956	1.003						
7/20/2016	0.987	0.979	0.948	1.004					
8/24/2016	0.927	0.911	0.900	0.979	1.003				
9/28/2016	0.715	0.690	0.731	0.819	0.922	1.007			
6/29/2017	0.960	0.950	0.884	0.991	0.981	0.840	1.003		
8/10/2017	0.931	0.916	0.862	0.978	0.992	0.888	0.998	1.003	
9/13/2017	0.746	0.721	0.696	0.847	0.937	0.980	0.895	0.937	1.009

Bridge Creek: Temperature Class Index (TCI) and Assemblage Tolerance Index (ATI)

	8/5/2015	9/2/2015	9/29/2015	7/20/2016	8/24/2016	9/28/2016	6/29/2017	8/10/2017	9/13/2017
TCI	1.793	1.802	1.635	1.708	1.611	1.397	1.724	1.668	1.495
ATI	3.590	3.612	3.292	3.406	3.202	2.760	3.422	3.303	2.941

Appendix J. Temperature class values and tolerance values assigned to fish taxa.

Taxa	Latin name	Temperature class value	Tolerance value
Bluegill	*Lepomis macrochirus*	5	8.2
Bullhead	*Ameiurus sp*	5	7.8
Brook Trout	*Salvelinus fontinalis*	1	1.7
Brown Trout	*Salmo trutta*	2	2.7
Bull Trout	*Salvelinus confluentus*	1	0.7
Coho Salmon	*Oncorhynchus kisutch*	1	2.1
Common Carp	*Cyprinus carpio*	5	9.0
Cutthroat Trout	*Oncorhynchus clarkii*	1	1.5
Goldfish	*Carassius auratus*	5	9.0
Lake Chub	*Couesius plumbeus*	1	5.5
Largescale Sucker	*Catostomus macrocheilus*	3	3.2
Longnose Dace	*Rhinichthys cataractae*	3	6.2
Longnose Sucker	*Catostomus catostomus*	3	4.6
Malheur Sculpin	*Cottus bendirei*	1	1.9
Mountain Whitefish	*Prosopium williamsoni*	1	2.5
Northern Pikeminnow	*Ptychocheilus oregonensis*	2	3.5
Pacific Lamprey	*Lampetra tridentata*	1	2.4
Pumpkinseeds	*Lepomis gibbosu*	5	7.9
Rainbow and Redband Trout	*Oncorhynchus mykiss*	1	2.1
Redside Shiner	*Richardsonius balteatus*	2	4.6
Reticulate Sculpin	*Cottus perplexus*	1	3.5
Riffle Sculpin	*Cottus gulosus*	1	3.1
Shorthead Sculpin	*Cottus confusus*	1	1.5
Slimy Sculpin	*Cottus cognatus*	1	3.0
Speckled Dace	*Rhinichthys osculus*	2	4.0
Threespine Stickleback	*Gasterosteus aculeatus*	1	4.7
Torrent Sculpin	*Cottus rhotheus*	1	2.8
Warmouth	*Lepomis gulosus*	5	8.1
Western Brook Lamprey	*Lampetra richardson*	2	1.3
Western Mosquitofish	*Gambusia affinis*	5	8.8

Appendix K. Estimated initial annual budget[a] of a FAC office for the NWR monitoring program.

Category	Cost basis	Amount
Salary	-1 pay period (1 week in each the field and office) (personnel specific)	TBD
Travel	-Housing ($96/night for 4 nights)	$384
	-Per diem (5 days—2 in travel at $41/day, 3 full days at $55/day)	$247
	-Mileage (office specific: mean distance of offices to NWRs 324 miles, range 93–493 miles)	TBD
Equipment [b]	-Temperature loggers (4 TidbiT loggers at $133/each, 1 HOBO shuttle at $249, HOBOware Pro at $99)	$880
	-Materials for logger deployment (PVC, cables, hardware, solar radiation shield)	$200
Supplies	-Misc. supplies, repair/replacement of gear (nets, waders, electrofisher parts, etc.)	$500
Total	(excluding items TBD)	$2,211

[a] Based on FY20 rates and costs.
[b] Occasional cost in future years.

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