



Integrated Aquatic Community and Water Quality Monitoring of Wadeable Streams in the Klamath Network – Annual Report

*2012 Results from Oregon Caves National Monument, Redwood
National and State Parks, and Crater Lake National Park*

Natural Resource Report NPS/KLMN/NRR—2015/1015



ON THE COVER

Munson Creek, Crater Lake National Park

Photograph by: Christa Torrens, 2012 Field Crew Leader

Integrated Aquatic Community and Water Quality Monitoring of Wadeable Streams in the Klamath Network – Annual Report

*2012 Results from Oregon Caves National Monument,
Redwood National and State Parks, and Crater Lake
National Park*

Natural Resource Report NPS/KLMN/NRR—2015/1015

Eric C. Dinger

National Park Service
1250 Siskiyou Blvd
Southern Oregon University
Ashland, OR 97520

September 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from Klamath Inventory and Monitoring Network (<http://science.nature.nps.gov/im/units/klmn/index.cfm>), and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Dinger, E. C. 2015. Integrated aquatic community and water quality monitoring of Wadeable streams in the Klamath Network – Annual report: 2012 results from Oregon Caves National Monument, Redwood National and State Parks, and Crater Lake National Park. Natural Resource Report NPS/KLMN/NRR—2015/1015. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	v
Tables.....	v
Appendices.....	vi
Executive Summary	vii
Acknowledgments.....	x
Introduction.....	1
Methods.....	2
Implementation Schedule	2
Site Selection.....	2
Site Layout	2
Water Chemistry and Quality.....	2
Stream Habitat/Riparian Corridor Characteristics.....	4
Aquatic Communities.....	4
Calculating Indicators of Ecological Condition	5
Total Phosphorous.....	5
Total Nitrogen	5
Salinity.....	6
Acid Neutralizing Capacity	6
Streambed Stability (aka Relative Bed Stability).....	6
In-stream Habitat Cover	7
Riparian Cover.....	7
Riparian Disturbance.....	7
Biological Indicators	7
Establishing Thresholds of Ecological Condition	9
Additional Macroinvertebrate Measures	9
Relationship of KLMN Indicators to Water Quality Standards	10
Results.....	11
Oregon Caves National Monument and Preserve	11

Contents (continued)

	Page
Physical Characteristics of Oregon Caves Streams.....	11
Physical Condition Metrics of Oregon Caves Streams	11
Chemical Characteristics and Condition Estimates of Oregon Caves Streams.....	14
Riparian Characteristics of Oregon Caves Streams.....	16
Vertebrate Assemblage and Condition of Oregon Caves Streams.....	16
Macroinvertebrate Assemblage and Condition of Oregon Caves Streams	16
Redwood National and State Parks	18
Physical Characteristics of Redwood Parks Streams	18
Physical Condition Metrics of Redwood Parks Streams.....	18
Chemical Characteristics and Condition Estimates of Redwood Parks Streams	24
Riparian Characteristics of Redwood Parks Streams	26
Vertebrate Assemblage and Condition of Redwood Parks Streams.....	26
Macroinvertebrate Assemblage and Condition of Redwood Parks Streams.....	29
Crater Lake National Park.....	31
Physical Characteristics of Crater Lake Streams.....	31
Physical Condition Metrics of Crater Lake Streams	31
Chemical Characteristics and Condition Estimates of Crater Lake Streams.....	37
Riparian Characteristics of Crater Lake Streams	39
Vertebrate Assemblage and Condition of Crater Lake Streams.....	39
Macroinvertebrate Assemblage and Condition of Crater Lake Streams	39
Discussion.....	44
General Issues.....	44
Oregon Caves National Monument and Preserve	45
Redwood National and State Parks	48
Crater Lake National Park.....	50
Conclusions.....	55
Literature Cited	56

Figures

	Page
Figure 1. Schematic of sampling site reach layout	3
Figure 2. Numeric range and thresholds for RBS condition assessment.	6
Figure 3. Sites sampled in Oregon Caves National Monument and Preserve, 2012.	12
Figure 4. Photos of three sites sampled in Oregon Caves.....	13
Figure 5. Stream sites sampled in Redwood National and State Parks, 2012.....	19
Figure 6. Examples of typical stream characteristics in Redwoods National and State Parks, 2012.....	21
Figure 7. Stream sites sampled in Crater Lake National Park, 2012.	32
Figure 8. Examples of typical stream characteristics in Crater Lake National Park, 2012.....	34
Figure 9. Geologic map of Oregon Caves National Monument and Preserve and 2012 stream sampling locations.....	47
Figure 10. Simplified geologic map of Crater Lake National Park and 2012 sampling locations.....	54

Tables

	Page
Table 1. Threshold for condition rating used in the Klamath Network.....	9
Table 2. Available water quality criteria used for possible exceedances, including drinking water (not applicable for natural waters, but provided for comparative reasons).	10
Table 3. Site list for streams sampled in Oregon Caves National Monument and Preserve.....	11
Table 4. Physical characteristics and locations of streams sampled in Oregon Caves, 2012.....	13
Table 5. Physical condition metrics for Oregon Caves streams sampled in 2012.	13
Table 6. Water chemistry parameters for streams sampled in Oregon Caves, 2012.....	15
Table 7. Riparian characteristics of Oregon Caves streams sampled in 2012.....	17
Table 8. The vertebrate species collected in Oregon Caves streams sampled in 2012 and the associated value for the EPA Vertebrate MMI.	17
Table 9. Macroinvertebrate indicators for Oregon Caves streams, 2012.....	18
Table 10. Site list for streams to be sampled in Redwood National and State Parks, 2012.....	20

Tables (continued)

	Page
Table 11. Physical characteristic and location of streams sampled in Redwood National and State Parks, 2012.	22
Table 12. Physical condition metrics for Redwood Parks streams sampled in 2012.	23
Table 13. Water chemistry parameters for streams sampled in Redwood Parks, 2012.	25
Table 14. Riparian characteristics of Redwood Parks streams sampled in 2012.	27
Table 15. Vertebrate species and metrics for Redwood Parks streams sampled in 2012.	28
Table 16. Macroinvertebrate metrics for Redwood Parks streams, 2012.	30
Table 17. Original site list for streams to be sampled in Crater Lake.	33
Table 18. Physical characteristics and location of streams sampled in Crater Lake, 2012.	35
Table 19. Physical condition metrics for Crater Lake streams sampled in 2012.	36
Table 20. Water chemistry parameters for streams sampled in Crater Lake, 2012.	38
Table 21. Riparian characteristics of Crater Lake streams, 2012.	41
Table 22. Vertebrate species and metrics for Crater Lake streams, 2012.	42
Table 23. Macroinvertebrate metrics for Crater Lake streams, 2012.	43
Table 24. Condition summary for Oregon Caves streams, 2012.	45
Table 25. Condition summary for Redwood Parks streams, 2012 (ordered by Site Code).	49
Table 26. Condition summary for Crater Lake streams, 2012 (ordered by Site Code).	51

Appendices

	Page
Appendix A. Example of MMI Calculation and Scoring	59
Appendix B. Benthic Macroinvertebrates of Oregon Caves National Monument and Preserve.....	61
Appendix C. Benthic Macroinvertebrates of Redwood National and State Parks.....	67
Appendix D. Benthic Macroinvertebrates of Crater Lake National Park	77

Executive Summary

The Inventory and Monitoring Program of the National Park Service sampled the status of stream ecological condition in three park units: Oregon Caves National Monument and Preserve, Redwood National and State Parks, and Crater Lake National Park. Sampling in these three park units occurs every three years (2012, 2015, 2018, etc.), and methods are largely based on standardized techniques utilized by the US Environmental Protection Agency (EPA) and adapted by the Klamath Inventory and Monitoring Network. The methods and variables measured encompass a range of physical, chemical, and biological parameters.

A key goal of the protocol (Dinger et al. 2013) was documenting the status of ecological condition, defined by the EPA as “the state of the physical, chemical and biological characteristics, and the processes and interactions that connect them.” Ecological condition was assessed using

- Four indicators of physical habitat
 - In-stream Habitat Cover—a measure of stream habitat complexity
 - Riparian Cover—a measure of streamside plant communities
 - Relative Bed Stability—a measure of sediment surplus/deficit
 - Riparian Disturbance—a measure of human streamside impact
- Four indicators of water quality
 - Total Phosphorus—measure of nutrient enrichment
 - Total Nitrogen—measure of nutrient enrichment
 - salinity—(measured as Conductivity) indicative of irrigation or water withdrawal
 - Acid Neutralizing Capacity—measure of sensitivity to acid rain
- Three indicators of biological condition for vertebrate (fish and amphibians) and benthic macroinvertebrate (e.g., insects, mites, and mollusks) communities
 - Aquatic Vertebrate Multi-Metric Index(MMI)
 - West-wide Macroinvertebrate MMI
 - A regional macroinvertebrate index

These indicators were then used either singularly or integrated together to assign sites to the condition categories of Least Disturbed, Intermediate, or Most Disturbed.

Oregon Caves National Monument and Preserve

A total of three sites were sampled and assessed for ecological condition at Oregon Caves from 13 June to 15 June, 2012. Due to the limited area of the park, sites were subjectively selected by park staff (including two sites in the proposed preserve expansion area), and are not intended for park-wide inference.

Physical habitat indicators. All of the streams were classified as Least Disturbed for In-stream Habitat Cover and Riparian Disturbance. All three stream sites were classified as Intermediate or Most Disturbed for Riparian Cover and Relative Bed Stability; however, these are likely due to the type of vegetation (heavy fern cover) in the riparian zone (for Riparian Cover) and geology of the park (for Relative Bed Stability) rather than truly impaired conditions.

Water quality indicators. All streams were assigned to the Least Disturbed category for all parameters except Total Phosphorus, for which two sample sites were assigned to the Intermediate category—although this assessment was also likely due to the geology of the watershed.

Biological condition indicators. The biological conditions for Oregon Caves were assessed using the Aquatic Vertebrate MMI, the West-wide Macroinvertebrate MMI and the Western Oregon MMI. Only one site was sampled for vertebrates because of permitting delays from the US Forest Service (the land is now part of the monument, but was US Forest Service land at the time of the sampling), so the assessment of the Aquatic Vertebrate MMI is incomplete. However, this site (Cave Creek) was classified as Least Disturbed using the Aquatic Vertebrate MMI. The one site sampled was composed of Tailed Frogs and Pacific Giant Salamanders. All three sites were sampled for benthic macroinvertebrates and both the West-wide MMI and Western Oregon MMI classified them as Least Disturbed. A total of 1,891 benthic macroinvertebrates were collected, comprising 110 separate taxa.

Redwood National and State Parks

A total of 23 sites were sampled and assessed for ecological condition at the Redwood Parks from 20 June to 2 August, 2012.

Physical habitat indicators. Several streams were classified in the Intermediate category. Riparian Cover in 14 sites was classified as Intermediate; however, this is a characteristic of the dense fern understory and not impairment. Relative Bed Stability was mixed, with eight sites in the Intermediate category; however, these classifications were due to larger than expected substrate sizes, and so are not an indicator of a sedimentation problem. One site, McArthur Creek, was classified as Most Disturbed for excess fine sediments, while another site on Redwood Creek was Most Disturbed for excess large substrates. Riparian Disturbance was classified as Least Disturbed for all sites.

Water quality indicators. All stream sites were assigned to Least Disturbed, with the exception of some of the nutrients. There were six sites Intermediate for Total Phosphorous, but not strongly so. There were three sites for Total Nitrogen that were Most Disturbed and were substantially higher than background levels. These three sites should be investigated further for potential anthropogenic sources of the nitrogen.

Biological condition indicators. The biological conditions for the Redwood Parks were assessed using the Aquatic Vertebrate MMI, the West-wide Macroinvertebrate MMI, and the California Northern Coastal Region MMI. Biota-based condition estimates showed excellent conditions. All sites were classified as Least Disturbed based on the Aquatic Vertebrate MMI and represented diverse vertebrate assemblages. Condition using benthic macroinvertebrate metrics showed most sites in the Least Disturbed category, with only three sites classified as Intermediate with the EPA

West-wide Macroinvertebrate MMI metric, and two sites classified as “Fair” according to the California Northern Coastal Region MMI. A total of 15,611 individuals were collected, comprising 285 separate taxa.

Crater Lake National Park

A total of 23 sites were sampled and assessed for ecological condition at Crater Lake from 7 August to 18 September 2012.

Physical habitat indicators. Several streams were in the Intermediate or Most Disturbed category. Particularly, the Riparian Cover indicator had 13 sites in the Intermediate category; however, this is a character of subalpine meadows and is not considered impairment. Relative Bed Stability was strongly negative for almost all sites, suggesting that Crater Lake has a preponderance of sedimentation. However, this is likely due to the volcanic pumice and the available substrate size (and not impairment). Riparian Disturbance was classified as Least Disturbed for all sites, except for two sites that were Most Disturbed (both near park infrastructure [campground and facilities]) and one site that was Intermediate.

Water quality indicators. Almost all stream sites were assigned to Least Disturbed, with the exception of some of the nutrients. Notably, all sites but one were flagged for Total Phosphorous. This is also likely due to the igneous, volcanic rock of the park and not impairment.

Biological condition indicators. Biota-based condition estimates showed mixed conditions. Using vertebrates, all sites were classified as Intermediate except one site with native Bull Trout (Sun Creek). The sites were Intermediate due to the presence of nonnative Brook Trout. Condition using benthic macroinvertebrate metrics showed some sites in the Least Disturbed category, with eight sites being Intermediate according to the EPA West-wide Macroinvertebrate MMI, and 11 sites being “Fair” according to the Western Oregon MMI. Despite these rankings, values for the Hilsenhoff Biotic Index, a measure of the how tolerant the community is (low-tolerance indicating a pristine assemblage; high-tolerance indicating a disturbed assemblage) were uniformly low, suggesting that the streams are relatively unimpacted. The discrepancy is caused by the naturally low diversity of the macroinvertebrate assemblage—probably a result of high elevation, the young geologic age of the area, and the impact of heavy snow cover. A total of 15,691 individuals were collected, comprising 165 separate taxa.

Conclusion

This was the second year of monitoring streams in the Klamath Network. Overall stream conditions in the three park service units that were surveyed appear to be in the Least Disturbed category, with specific concerns identified. No indications of large scale water quality criteria exceedances were observed. Criteria set forth by the EPA Wadeable Streams Assessment provide some guidance and assessment for stream condition, but may need regional calibration owing to natural, localized reference conditions. Sampling will continue at these parks in 2015, with annual reports and more comprehensive Analysis and Synthesis reports completed thereafter.

Acknowledgments

This project was supported by many thoughtful discussions with park staff in the development of the streams monitoring protocol, including discussions about reporting strategies. For this field season, we especially acknowledge the diligence of the streams field crew: Christa Torrens (Field Crew Leader), Joshua Jiannino, Virginia Jimenez, and Kelly Lawrence. Park specialists and resource staff were also invaluable in implementing the monitoring. At Oregon Caves National Monument and Preserve, special thanks go to John Roth and Emily Ring. At Redwood National and State Parks, special thanks to David Anderson, Terry Hines, and Vicki Ozaki. At Crater Lake National Park, special thanks to David Hering and Mark Buktenica. Thanks to Ashley Rawhauser of North Coast Cascades Network and Vicki Ozaki for helpful reviews of the report.

Introduction

The Klamath Network (KLMN) vital signs selection process identified two freshwater vital signs for monitoring: Aquatic Communities and Water Quality (Sarr et al. 2007). Prioritization of these vital signs was driven by potential natural and anthropogenic impacts to freshwater habitats and resources.

During the initial process of selecting Aquatic Communities and Water Quality as vital signs, National Park Service (NPS) staff did not differentiate between lentic (lake and pond) and lotic (stream) habitats. However, fundamental differences in ecosystem structure and process between streams and lakes dictated a basic division in sampling methodology and the development of separate protocols for each of these habitats. This report is intended to cover lotic habitats; lentic sampling is covered in a separate protocol (Dinger et al. 2012).

Because streams are integrated ecosystems central to park landscapes, we chose to monitor a combination of physical, biological, and chemical parameters together. These parameters allow measurement of change on multiple scales in time and space. For instance, macroinvertebrate assemblages respond rapidly to impacts, whereas fish and amphibians (with longer life cycles) will demonstrate longer duration, time-integrated responses. Changes in geomorphic and riparian vegetation features will likely manifest at yet longer time scales. The use of multiple indicators for measuring ecosystem change provides an integrated and robust system for interpreting natural dynamics, and for detecting trends in key ecological features and diverse impacts over time.

Sampling was undertaken to determine the status of stream ecological conditions in three network parks: Oregon Caves National Monument and Preserve (hereafter “Oregon Caves”), Redwood National and State Parks (hereafter “Redwood Parks”), and Crater Lake National Park (hereafter “Crater Lake”). To meet this goal, two definitions are important:

- “Ecological condition”—From the Environmental Protection Agency (EPA) Report on the Environment, “ecological condition” is defined as “the state of the physical, chemical and biological characteristics of the environment, and the processes and interactions that connect them” (USEPA 2008).
- “Status”—“defined as some statistic (e.g., a mean/median/proportion) of a parameter over all monitoring sites within a single or well-bounded window of time. Status will always have some measure of statistical precision (e.g., a confidence interval, standard error, variance)” (Sarr et al. 2007).

For determining the common conceptual use of ecological condition and status we use condition thresholds of 11 indicators used by the EPA. These thresholds are used to categorize sites into condition classes: “Least Disturbed, Intermediate, and Most Disturbed.” Other reports by the EPA use “Good, Fair, and Poor” for the same classes and indicators. These classes, based on West-wide and mountainous reference conditions, are meant to be guides and not absolutes in defining park condition. Final assessment may require follow-up investigations or consultation with park specialists.

Methods

The methods used for monitoring KLMN streams were adapted from the EPA Environmental Monitoring and Assessment Program—now the National Rivers and Streams Assessment program (USEPA 2009)—with modifications to fit KLMN time, logistics, and budgetary constraints. The methods described below are abbreviated descriptions of the methods used in data and sample collection. Full descriptions of methodology are contained in the protocol for Integrated Aquatic Community and Water Quality Monitoring of Wadeable Streams in the Klamath Network (Dinger et al. 2013). Additionally, methods are provided for some field sampling that is not analyzed or reported herein—they are included here for providing an overview of the portfolio of data that will be available in future Analysis and Synthesis reports (Dinger et al. 2013), or upon request.

Implementation Schedule

The KLMN aquatics sampling plan calls for the wadeable streams protocol to be implemented every two years out of three, with the alternate year being mountain lakes and pond sampling. The first year of wadeable streams sampling was 2011, and streams were sampled in Whiskeytown National Recreation Area and Lassen Volcanic National Park (Dinger and Sarr 2014). The second year (2012), the subject of this report, was the sampling of Oregon Caves, Redwood Parks, and Crater Lake; this was the first year of sampling in these parks. Per the three year rotation, these parks will be revisited in 2015.

Site Selection

A total of 49 sites were sampled in 2012, with three sites in Oregon Caves, and 23 sites each sampled in Redwood Parks and Crater Lake. Sample sites were located probabilistically using Generalized Random Tessellation Stratified (GRTS) spatially balanced design (Stevens and Olson 2004) in the *spsurvey* package (Kincaid 2012) for R statistical software (version 2.11.1; R Core Development Team, Vienna, Austria). The sampling frame included all perennial streams within a park unit that (1) were <1000 m from an established road or trail, and (2) had a streambed gradient less than 15% based on data that were obtained from the USGS National Hydrography Dataset (www.nhd.usgs.gov). The final selection or rejection of sample sites was determined by the field crew leader on site, who also considered access and safety issues. Oregon Caves, due to the limited areal extent, had sites selected by park staff. However, the park staff picked two of the three sites to be in the proposed expansion area and not inside the 2012 park boundaries.

Site Layout

At each selected sample site, a sample reach 40 times longer than the typical wetted width of the stream was established and 11 equally spaced transects perpendicular to stream flow were marked with temporary flagging (Figure 1). A minimum reach length of 150 m and a maximum reach length of 500 m were imposed.

Water Chemistry and Quality

Measurements of temperature (°C), pH, specific conductivity ($\mu\text{S cm}^{-1}$), dissolved oxygen (mg L^{-1}), and turbidity (NTU) were made at mid-depth in seven locations along a cross-section that extended perpendicular to stream flow in a well-mixed riffle using an Eureka Environmental “Manta” water

quality probe. Specific conductivity was used to ensure that the riffle was well mixed by assessing the seven cross-section measurements for variability. If the specific conductivity varied more than a $5 \mu\text{S cm}^{-1}$ differential across the stream, the measurement was repeated in an upstream riffle until a well-mixed riffle was confirmed.

When a well-mixed riffle was confirmed, a 2 L amber high-density poly-ethylene (HDPE) sample bottle was submerged to collect a water sample. On shore, using a 60 ml syringe and filter holder, a portion of each water sample was filtered through a $0.45 \mu\text{m}$ nylon membrane filter into an amber, acid washed 250 ml HDPE bottle for cation (Ca^{2+} , Na^+ , K^+ , and Mg^{2+}) and anion (SO_4^{2-} and Cl^-)

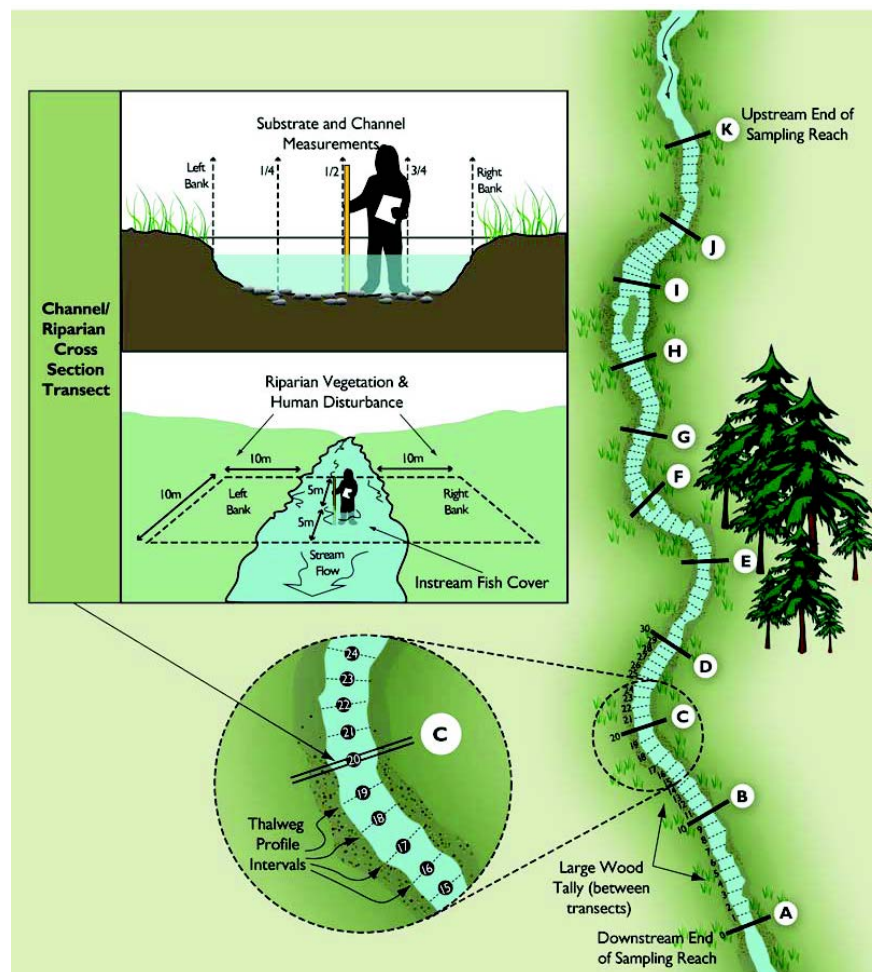


Figure 1. Schematic of sampling site reach layout (from EPA Wadeable Streams Assessment, 2006, Figure 11).

analyses. An additional unfiltered 250 ml of water was decanted into an identical bottle for nutrient analyses (Total Nitrogen, Total Phosphorous). Both bottles were kept cool until we were able to freeze them (generally <4 hours). Additionally, 120 mL of water were filtered through precombusted glass fiber filters into an acid-washed, precombusted glass vial for Dissolved Organic Carbon (also kept cool and later refrigerated). These samples were then shipped to the Cooperative Chemical

Analytical Laboratory at Oregon State University, Corvallis. See Dinger et al. (2013) for details on detection limits and analytical techniques for each parameter.

Stream Habitat/Riparian Corridor Characteristics

For the length of the reach, we assessed the following geomorphic characteristics: channel constraint type and percent constrained, channel pattern (braided, anastomosing, single), and evidence of recent torrents.

At each of the 11 transects, we measured cross-sectional information including wetted width, bank angles, undercut banks, presence and height of incised banks, and bankfull width and height. Across the transect (left bank, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and right bank), we measured depth, substrate embeddedness, substrate size, and algal periphyton thickness (as in Fetscher et al. 2010).

On each bank and in the middle of the stream at each transect, we collected measures of overhead shading with a convex, spherical densiometer. Areal categorization of fish habitat cover 5 m above and 5 m below the transect in the following classes were estimated: artificial substrate, boulders, filamentous algae, large wood, macrophytes, overhanging banks, roots, small wood, and undercut banks. In a 10 × 10 m quadrat next to the transect, we also estimated measures of riparian structure (dominant vegetation type; cover classes [sparse, moderate, heavy, very heavy] of small trees and large trees, herbs, grasses, etc.) in the ground layer (<0.5 m), understory (0.5 to 5.0 m), and overhead canopy (>5 m). In this same quadrat, we quantified the presence of human influences (e.g., walls, dikes, inlet/outlet pipes, camping, etc.).

We also measured thalweg depths along a longitudinal profile that extended throughout the length of the reach, taking equally spaced measurements of max depth, presence of soft or small sediments, and channel form type (pool, glide, riffle, rapid, etc.). At the midpoint between transects, we repeat the cross-section measurements (as above) of substrate type and algal thickness.

Inter-transect measures of downed woody debris were also made for the length of the reach. Woody debris was tallied for categories of length and diameter, both within the bankfull stream channel and in adjacent areas above bankfull height.

Stream gradient is measured between transects using a stadia rod and handheld level. An observer with the hand level stands at the approximate halfway point, and a stadia rod is placed at the transects; the difference between upstream and downstream is recorded for the rise. In this way, the total slope and variation in stream gradient can be measured.

The height and broad taxonomic grouping (Alder/Birch, Willow, Maple, Oak, Pine, Spruce, etc.) of the dominant tree located at each cross-sectional transect were also measured and recorded.

Aquatic Communities

Benthic macroinvertebrates were collected using the EPA reach-wide benthos technique (USEPA 2009). At each transect, a 1 ft. wide D-frame net (500 μ m pore size) was used; in fast water habitats, the upstream substrate in a 1 ft.² area was disturbed so that organisms flowed into the net for collection. In slack water habitats, an active sweep was used in a 1 ft.² area to collect the organisms.

The 11 collections were composited and elutriated (i.e., the lighter debris/macrobenthos are separated from the heavier inorganic substrates). The sample was then preserved in 90% ethanol and sent to a contract taxonomy lab for enumeration and identification. (For this sampling year, the samples were sent to Rhithron Associates, Inc.).

Aquatic vertebrates were sampled with a Smith-Root LR-24 electrofisher, using single pass. The time spent on a particular reach varies, but total targeted shock time was between 900 and 1,200 seconds. Fish and amphibians netted were stored in a bucket with a battery powered aerator. Specimens were recorded to species, enumerated, and the total lengths of the longest and smallest specimen were recorded. For salmonid species, the number in each size class was also recorded (<60 mm, 60–90 mm, 90–120 mm, 120–150 mm, and >150 mm).

Algal biomass was collected by taking a sample from each transect, following the reach-wide benthic technique. Collection technique varied based on dominant substrate at each transect: (1) if cobble, then a 12.6 cm² area was scrubbed using a stiff brush and a rubber delimiter to mark the area, (2) if gravel/sand, then a 12.6 cm² core was used to collect the substrate, and (3) if bedrock, then a 5.3 cm² sample was taken with a disposable scrubber in situ. Samples from each transect were processed, and composited into a single container. An aliquot was then taken for Ash Free Dry Mass and filtered onto a glass-fiber filter. A second aliquot was filtered on nylon membrane filters for chlorophyll *a* analysis. Filters were then kept on ice and frozen as soon as possible (along with water samples). Chlorophyll processing (extraction and measurement of concentration with fluorometer) was completed at a contract laboratory; in this sample year we worked with Cascade Research (John Salinas of Grants Pass, Oregon).

Calculating Indicators of Ecological Condition

Following the EPA established “indicators of aquatic stress” in its Wadeable Streams Assessment (USEPA 2006) and the EPA EMAP Ecological Assessment of Western Streams and Rivers (Stoddard, Peck, Paulsen et al. 2005), we use 10 indicators of condition. These indicators cover three broad categories of assessment: 1) biological, 2) chemical, and 3) physical habitat conditions of a stream. For each indicator, the EPA uses thresholds for determining three condition classes: “Least Disturbed,” “Intermediate,” and “Most Disturbed.” Additionally, a regional macroinvertebrate Multi-Metric Index using state of California thresholds was used in assessing condition. Each indicator and its calculation are described briefly below (text adapted from Stoddard, Peck, Paulsen et al. 2005).

Total Phosphorous

Phosphorous is a nutrient, and is usually considered to be the most likely nutrient limiting algal growth in freshwaters throughout the United States. It is a common ingredient in fertilizers, and high concentrations may be associated with agricultural and urban land use. In the KLMN, this sample is taken at a single, well-mixed riffle near the midpoint of the stream reach, and an unfiltered portion is frozen and sent to an analytical laboratory for analysis.

Total Nitrogen

Nitrogen is another nutrient, and is particularly important as a contributor to coastal and estuarine algal blooms. Sources include fertilizers, wastewater, animal wastes, and atmospheric deposition. In

the KLMN, this sample is taken at a single, well-mixed riffle near the midpoint of the stream reach, and an unfiltered portion is frozen and sent to an analytical laboratory.

Salinity

Excessive salinity occurs in areas with high evaporative losses of water, and can be exacerbated by repeated use of water for irrigation, or by water withdrawals (by slowing transit time of flowing waters). Both electrical conductivity and total dissolved solids (TDS) can be used as measures of salinity; for KLMN monitoring we follow NPS Water Resources Division (WRD) guidance and measure specific conductivity.

Acid Neutralizing Capacity

From the Wadeable Streams Assessment (USEPA 2006), streams and rivers can become acidic through the effect of acid deposition (e.g., acid rain) or acid mine drainage, particularly from coal mining. In assessing acid pollution (either acid rain or mine drainage), the KLMN relies on a measure of water's ability to buffer inputs of acid (Acid Neutralizing Capacity; ANC). When ANC falls below zero, the water is considered acidic and can be directly or indirectly toxic to biota (i.e., by mobilizing toxic metals, such as aluminum). When ANC is between 0 and 25 $\mu\text{eq/L}$ (0 and 1.25 mg/L CaCO_3), a stream is considered sensitive to episodic acidification.

Streambed Stability (aka Relative Bed Stability)

Streams and rivers adjust their channel shape and streambed particle size in response to the supply of water and sediments from their drainage areas. One measure of this interplay between sediment supply and transport is relative bed stability (RBS). The measure of RBS used here is a ratio comparing the particle size of observed sediments to the size of sediment each stream can move or scour during flood stage, based on the size, slope and other physical characteristics of the stream channel. The RBS ratio differs naturally among regions, depending upon landscape characteristics that include geology, topography, hydrology, natural vegetation, and natural disturbance history. Values of the RBS can be substantially lower (prevalence of fine sediments) or higher (coarser, more stable streambeds) than those expected based on the range of the least disturbed sites—both high (stressor-altered flow) and low (stressor-increased sedimentation) values are considered to be indicative of impairment (Figure 2). Currently we utilize an RBS value based purely on stream gradient and average stream depth (Kaufmann et al. 1999). A more refined RBS, incorporating residual pool depth, woody debris, and bankfull characteristics will be used in later reports when reporting and analysis tools are available from the EPA.



Figure 2. Numeric range and thresholds for RBS condition assessment. Red line = Most Disturbed, yellow line = Intermediate, and green line = Least Disturbed. Higher values suggest stable streambeds

with altered flow regimes (e.g., upstream dams) and lower values suggest increased sediments from human landscape use. See text for more details.

In-stream Habitat Cover

This metric is termed “habitat complexity” in Stoddard, Peck, Paulsen et al. (2005), but is synonymous with In-stream Fish Habitat in USEPA (2006), and Fish Cover in Kaufmann et al. (1999). We follow the terminology of Stoddard, Peck, Paulsen et al (2005).

The most diverse fish and macroinvertebrate assemblages are found in streams and rivers that have complex forms of habitat: large wood, boulders, undercut banks, tree roots, etc. Human use of streams and riparian areas often results in the simplification of this habitat, with potential effects on biotic integrity. We use a measure that sums the amount of in-stream habitat consisting of undercut banks, boulders, large pieces of wood, and cover from overhanging vegetation within a meter of the water surface. It is a scalar metric for which the highest values represent the highest habitat complexity. Because multiple categories of areal coverage are summed, values can exceed 100% (or 1.0 on a decimal scale).

Riparian Cover

The presence of a complex, multilayered vegetation corridor along streams and rivers is an indication of how well the stream network is buffered against sources of stress in the watershed. Intact riparian areas can help reduce nutrient and sediment runoff from the surrounding landscape, prevent bank erosion, provide shade to reduce water temperature, and provide leaf litter and large wood that serve as food and habitat for stream organisms. The presence of canopy trees in the riparian corridor indicates longevity; the presence of smaller woody vegetation typically indicates that riparian vegetation is reproducing, and suggests the potential for future sustainability of the riparian corridor. As in Stoddard, Peck, Paulsen et al. (2005), we use a measure of riparian complexity that sums the amount of woody cover provided by three layers of riparian vegetation: ground layer, woody shrubs (understory layer), and the overhead canopy. Because multiple categories of areal coverage are summed, values can exceed 100% (or 1.0 on a decimal scale).

Riparian Disturbance

The vulnerability of the stream network to potentially detrimental human activities increases with the proximity of those activities to the streams themselves. For this assessment, we use a direct measure of riparian human disturbance that tallies 11 specific forms of human activities and disturbances (e.g., roads/trails, landfills, piping, building, farming, etc.), and weights them according to how close to the stream channel they are observed. The index generally varies from 0 (no observed disturbance) to 6 (multiple types observed in the stream, throughout the reach).

Biological Indicators

Ecological condition can be assessed using biological assemblages because of the inherent capacity of organisms to integrate chemical and physical stressors that affect them over varying spatial and temporal time scales (Rosenberg and Resh 1993, Karr and Chu 1999, Brousseau and Randall 2008). We use three MMIs to assess each stream: 1) Aquatic Vertebrates index; 2) West-wide Macroinvertebrates index, and 3) a regional or state-based Macroinvertebrate index. Multi-Metric

Indices use a sum of scores for a variety of individual measures that make up the key characteristics of biotic integrity (e.g., taxonomic richness, habitat/trophic composition, sensitivity to human disturbance, etc.). Examples of how the metrics were calculated are presented in Appendix A.

Aquatic Vertebrate MMI

Aquatic vertebrates were assessed using the Aquatic Vertebrate Multimetric Index (MMI) that included measures chosen to represent selected key characteristics of biological integrity: taxonomic richness, taxonomic composition, habitat use, reproductive strategies, pollution tolerance, feeding groups, and the presence of nonnative species. The resulting MMI combines all the measures into an index for which values range from 0 to 100, with 100 denoting the best possible condition. The development process is given in more detail in the EMAP West statistical summary (Stoddard, Peck, Olsen et al. 2005).

West-Wide Macroinvertebrate MMI

Characteristics used for the West-Wide Macroinvertebrate MMI were: taxonomic richness, taxonomic compositions, taxonomic diversity, feeding groups, habits, and pollution tolerance. Like the Vertebrate MMI, the scores in each category are summed, and scaled to a 0 to 100 range, with 100 denoting the best possible condition.

Regional or State Macroinvertebrate Indices

We utilized two regionally relevant MMIs developed by state or academic researchers in different part of the Klamath Region: 1) the California Surface Water Ambient Monitoring Program (SWAMP) developed an MMI for the North Coast Region, including the coastal area of the Redwoods Parks (Rehn et al. 2005); and 2) the Oregon Watershed Enhancement Board (1999) developed the Western Oregon MMI, which covers both Oregon Caves and Crater Lake. Both of these are briefly described below.

California Northern Coastal Region MMI

This MMI was developed for three northern California Omernik Level III ecoregions (Omernik 1987): coast range, Klamath Mountains, and the southern and central California chaparral and oak woodlands. The components used were total richness of mayflies, stoneflies, and caddisflies; beetle richness; true fly richness, tolerant individuals, nonsnail scraping individuals, predatory individuals, and shredding functional feeding group taxa; and the number of noninsect taxa. It is scored from 0 to 100 (100 denoting the best possible condition), and condition assessed on categories of Very Poor, Poor, Fair, Good, and Very Good.

Western Oregon MMI

This MMI was developed by the state of Oregon Watershed Enhancement Board as part of the Oregon Plan for Salmon and Watershed (Oregon Watershed Enhancement Board 1999), and is regionally relevant to the streams of Crater Lake and Oregon Caves. The components used were taxa richness, mayfly richness, stonefly richness, caddisfly richness, sensitive taxa, sediment sensitive taxa, modified HBI (modified for Oregon specific taxa), % tolerant taxa, % sediment tolerant taxa, and % of the single most dominant taxa. It is scored on a scale of 10–50 (50 denoting the best possible score), and assessed in the categories of 1) >39 “no impairment,” 2) 30–39 “slight

impairment,” 3) 20–29 “moderate impairment,” and 4) <20 “severe impairment.” However, to facilitate comparisons of this MMI to the others, we have scaled the original scores from 20 to 100, with 100 denoting the best possible condition.

Establishing Thresholds of Ecological Condition

The EPA derived three categories (Least Disturbed, Intermediate and Most Disturbed) that can be used to describe the status of the ecological condition of a stream. These thresholds were established using data collected across the western United States and we applied these thresholds to determine the status of the streams sampled for this project (Table 1).

Table 1. Threshold for condition rating used in the Klamath Network. See text for further description and source of threshold values.

Category	Most Disturbed	Intermediate	Least Disturbed
Biological			
EPA Invert West-wide MMI	<57	57 to 70	≥71
EPA Vertebrate MMI	<37	37 to 61	≥62
Chemical			
Acid Neutralizing Capacity (µeq/L)	<0	Not Applicable	>0
Specific Conductance (µS/cm)	>1000	1000 to 501	≤500
Total Nitrogen (mg/L)	>0.2	0.2 to 0.126	≤0.125
Total phosphorous (mg/L)	>0.04	0.04 to .011	≤0.01
Physical			
In-stream Habitat Cover	<0.14	0.14 to 0.34	≥0.33
Relative Bed Stability	<-1.3 or >0.6	-1.3 to -0.71 and 0.6 to 0.11	≥-0.7 or ≤0.1
Riparian Cover	<0.23	0.23 to 0.66	≥0.67
Riparian Disturbance	>0.95	0.95 to 0.36	≤0.35
State Regional Macroinvertebrate Metrics			
Western Oregon MMI	“severe to moderate impairment” ≤60	Not Applicable	“slight to no impairment” ≥60
CA North Coast MMI	“fair to poor” ≤60	Not Applicable	“good to very good” ≥60

Additional Macroinvertebrate Measures

In addition to the metrics used for condition assessment, we report on two commonly used macroinvertebrate metrics (Shannon Index and Hilsenhoff Biotic Index). The Shannon Index (H') is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundance, incorporating both into a single number. It is calculated as: $H' =$

– $\sum p_i \ln p_i$ where p_i is the proportion of the i th species. Values generally range from 0 to 3. Higher values generally suggest a more balanced, diverse and cosmopolitan assemblage. The Hilsenhoff Biotic Index (HBI) is a weighted average of tolerance values derived from empirical observations of macroinvertebrate responses to pollution (Hilsenhoff 1987, 1988). It is calculated as $HBI = \frac{\sum n_i a_i}{N}$

where n_i = the number of individuals for taxa i , a_i = the assigned tolerance value of taxa i , and N = the total number of individuals for a sample. The HBI sums the overall tolerances of the taxa collected. This index is used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. Shifts in HBI from low values to high values suggest a community change towards a more pollutant tolerant community. The source of tolerance values we used was the list developed by the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT) (<http://www.safit.org/index.php>). Despite the name, the taxa lists are broadly applicable to the entire western United States.

Relationship of KLMN Indicators to Water Quality Standards

States implement water quality criteria with strict methodologies (for example, a 4 or 5 day average water temperature, so there is no applicability using KLMN methods). This protocol, focused on ecological and environmental status and trends, is not a perfect fit for many of these parameters because it only collects single measurements triennially. However, when there is some indication of an exceedance, it should be reported with the suggestion that the park follow up with site-specific measurements, if warranted. The thresholds used are based on NPS criteria established by the NPS Water Resource Division, the State of California drinking water criteria, and EPA criteria for drinking water, health advisory, and National Ambient Water Quality Criteria (Table 2). However, note that although these are promulgated thresholds, their applicability is not strict; we provide the drinking water criteria and health advisory criteria only for comparative purposes, because the streams sampled by the KLMN are not considered primary drinking water sources for people.

Table 2. Available water quality criteria used for possible exceedances, including drinking water (not applicable for natural waters, but provided for comparative reasons). See Dinger et al. 2013 for sources.

Parameter	NPS Criteria	Oregon Department of Environmental Quality	California Drinking Water	EPA Criteria		
				Drinking Water	Health Advisory	National Ambient Water Quality Criteria
Alkalinity (mg/l)	>10	>20				>20
Chloride (mg/l)			<250			<230 ¹ ; <860 ² - when associated only with Sodium
Dissolved Oxygen (mg/l)	>4	>8				>8.0 1-day minimum (water column)
Total Nitrogen (as NO ₂ + NO ₃) (mg/l)			<10	<10		
pH	>6.5	6.5–8.5		6.5 to 8.5		5 to 9 ³ , 6.5 to 9 ¹ (max)
Sodium (mg/l)					20	
Sulfate (mg/l)				500		250 ³
Turbidity (NTU)	<50	<10% above natural	<1	<1		

¹Freshwater aquatic life protection (4 day average)

²Max concentration (1 hour average)

³Taste and odor

Results

Oregon Caves National Monument and Preserve

Three sites were sampled in and around Oregon Caves between June 13 and June 15, 2012 (Figure 3). Due to the limited acreage of the monument, the sites were selected by monument staff (Chief of Resources, John Roth, and Physical Scientist Emily Ring). Due to a pending and anticipated expansion of the monument, two of the three sites were selected from neighboring US Forest Service lands (Table 3). The expansion has since been approved, and all sites are now located within the park boundary (Public Law 113-291; enacted on 12/19/2014). Since these sites were not selected using probabilistic methodology, they cannot be used for park-wide inferences of status (i.e., average condition). However, since streams integrate upstream impacts and disturbances, the sample sites can be used to assess water quality and the ecological condition for the watersheds that contain them.

The only problem or limitation in the sampling was due to the ownership at the time of the two sites on US Forest Service land (ORCAWQ02, Lake Creek; ORCAWQ03, No Name Creek). Permits for sampling fish and amphibians were not obtained in time (permission to sample was granted one week after conclusion of sampling in Oregon Caves).

Because the sample sites were selected by staff, the standard protocol (Dinger et al. 2013) sampling frame limits were not enforced, so that two of the sites (ORCAWQ01, Cave Creek; and ORCAWQ03, No Name Creek) had substantially higher gradients than other streams sampled under this protocol. The streams of Oregon Caves are small, high gradient, headwater streams characterized by large amounts of woody debris. Photos typifying the three stream reaches are presented in Figure 4.

Table 3. Site list for streams sampled in Oregon Caves National Monument and Preserve. * = as of sampling in 2012.

Stream Name	Site Code	Date Sampled	Notes*
Cave Creek	ORCAWQ01	6/13/2012	within park boundary
Lake Creek	ORCAWQ02	6/15/2012	outside of park boundary
No Name Creek	ORCAWQ03	6/14/2012	outside of park boundary

Physical Characteristics of Oregon Caves Streams

Summary statistics for the monitored streams are presented in Table 4. These are general geomorphological characteristics of the streams (e.g., location, elevation, slope, discharge) and are used to provide a context for the environmental setting; they are not intended to impart any information about the ecological condition of a sample site. All streams had low discharge, with Cave Creek being the highest, at only $0.034 \text{ m}^3 \text{ s}^{-1}$ ($1.20 \text{ ft}^3 \text{ s}^{-1}$) of flow.

Physical Condition Metrics of Oregon Caves Streams

The four EPA physical condition metrics along with substrate size and average embeddedness for Oregon Caves are presented in Table 5.

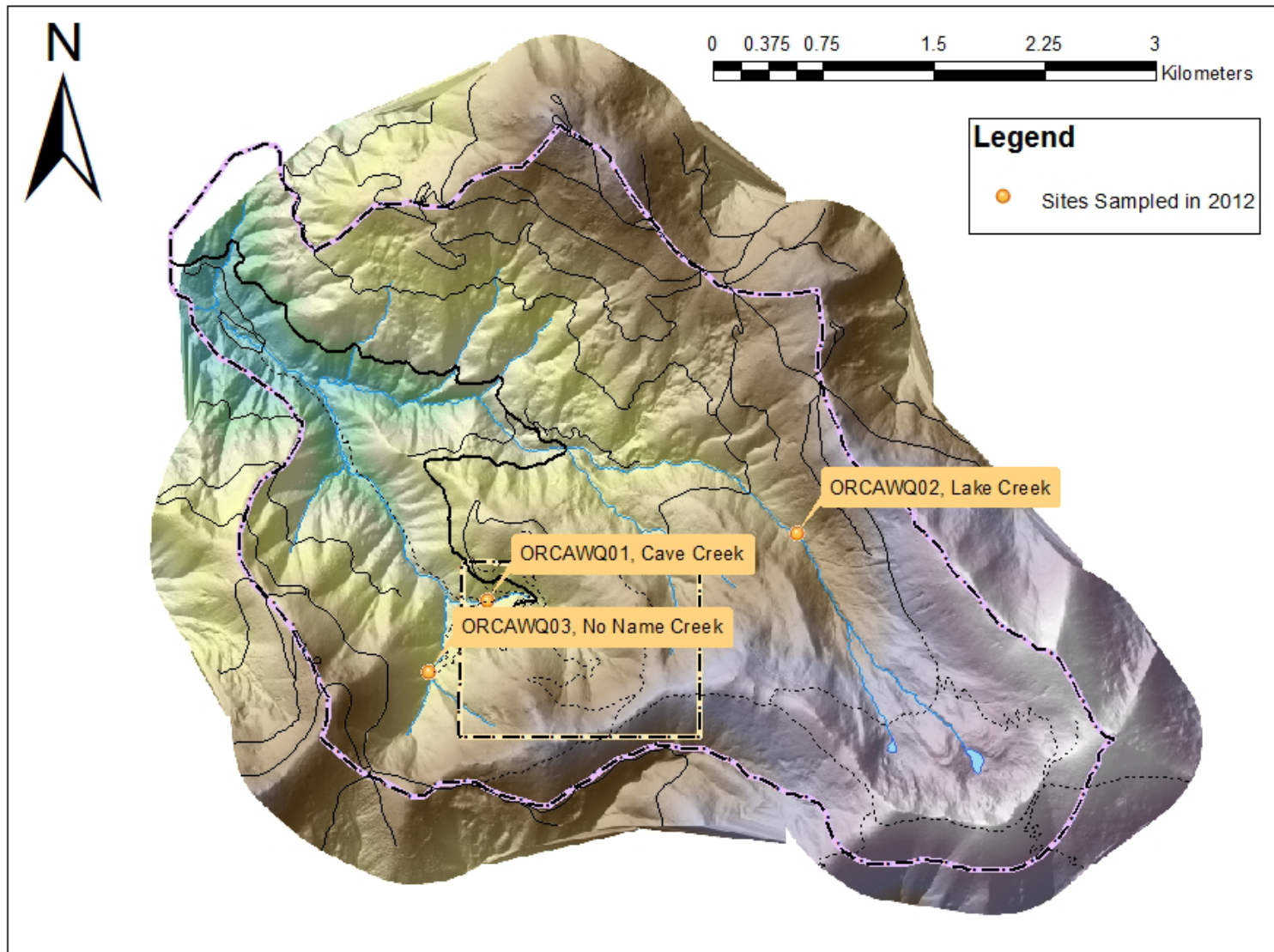


Figure 3. Sites sampled in Oregon Caves National Monument and Preserve, 2012.

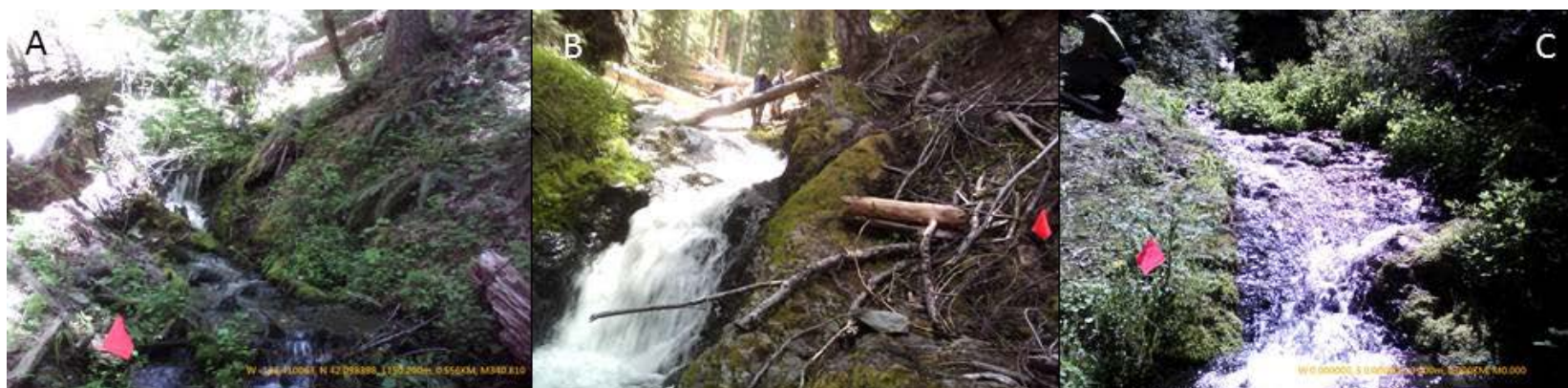


Figure 4. Photos of three sites sampled in Oregon Caves. A = Cave Creek (ORCAWQ01); B = Lake Creek (ORCAWQ02); and C = No Name Creek (ORCAWQ03).

Table 4. Physical characteristics and locations of streams sampled in Oregon Caves, 2012. Coordinates in NAD 1983 datum (Zone 10N).

Stream Name	Site Code	Date Sampled	Coordinates		Elevation (m)	Reach Length (m)	Average Width (m)	Average Depth (cm)	Slope	Instantaneous Discharge	
			X	Y						m ³ s ⁻¹	ft ³ s ⁻¹
Cave Creek	ORCAWQ01	6/13/2012	465881	4660767	1196	150	2.1	7.8	19.4%	0.034	1.2
Lake Creek	ORCAWQ02	6/15/2012	468082	4661233	1405	150	3.1	21.6	14.4%	0.013	0.4
No Name Creek	ORCAWQ03	6/14/2012	465633	4660204	1225	150	1.5	6.5	22.1%	0.025	0.9

Table 5. Physical condition metrics for Oregon Caves streams sampled in 2012. Cells marked in sage (lightest shading) are sites for Least Disturbed, amber (medium shading) are sites meeting EPA threshold criteria for Intermediate, whereas cells marked in red (darkest shading) are sites meeting EPA criteria for Most Disturbed.

Site Code	Date Sampled	Stream Substrate diameter (mm)		Average Embeddedness (%)	Pool (%)	Riffle (%)	Physical Habitat Condition Metrics			
		Average	Median				In-stream Habitat Cover	Riparian Cover	Relative Bed Stability	Riparian Disturbance
ORCAWQ01	6/13/2012	35.3	38.0	15.6	15%	64%	0.83	0.36	-0.87	0.27
ORCAWQ02	6/15/2012	1966.1	9549.9	1.1	19%	79%	0.87	0.23	0.81	0.00
ORCAWQ03	6/14/2012	716.9	9549.9	2.5	5%	91%	0.48	0.34	0.55	0.07

In-stream Habitat Cover, an indicator of habitat complexity (consisting of boulders, overhanging banks, and the like) was high in all Oregon Caves monitored streams. The Riparian Disturbance indicator was correspondingly low in all streams, with all meeting the EPA threshold of Least Disturbed, although the highest value was in Cave Creek (ORCAWQ01), a stream in close proximity to visitor use hiking trails.

Examination of Stream Substrate diameter and the Relative Bed Stability metric shows that one stream, Cave Creek (ORCAWQ01), had a smaller sediment size compared to the other two Oregon Caves streams. Cave Creek had a median substrate size of 38 mm, and a negative Relative Bed Stability, suggesting the dominance of smaller sized sediment, and hence an increased sediment input. Conversely, the other streams (Lake Creek, ORCAWQ02; No Name Creek, ORCAWQ03) had large median substrate sizes and positive values for Relative Bed Stability, suggesting low levels of sediment recruitment.

Chemical Characteristics and Condition Estimates of Oregon Caves Streams

Selected water chemistry results are presented in Table 6. Parameters measured in-situ with a water probe (see Methods) are listed under “Water Quality” and parameters measured in an analytical laboratory or with a stream-side assay (Acid Neutralizing Capacity) are presented as “Water Chemistry.”

Distinct differences between Lake Creek (ORCAWQ02) and the two other streams suggest edaphic factors vary between the water sources. For example, Lake Creek has lower pH, Specific Conductivity, cations/anions, and Acid Neutralizing Capacity than both Cave Creek and No Name Creek, suggesting that Lake Creek water is derived from rain water, whereas the other two have groundwater influences.

pH found at the three streams was circum-neutral (pH of 7 = neutral), with alkaline values at Cave Creek (ORCAWQ01) and No Name Creek (ORCAWQ03). Values did not exceed any water quality criteria (Table 2). **Acid Neutralizing Capacities** were all positive, indicating Least Disturbed.

Temperature is presented as a descriptor of conditions during sampling, but varies on a daily, monthly, and seasonal basis. As such, no status or condition should be inferred from temperature readings. **Specific Conductivity** was uniformly low, and well under the EPA threshold criteria for Least Disturbed at all sites (used as a surrogate for salinity by the EPA). **Dissolved Oxygen** values are all well above regulatory thresholds (Table 2).

Turbidity readings were low (Table 6). However, the Turbidity for Cave Creek (ORCAWQ01) and No Name Creek (ORCAWQ03) were elevated with respect to EPA drinking water criteria, and no sites were above the NPS criteria. The **anions and cations** with available thresholds for water quality were all far below promulgated values (Table 2). **Total Nitrogen** values were all well below EPA thresholds for Least Disturbed. **Total Phosphorous** values for two sites, Cave Creek (ORCAWQ01) and No Name Creek (ORCAWQ03) were in the elevated EPA threshold for Intermediate.

Table 6. Water chemistry parameters for streams sampled in Oregon Caves, 2012. Data collected with water probe are under “Water Quality,” whereas data from laboratory analyses are under “Water Chemistry.” Cells marked in sage (lightest shading) are sites for Least Disturbed, amber (medium shading) are sites meeting EPA threshold criteria for Intermediate, whereas cells marked in red (none in this table) are sites meeting EPA criteria for Most Disturbed.

Stream Name	Site Code	Water Quality					Water Chemistry						
		pH	Temp (°C)	Specific Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Sodium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Acid Neutralizing Capacity	
												(µeq/L)	(mg/L)
Cave Creek	ORCAWQ01	8.39	7.02	198.1	11.43	1.64	2.32	0.35	1.07	0.05	0.026	2440	122.0
Lake Creek	ORCAWQ02	7.48	7.05	27	10.05	0	1.24	0.13	0.34	0.10	0.006	271	13.6
No Name Creek	ORCAWQ03	8.35	7.17	186.4	10.27	4.08	2.61	0.56	0.87	0.02	0.013	1860	93.0

Riparian Characteristics of Oregon Caves Streams

All the streams of Oregon Caves were well shaded, with the lowest value at No Name Creek (ORCAWQ03) with 84% shading (Table 7). Canopy cover varied, with one site (Cave Creek; ORCAWQ01) being dominated by mixed (10% or more of multiple groups: deciduous, coniferous, broadleaf evergreen), and Lake Creek (ORCAWQ02) being dominated by conifer trees. Understory was also varied, with all sites having large amounts of conifer, deciduous and mixed species.

Vertebrate Assemblage and Condition of Oregon Caves Streams

We were only able to electrofish a single site (Cave Creek, ORCAWQ01) at Oregon Caves, since the Forest Service/State of Oregon were delayed in the permit approval. Within this one stream reach, we encountered four Pacific Giant Salamanders (*Dicamptodon tenebrosus*) and five Tailed Frog (*Ascaphus truei*) tadpoles (Table 8), both species on the existing park species list.

The condition assessment of Cave Creek, utilizing the EPA Vertebrate MMI, ranked the site as Least Disturbed.

Macroinvertebrate Assemblage and Condition of Oregon Caves Streams

A total of 1,891 macroinvertebrates were collected from all three sample reaches and 120 taxa were identified by taxonomists (a complete list of taxa from Oregon Caves samples is given in Appendix B.) Accounting for ambiguous taxa following Cuffney et al. (2007) and Dinger et al. (2013), the estimated richness for the sampled streams was 110 species and all of the sites were within the range of Least Disturbed conditions. Summary statistics (Taxa Richness and measures of biological condition) for each site are provided in Table 9.

All three sites were characterized by high diversity (Cave Creek, ORCAWQ01, was the highest at 73 taxa). Tolerance values were available for 122 out of 125 identified taxa, which include individuals only identified to higher taxonomic units due to poor keys, damaged specimens, or immature life stages. Taxa with no tolerance value were excluded from HBI calculations. The HBI for the three streams were well within the range for “excellent” water quality conditions (Hilsenhoff 1988).

Table 7. Riparian characteristics of Oregon Caves streams sampled in 2012. For composition: D = Deciduous, C = Coniferous, E = Broadleaf Evergreen, N = None, and M = Mixed, and * = Data unavailable.

Stream name	Site Code	Shading	Legacy Tree Height (m)	Canopy			Understory		
				Big Tree	Small Tree	Composition	Woody	Non-Woody	Composition
Cave Creek	ORCAWQ01	92%	34.3	12%	10%	36% M, 32% C, 23% D, 9% N	12%	0%	55% D, 18% M, 18% N, 9% C
Lake Creek	ORCAWQ02	91%	*	6%	0%	55% C, 45% N	15%	0%	55% C, 23% M, 14% D, 9% N
No Name Creek	ORCAWQ03	84%	21.7	3%	4%	68% N, 32% C	26%	0%	41% C, 36% M, 23% D

Table 8. The vertebrate species collected in Oregon Caves streams sampled in 2012 and the associated value for the EPA Vertebrate MMI. The sage shaded cell indicates Least Disturbed where EPA thresholds exist. * indicates no data—permits were not granted prior to sampling.

Stream Name	Site Code	Metrics			Amphibian	
		Total Abundance	Total Richness	EPA Vertebrate MMI	Pacific Giant Salamander (<i>Dicamptodon tenebrosus</i>)	Tailed Frog (<i>Ascaphus truei</i>)
Cave Creek	ORCAWQ01	9	2	79.7	4	5
Lake Creek	ORCAWQ02	*	*	*	*	*
No Name Creek	ORCAWQ03	*	*	*	*	*

Table 9. Macroinvertebrate indicators for Oregon Caves streams, 2012. All metrics scored the streams as Least Disturbed, indicated by sage-colored shaded cells.

Stream Name	Site Code	Total Taxa Richness	Shannon Diversity	Hilsenhoff Biotic Index	EPA West-Wide Macroinvertebrate MMI	Regional	
						CA North Coast IBI	Western Oregon IBI
Cave Creek	ORCAWQ01	73	3.52	2.98	84	83	96
Lake Creek	ORCAWQ02	72	3.24	3.01	86	89	92
No Name Creek	ORCAWQ03	64	3.11	2.58	79	74	96

Redwood National and State Parks

Sampling occurred in the Redwood Parks between June 20 and August 2, 2012, at which point the crew transitioned to Crater Lake National Park. Twenty-three stream reaches were sampled during this time; the original target was 25 to 30, but we were unable to sample several sites due to logistical constraints (too far from vehicles to safely sample within a day) (Figure 5, Table 10).

The first 22 sites (REDWWQ01 – REDWWQ22) were sites colocated with KLMN Vegetation Community Sampling (Odion et al. 2011), and selected under the KLMN Vegetation GRTS routine. The additional sites (REDWWQ23 – REDWWQ25) were selected under an additional GRTS routine to increase the sample size per the streams protocol (Dinger et al. 2013). The major challenge in data completeness was in dealing with precipitation and high humidity, which compromised electronic and other gear. Due to this, certain measurements were unable to be performed at select sites.

The streams of the Redwood Parks are densely shaded, heavily forested, low gradient streams. Stream order ranges from 1st order headwater streams with low seasonal discharge, to 5th order streams with inaccessible deep pools (Redwood Creek). Examples of stream reaches sampled are presented in Figure 6. Access to these streams was slow, owing to the heavy overgrowth, downed trees, and general hazardous conditions of off-trail travel in redwood country.

Physical Characteristics of Redwood Parks Streams

Summary statistics for the monitored streams are presented in Table 11. These are general geomorphological characteristics of the streams (e.g., location, elevation, slope, discharge) and do not impart any conditional information. The smallest stream sampled was an unnamed stream (REDWWQ10), a 1st order tributary to Prairie Creek, with both the smallest average width (1.7 m) and one of the lowest measured discharges ($0.01 \text{ m}^3 \text{ s}^{-1}$ [$0.2 \text{ ft}^3 \text{ s}^{-1}$]). The largest stream sampled was Redwood Creek (4 reaches – REDWWQ04, REDWWQ16, REDWWQ20, and REDWWQ25). This is a fifth order stream with average widths from 19.1 m to 28.8 m for the reaches sampled, and discharge up to $2.58 \text{ m}^3 \text{ s}^{-1}$ ($89.35 \text{ ft}^3 \text{ s}^{-1}$).

Physical Condition Metrics of Redwood Parks Streams

The four EPA physical condition metrics, along with substrate size and average embeddedness for Redwood Parks streams are presented in Table 12. A stream's median substrate size is a more useful

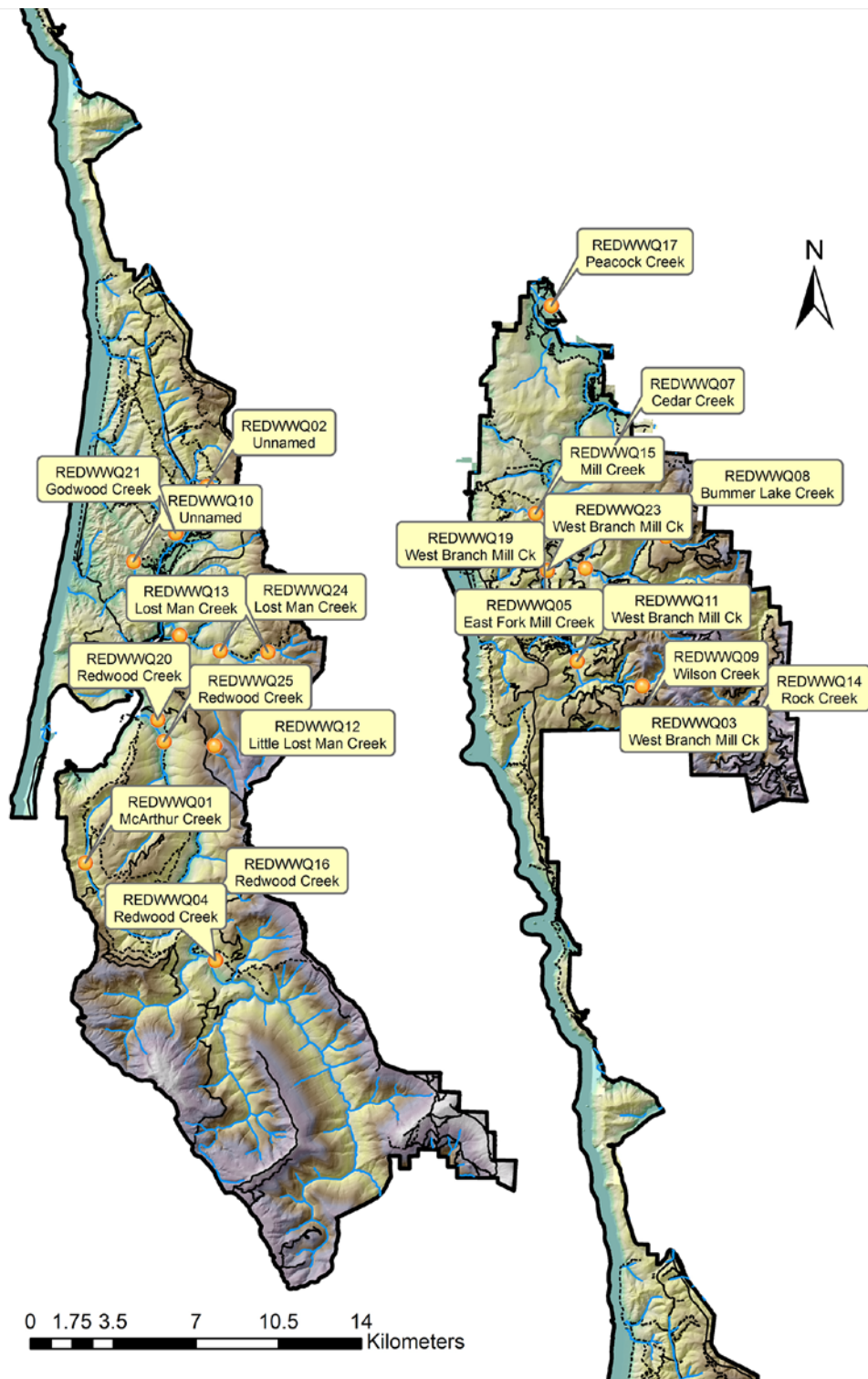


Figure 5. Stream sites sampled in Redwood National and State Parks, 2012. South portion of park on left, North portion on right.

Table 10. Site list for streams to be sampled in Redwood National and State Parks, 2012. Sites marked with * were not sampled due to distance from vehicles requiring more than 1.5 hours travel time—too far for safe sampling within a work day.

Stream Name	Site Code	Date Sampled	Reason for not sampling
McArthur Creek	REDWWQ01	6/26/2012	
Unnamed (Trib to Redwood Creek)	REDWWQ02	6/25/2012	
West Branch Mill Creek	REDWWQ03	7/12/2012	
Redwood Creek	REDWWQ04	7/10/2012	
East Fork Mill Creek	REDWWQ05	7/4/2012	
Lost Man Creek	REDWWQ06	6/21/2012	
Cedar Creek	REDWWQ07	7/16/2012	
Bummer Lake Creek	REDWWQ08	7/9/2012	
Wilson Creek	REDWWQ09	7/17/2012	
Unnamed (Streelow Creek Trail)	REDWWQ10	6/20/2012	
West Branch Mill Creek	REDWWQ11	7/3/2012	
Little Lost Man Creek	REDWWQ12	7/5/2012	
Lost Man Creek	REDWWQ13	7/6/2012	
Rock Creek	REDWWQ14	7/11/2012	
Mill Creek	REDWWQ15	7/18/2012	
Redwood Creek	REDWWQ16	7/26/2012	
Peacock Creek	REDWWQ17	7/24/2012	
Little Lost Man Creek	REDWWQ18	*	Too distant from vehicle
West Branch Mill Creek	REDWWQ19	7/25/2012	
Redwood Creek	REDWWQ20	7/27/2012	
Godwood Creek	REDWWQ21	6/22/2012	
Devils Creek	REDWWQ22	*	Too distant from vehicle
West Branch Mill Creek	REDWWQ23	7/31/2012	
Lost Man Creek	REDWWQ24	8/2/2012	
Redwood Creek	REDWWQ25	8/1/2012	



Figure 6. Examples of typical stream characteristics in Redwoods National and State Parks, 2012. A = McArthur Creek (REDWWQ01); B = Lost Man Creek (REDWWQ06); C = Godwood Creek (REDWWQ21); D = West Branch Mill Creek (REDWWQ11); E = Lost Man Creek (REDWWQ13); and F = Redwood Creek (REDWWQ04).

Table 11. Physical characteristic and location of streams sampled in Redwood National and State Parks, 2012. Coordinates in NAD 1983 datum (Zone 10N). * indicates measurement was taken with clinometer. NA = Not Available.

Stream Name	Site Code	Date Sampled	Coordinates		Elevation (m)	Reach Length (m)	Average Width (m)	Average Depth (cm)	Slope	Instantaneous Discharge	
			X	Y						m ³ s ⁻¹	ft ³ s ⁻¹
McArthur Creek	REDWWQ01	6/26/2012	410481	4566200	224	150	2.4	17.2	1.1%	0.06	2.0
Unnamed (Trib to Redwood Creek)	REDWWQ02	6/25/2012	415605	4582096	153	150	1.9	6.5	*5.4	0.01	0.4
West Branch Mill Creek	REDWWQ03	7/12/2012	411843	4615345	237	150	2.6	8.7	*3.3	0.04	1.3
Redwood Creek	REDWWQ04	7/10/2012	416026	4562040	35	500	19.1	45.5	*0.6	2.58	91.2
East Fork Mill Creek	REDWWQ05	7/4/2012	409468	4620311	70	280	9.3	24.9	0.6%	0.35	12.4
Lost Man Creek	REDWWQ06	6/21/2012	414466	4575806	42	360	8.8	15.0	0.7%	0.27	9.6
Cedar Creek	REDWWQ07	7/16/2012	410758	4625524	154	150	3.4	8.9	*3.8	0.02	0.6
Bummer Lake Creek	REDWWQ08	7/9/2012	412899	4621651	239	150	3.2	10.3	*8.2	0.02	0.6
Wilson Creek	REDWWQ09	7/17/2012	411761	4613997	298	150	3.0	11.3	*3.9	0.03	1.1
Unnamed (Streelov Creek Trail)	REDWWQ10	6/20/2012	412510	4578933	79	150	1.7	10.9	1.4%	0.01	0.2
West Branch Mill Creek	REDWWQ11	7/3/2012	409124	4616390	137	160	5.9	13.0	0.6%	0.16	5.5
Little Lost Man Creek	REDWWQ12	7/5/2012	415934	4571098	440	150	3.0	11.3	4.4%	NA	NA
Lost Man Creek	REDWWQ13	7/6/2012	418221	4575118	207	150	3.8	11.8	6.3%	0.06	2.0
Rock Creek	REDWWQ14	7/11/2012	416060	4612950	381	150	3.3	7.4	*2.7	0.02	0.8
Mill Creek	REDWWQ15	7/18/2012	407305	4622635	88	150	2.4	7.5	1.9%	0.02	0.7
Redwood Creek	REDWWQ16	7/26/2012	415324	4563603	32	500	28.8	33.8	0.3%	1.79	63.3
Peacock Creek	REDWWQ17	7/24/2012	408041	4631415	42	160	4.2	9.4	1.3%	0.03	1.1
West Branch Mill Creek	REDWWQ19	7/25/2012	407709	4619516	103	200	7.2	19.1	0.6%	0.15	5.2
Redwood Creek	REDWWQ20	7/27/2012	413533	4572248	11	500	26.4	20.0	0.3%	1.77	62.7
Godwood Creek	REDWWQ21	6/22/2012	414292	4580140	48	150	3.5	19.7	0.8%	0.13	4.4
West Branch Mill Creek	REDWWQ23	7/31/2012	407961	4620044	90	200	7.9	20.8	0.6%	0.16	5.7
Lost Man Creek	REDWWQ24	8/2/2012	416171	4575132	81	200	7.1	10.9	1.7%	0.17	5.9
Redwood Creek	REDWWQ25	8/1/2012	413713	4571322	13	500	19.2	27.5	0.2%	1.68	59.4
Average					139	233	8	16	2.2%	0	15
SD					118	135	8	10	2.2%	1	27
Median					90	150	3.755	11.8	1%	0.09	3.2
Range					11–440	150–500	1.7–28.8	6.5–45.5	0.2%–8.2%	0.01–2.58	0.2–91.2

Table 12. Physical condition metrics for Redwood Parks streams sampled in 2012. Cells marked in sage (lightest shading) are sites for Least Disturbed, amber (medium shading) are sites meeting EPA threshold criteria for Intermediate, whereas cells marked in red (darkest shading) are sites meeting EPA criteria for Most Disturbed. * indicates that metric not available (requires measure of slope; data not available for those sites).

Stream Name	Site Code	Date Sampled	Stream Substrate diameter (mm)		Average Embedded-ness (%)	Pool (%)	Riffle (%)	Physical Habitat Condition Metrics			
			Average	Median				In-stream Habitat Cover	Riparian Cover	Relative Bed Stability	Riparian Disturbance
McArthur Creek	REDWWQ01	6/26/2012	0.1	0.5	9.5	36%	11%	0.38	0.64	-2.48	0.00
Unnamed (Trib to Redwood Creek)	REDWWQ02	6/25/2012	16.6	38.0	24.5	37%	59%	0.91	0.63	-0.51	0.00
West Branch Mill Creek	REDWWQ03	7/12/2012	133.2	114.8	8.4	45%	47%	0.51	0.47	0.38	0.00
Redwood Creek	REDWWQ04	7/10/2012	35.1	38.0	41.1	62%	22%	0.71	0.32	1.88	0.03
East Fork Mill Creek	REDWWQ05	7/4/2012	43.7	38.0	33.6	72%	19%	0.98	0.88	0.15	0.00
Lost Man Creek	REDWWQ06	6/21/2012	27.2	38.0	33.5	34%	21%	0.34	0.80	0.14	0.00
Cedar Creek	REDWWQ07	7/16/2012	54.0	114.8	26.7	31%	43%	1.47	0.51	-0.08	0.00
Bummer Lake Creek	REDWWQ08	7/9/2012	80.8	114.8	20.4	34%	50%	0.50	0.68	-0.42	0.00
Wilson Creek	REDWWQ09	7/17/2012	83.7	114.8	20.9	42%	40%	1.39	0.83	0.05	0.00
Unnamed (Streelov Creek Trail)	REDWWQ10	6/20/2012	6.3	12.6	37.3	58%	24%	1.26	0.57	-0.04	0.00
West Branch Mill Creek	REDWWQ11	7/3/2012	24.8	38.0	34.9	48%	14%	0.55	0.54	0.29	0.07
Little Lost Man Creek	REDWWQ12	7/5/2012	39.3	38.0	26.2	39%	45%	0.82	0.55	-0.21	0.00
Lost Man Creek	REDWWQ13	7/6/2012	29.4	38.0	40.9	25%	60%	1.80	0.59	-0.55	0.00
Rock Creek	REDWWQ14	7/11/2012	84.4	114.8	17.6	40%	43%	0.36	0.67	0.32	0.00
Mill Creek	REDWWQ15	7/18/2012	42.3	38.0	11.1	13%	55%	0.54	0.89	0.29	0.00
Redwood Creek	REDWWQ16	7/26/2012	22.0	38.0	45.5	60%	5%	0.22	0.54	0.01	0.33
Peacock Creek	REDWWQ17	7/24/2012	17.9	38.0	40.0	51%	39%	0.43	0.72	-0.07	0.00
West Branch Mill Creek	REDWWQ19	7/25/2012	33.4	38.0	22.5	48%	24%	0.18	0.53	0.23	0.00
Redwood Creek	REDWWQ20	7/27/2012	20.1	38.0	25.6	36%	14%	0.44	0.25	0.25	0.07
Godwood Creek	REDWWQ21	6/22/2012	8.3	6.2	42.2	58%	18%	1.69	0.52	-0.38	0.00
West Branch Mill Creek	REDWWQ23	7/31/2012	29.6	38.0	27.5	48%	20%	0.81	0.46	0.09	0.07
Lost Man Creek	REDWWQ24	8/2/2012	118.5	114.8	39.3	43%	42%	0.48	0.90	0.46	0.33
Redwood Creek	REDWWQ25	8/1/2012	20.6	38.0	33.3	25%	28%	0.35	0.16	0.29	0.33
Average			42.2	53.9	28.8	43%	32%	0.74	0.59	0.02	0.05
SD			35.1	38.5	10.9	14%	16%	0.47	0.19	0.72	0.11
Median			29.6	38.0	27.5	42%	28%	0.54	0.57	0.11	0.00
Range			0.1–133.2	0.5–114.8	8.4–45.5	13–72%	5–60%	0.18–1.80	0.16–0.90	-2.48–1.88	0–0.33

descriptor because the average substrate size can be influenced by a few, very large pieces of substrate. Redwood Parks streams were characterized by small sediment sizes; however the Relative Bed Stability metric (a predictive metric based on slope and other geomorphic features) that compares the observed sediment size to expected sediment size was often in the Least Disturbed state for many of the streams, even those characterized by small sediments. Ten stream reaches were in an Intermediate state, and two site reaches were rated as Most Disturbed. One, McArthur Creek (REDWWQ01), was in the Most Disturbed category for having higher than expected amounts of small sediments, while Redwood Creek (REDWWQ04) had larger sediment sizes than expected (generally indicative of water withdrawal).

Fourteen stream reaches were in the Intermediate condition based on the Riparian Cover metric. One, Redwood Creek (REDWWQ25), was in the Most Disturbed condition. The high number of sites categorized as Intermediate or Most Disturbed is detailed more in the discussion.

All sites were in the Least Disturbed condition for the Riparian Disturbance metric. Most sites were also within the Least Disturbed condition for In-stream Habitat Cover, a measure of stream habitat complexity. Only two sites were Intermediate, Redwood Creek (REDWWQ16) and West Branch Mill Creek (REDWWQ19).

Chemical Characteristics and Condition Estimates of Redwood Parks Streams

Selected water chemistry results are presented in Table 13. Parameters measured in-situ with a water probe (see Methods) are listed under “Water Quality” and parameters measured in an analytical laboratory or with a stream-side assay (Acid Neutralizing Capacity) are presented as “Water Chemistry.”

At two sites, Cedar Creek (REDWWQ07) and Rock Creek (REDWWQ14), the water probe was not functioning correctly, preventing the collection of water quality data at these sites.

pH was found to be circum-neutral (pH of 7 = neutral), with an average of 7.33. Values did not exceed any water quality criteria (Table 2), and the average pH was solidly within the acceptable range. **Acid Neutralizing Capacities** were all positive, indicating Least Disturbed.

Temperature is presented as a descriptor of conditions during sampling, but varies on a daily, monthly, and seasonal basis. As such, no status or condition should be inferred from temperature readings. However, not surprisingly, the highest temperatures recorded were on Redwood Creek (REDWWQ04, REDWWQ16, REDWWQ20 and REDWWQ25), with temperatures ranging from 16.5 °C to 17.7 °C. Redwood Creek is a 303(d) site listed under the Clean Water Act as temperature (and sediment) impaired (Hoffman et al. 2005)

Specific Conductivity was uniformly low, and well under the EPA threshold criteria for Least Disturbed at all sites (used as a surrogate for salinity by the EPA). **Dissolved Oxygen** values also appear well within regulatory criteria for available water quality thresholds (Table 2). Turbidity readings were generally low, with recorded values only above 0 NTUs at two sites: McArthur Creek (REDWWQ01) and an unnamed stream (REDWWQ10). Although these two values were above strict *drinking water* criteria, they were under the NPStoret thresholds

Table 13. Water chemistry parameters for streams sampled in Redwood Parks, 2012. * indicates Not Available; probe was malfunctioning during the site visit. Data collected with water probe are under “Water Quality,” whereas data from laboratory analyses are under “Water Chemistry.” Cells marked in sage (lightest shading) are sites for Least Disturbed, amber (medium shading) are sites meeting EPA threshold criteria for Intermediate, whereas cells marked in red (darkest shading) are sites meeting EPA criteria for Most Disturbed.

Stream Name	Site Code	Water Quality					Water Chemistry						
		pH	Temp (°C)	Specific Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Sodium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Acid Neutralizing Capacity	
												(µeq/L)	(mg/L)
McArthur Creek	REDWWQ01	6.74	9.7	61	10.5	2.8	5.82	0.61	7.99	0.96	0.006	210	11
Unnamed (Trib to Redwood Creek)	REDWWQ02	7.57	10.4	75	11.4	0.0	6.23	0.85	7.83	0.07	0.022	445	22
West Branch Mill Creek	REDWWQ03	7.15	11.7	53	10.2	0.0	3.93	0.61	3.36	0.09	0.012	389	19
Redwood Creek	REDWWQ04	7.70	17.7	116	9.0	0.0	3.56	2.49	3.04	0.08	0.006	899	45
East Fork Mill Creek	REDWWQ05	7.35	11.9	60	10.6	0.0	3.59	0.62	3.32	0.14	0.013	458	23
Lost Man Creek	REDWWQ06	7.34	11.0	66	10.4	0.0	4.91	0.79	4.83	0.10	0.008	444	22
Cedar Creek	REDWWQ07	*	*	*	*	*	3.10	0.63	4.83	0.09	0.007	470	24
Bummer Lake Creek	REDWWQ08	7.55	11.5	107	10.5	0.0	3.06	0.49	2.96	0.12	0.009	570	29
Wilson Creek	REDWWQ09	7.29	11.6	56	10.0	0.0	3.63	0.73	3.07	0.09	0.009	445	22
Unnamed (Streelow Creek Trail)	REDWWQ10	7.05	9.3	76	10.0	3.9	7.40	0.64	11.02	0.17	0.008	327	16
West Branch Mill Creek	REDWWQ11	6.98	11.6	50	10.6	0.0	3.98	0.59	3.85	0.14	0.010	371	19
Little Lost Man Creek	REDWWQ12	7.18	10.2	53	10.2	0.0	5.01	0.42	4.94	0.03	0.014	356	18
Lost Man Creek	REDWWQ13	7.36	10.6	58	10.8	0.0	4.35	0.76	4.25	0.06	0.008	392	20
Rock Creek	REDWWQ14	*	*	*	*	*	2.81	0.49	2.32	0.10	0.008	277	14
Mill Creek	REDWWQ15	7.10	11.7	62	10.3	0.0	5.56	0.64	7.20	0.61	0.009	360	18
Redwood Creek	REDWWQ16	7.74	17.6	124	9.0	0.0	3.77	2.49	3.33	0.08	0.002	931	47
Peacock Creek	REDWWQ17	7.61	12.5	112	10.3	0.0	3.83	0.72	4.69	0.36	0.010	899	45
West Branch Mill Creek	REDWWQ19	6.91	13.8	52	9.9	0.0	2.10	0.32	2.12	0.05	0.006	328	16
Redwood Creek	REDWWQ20	7.57	16.5	123	8.9	0.0	3.92	2.22	3.80	0.11	0.005	977	49
Godwood Creek	REDWWQ21	7.48	10.5	104	10.4	0.0	7.73	0.67	10.69	0.04	0.018	632	32
West Branch Mill Creek	REDWWQ23	7.13	13.5	53	9.9	0.0	4.22	0.58	4.20	0.14	0.006	361	18
Lost Man Creek	REDWWQ24	7.55	12.0	73	10.9	0.0	5.12	0.78	4.72	0.11	0.011	522	26
Redwood Creek	REDWWQ25	7.63	16.6	128	8.7	0.0	4.00	2.24	3.87	0.11	0.008	974	49
Average		7.33	12.5	79	10.1	0.3	4.42	0.93	4.88	0.17	0.009	523	26
SD		0.28	2.6	28	0.7	1.0	1.39	0.68	2.44	0.21	0.004	240	12
Median		7.35	11.7	66	10.3	0.0	3.98	0.64	4.20	0.10	0.008	445	22
Range		6.74–7.74	9.3–17.7	50 - 128	8.7–11.4	0–3.9	2.10–7.73	0.32–2.49	2.12–11.02	0.03–0.96	0–0.02	210–977	11–49

The **anions and cations** with available thresholds for water quality were all far below promulgated values. Although no strong patterns emerged with a stream having uniformly high anions and cations, all Redwood Creek sites were substantially higher in sulfate than other Redwood Parks streams.

Total Nitrogen, a key ecosystem nutrient, had low measured levels in 16 sites, all well below the EPA threshold for Least Disturbed. However, four sites were Intermediate, and three were rated Most Disturbed. The presence of a substantial number of low level sites in the parks suggests that the background level of Total Nitrogen is low, and there are secondary sources of nitrogen in the Intermediate and Most Disturbed sites (McArthur Creek, REDWWQ01; Mill Creek, REDWWQ15; and Peacock Creek, REDWWQ17). **Total Phosphorous**, another key ecosystem nutrient, was low in 17 Redwood Park stream sites, meeting the EPA criteria for Least Disturbed. Six sites were Intermediate, but several of these were very close to the threshold for Least Disturbed. Only one site, East Fork Mill Creek (REDWWQ05), had elevated levels of both Total Nitrogen and Total Phosphorous.

Riparian Characteristics of Redwood Parks Streams

The riparian zones of Redwood Parks streams were characterized by heavy shading (average stream shading of 82%), with a median shading of 96% (Table 14). Likewise, most sites were characterized by tall legacy trees with an average height of 43.2 m, compared to an average in Whiskeytown of 26.8 m, Lassen Volcanic of 28.1 m, and Crater Lake 30.3 m. The tallest average height was in an Unnamed stream (REDWWQ02) that is a tributary to Brown Creek. The canopy cover was often mixed, with deciduous, coniferous, and mixed compositions composing the canopy. The understory, however, was largely deciduous in most locations.

Vertebrate Assemblage and Condition of Redwood Parks Streams

Results of electrofishing and visual encounters of vertebrate species, along with summaries of abundance, richness, and the EPA Vertebrate MMI are presented in Table 15. One reach on Redwood Creek (REDWWQ04) could not be sampled due to deep pool depth. A total of four amphibian and nine fish taxa were encountered, with at least one species at each site. The most widespread was Pacific Giant Salamander (*Dicamptodon tenebrosus*) at 19 of the 22 sampled reaches. The next most widespread was Steelhead/Rainbow Trout (*Oncorhynchus mykiss*) at 15 of the 22 sampled reaches. Speckled Dace (*Rhinichthys osculus*) and the Northern Red-Legged Frog (*Rana aurora*) were the most infrequent, seen at only one sampled reach each. Note that species richness estimates are conservative, since field collection and growth stage of many species prevent species identification (e.g., lampreys were seen at seven sites, but we could only identify them to genus [*Lamprreta*], so there may be as many six species in this region).

Condition assessments using the EPA Vertebrate MMI ranked all sites as Least Disturbed. No species that we could assess as nonnative fish were collected or encountered.

Table 14. Riparian characteristics of Redwood Parks streams sampled in 2012. For composition: D = Deciduous, C = Coniferous, E = Broadleaf Evergreen, N = None, and M = Mixed (10% or more of multiple types).

Stream name	Site Code	Shading	Legacy Tree Height (m)	Canopy			Understory		
				Big Tree	Small Tree	Composition	Woody	Non-Woody	Composition
McArthur Creek	REDWWQ01	100%	27.6	25%	6%	59% D, 23% M, 14% C, 5% N	31%	25%	100% D
Unnamed (Trib to Redwood Creek)	REDWWQ02	98%	101.6	16%	6%	77% C, 14% N, 9% M	39%	40%	86% D, 14%M
West Branch Mill Creek	REDWWQ03	99%	43.7	3%	14%	68% D, 18% N, 9% C, 5% M	30%	10%	95% D, 5%M
Redwood Creek	REDWWQ04	51%	76.2	2%	9%	55%N, 41% D	20%	4%	55% N, 45% D
East Fork Mill Creek	REDWWQ05	82%	24.1	19%	28%	73% D, 18% M, 5% C, 5% N	41%	16%	95% D, 5%M
Lost Man Creek	REDWWQ06	84%	47.9	3%	31%	100% D	25%	19%	100% D
Cedar Creek	REDWWQ07	98%	57.1	16%	10%	64% C, 18% N, 14% D, 5% M	25%	54%	77% D, 23% M
Bummer Lake Creek	REDWWQ08	98%	37.3	18%	14%	64% D, 36% M	34%	2%	100% D
Wilson Creek	REDWWQ09	99%	28.0	10%	28%	64% D, 32% M, 5% N	45%	19%	82% D, 18% M
Unnamed (Streelow Creek Trail)	REDWWQ10	98%	31.2	16%	17%	82% C, 14% N, 5% M	24%	14%	86% D, 9% M, 5% C
West Branch Mill Creek	REDWWQ11	67%	30.9	8%	10%	59% D, 41% N	34%	26%	91% D, 5% N, 5% M
Little Lost Man Creek	REDWWQ12	96%	66.1	15%	18%	91% C, 9% N	21%	11%	50% D, 27% M, 14% C, 9% N
Lost Man Creek	REDWWQ13	98%	45.4	21%	18%	50% C, 36% M, 14% D	20%	40%	59% D, 23% M, 18% C
Rock Creek	REDWWQ14	100%	32.5	20%	20%	95% D, 5% N	26%	3%	95% D, 5%M
Mill Creek	REDWWQ15	97%	18.6	19%	15%	100% D	53%	2%	100% D
Redwood Creek	REDWWQ16	61%	55.7	23%	13%	41% D, 41% N, 18% M	17%	2%	73% D, 27% N
Peacock Creek	REDWWQ17	98%	39.5	24%	18%	73% M, 23% D, 5% N	29%	0%	100% D
West Branch Mill Creek	REDWWQ19	76%	26.1	7%	29%	82% D, 18% M	14%	16%	86% D, 9% N, 5% M
Redwood Creek	REDWWQ20	10%	19.4	1%	7%	68% N, 27% D, 5% M	15%	2%	68% D, 32% N
Godwood Creek	REDWWQ21	96%	73.2	12%	4%	59% C, 36%N, 5% D	36%	78%	77% D, 23% M
West Branch Mill Creek	REDWWQ23	75%	25.1	11%	13%	73% D, 27% N	22%	6%	91% D, 9% N
Lost Man Creek	REDWWQ24	86%	63.0	26%	21%	64% D, 27% M, 5% C, 5% N	40%	4%	100% D
Redwood Creek	REDWWQ25	23%	24.1	0%	6%	66% N, 34% D	9%	4%	50% D, 50% N
	Average	82%	43.2	14%	15%		28%	17%	
	SD	25%	21.5	8%	8%		11%	20%	
	Median	96%	37.3	16%	14%		26%	11%	
	Range	10–100%	18.6–101.6	0–26%	4–31%		9–53%	0–78%	

Table 15. Vertebrate species and metrics for Redwood Parks streams sampled in 2012. All sites were rated Least Disturbed by the EPA MMI (sage-colored shading).

Stream Name	Site Code	Metrics			Amphibian					Fish							
		Total Abundance	Total Richness	EPA Vertebrate MMI	Pacific Giant Salamander (<i>Dicamptodon tenebrosus</i>)	Tailed Frog (<i>Ascaphus truei</i>)	Northern Red Legged Frog (<i>Rana aurora</i>)	Foothill Yellow Legged Frog (<i>Rana boylei</i>)	Cutthroat Trout (<i>Oncorhynchus clarki</i>)	Rainbow Trout /Steelhead (<i>Oncorhynchus mykiss</i>)	Three Spine Stickleback (<i>Gasterosteus aculeatus</i>)	Coho Salmon (<i>Oncorhynchus kisutch</i>)	Unid Sculpin (<i>Cottus</i> sp.)	Unid Salmonid (<i>Oncorhynchus</i> sp.)	Lamprey (<i>Lamprera</i> sp.)	"Cutbow" Rainbow X Cutthroat Hybrid	Speckled Dace (<i>Rhinichthys osculus</i>)
McArthur Creek	REDWWQ01	28	1	85.2	28												
Unnamed (Trib to Redwood Creek)	REDWWQ02	20	3	79.7	14	2			4								
West Branch Mill Creek	REDWWQ03	31	3	80.2	12	2			17								
Redwood Creek	REDWWQ04	*			Too deep to safely sample												
East Fork Mill Creek	REDWWQ05	34	6	78.0	3	1				10	3	12	3	2			
Lost Man Creek	REDWWQ06	74	6	82.8		1			3	22	1	19	25		2	1	
Cedar Creek	REDWWQ07	60	4	92.5	13	14			10	7				15		1	
Bummer Lake Creek	REDWWQ08	61	4	94.2	9	7			22	19				2		2	
Wilson Creek	REDWWQ09	27	3	79.6	23	3				1							
Unnamed (Streelow Creek Trail)	REDWWQ10	25	2	89.3	10				15								
West Branch Mill Creek	REDWWQ11	65	7	77.6	9	3			2	9	6	32	4				
Little Lost Man Creek	REDWWQ12	49	3	73.4	42	6	1										
Lost Man Creek	REDWWQ13	65	2	73.1	42	23											
Rock Creek	REDWWQ14	79	4	90.2	5	3			3	21				47			
Mill Creek	REDWWQ15	57	3	86.9	10	4			27					16			
Redwood Creek	REDWWQ16	60	4	71.3				1		33			23		3		
Peacock Creek	REDWWQ17	86	4	80.3	3	3				9			39	30		2	
West Branch Mill Creek	REDWWQ19	83	7	80.2	7	1				45	2	11	7	9	1		
Redwood Creek	REDWWQ20	71	7	67.4					1	16	8	1	38		3		4
Godwood Creek	REDWWQ21	20	5	91.8	5	1			3	1		8				2	
West Branch Mill Creek	REDWWQ23	91	7	84.2	8				5	48	3	12	13	1	1		
Lost Man Creek	REDWWQ24	87	6	91.6	11	17			4	21		13		15	1	5	
Redwood Creek	REDWWQ25	89	5	67.1	1			1		26			51		10		
	Average		4.4	81.7													
	SD		1.8	8.1													
	Median		4	80.3													
	Range		1–7	67.1–94.2													

Macroinvertebrate Assemblage and Condition of Redwood Parks Streams

A total of 15,611 individual macroinvertebrates were collected, sorted, and identified from Redwood Parks streams (a complete taxa list for the Redwood Parks samples is given in Appendix C). A conservative estimate of the total species richness is 285 separate species (many taxa are only identified to family or genus level, hence the true species richness is likely higher; likewise there are instances where a specific individual was only able to be identified to family, but a separate individual was identified to genus or species, duplicating the “taxonomic units.” (See the full protocol [Dinger et al. 2013] or Cuffney et al. 2007 for more detail on ambiguous taxa). Summary statistics (Taxa Richness and measures of biological integrity) for each site are provided in Table 16. The most diverse site was Peacock Creek (REDWWQ17) with 77 taxa, although Redwood Creek (REDWWQ04) also had high taxa richness, with 75. The most depauperate site was Wilson Creek (REDWWQ09), with 45 taxa.

For calculating Hilsenhoff Biotic Index (HBI), tolerance values were available for 278 of the 285 taxonomic units (which include individuals only identified to higher taxonomic units due to poor keys, damaged specimens, or immature life stages). Taxa with no tolerance value were excluded from HBI calculations. The lowest HBI (indicating a preponderance of intolerant, clean-water indicating organisms) was Wilson Creek (REDWWQ09)—paradoxically the lowest taxa richness site—suggesting lower diversity but composed of mostly intolerant, clean water organisms. The highest HBI (indicating more organisms tolerant of poor water quality conditions) was Redwood Creek (REDWWQ04), also paradoxically the most taxa rich site.

All but three stream reaches were categorized as Least Disturbed by the EPA Macroinvertebrate MMI index. McArthur Creek (REDWWQ01), an Unnamed stream (REDWWQ02), and a section of Redwood Creek (REDWWQ25) were rated as Intermediate, but should be pointed out as being within a percentage point (or two) for meeting the threshold for Least Disturbed. Ecosystem condition based on the California Game and Fish North Coast IBI (Rehn et al. 2005) rated most sites as “good” (61–80). Two reaches, both on Redwood Creek (REDWWQ20 and REDWWQ25) were rated at “fair” (41–60).

Table 16. Macroinvertebrate metrics for Redwood Parks streams, 2012. Cells colored amber (medium shading) indicate EPA condition estimate of Intermediate or California IBI category of Fair. Sage colored cells (lightest shading) indicate Least Disturbed or “good-very good” for California IBI.

Stream Name	Site Code	Total Taxa Richness	Shannon Diversity	Hilsenhoff Biotic Index	EPA West-Wide Macroinvertebrate MMI	Regional
						California North Coast IBI
McArthur Creek	REDWWQ01	59	3.55	4.13	69.0	61.25
Unnamed (Trib to Redwood Creek)	REDWWQ02	66	3.42	3.51	70.0	67.5
West Branch Mill Creek	REDWWQ03	58	3.36	3.09	87.7	73.75
Redwood Creek	REDWWQ04	75	3.41	4.91	72.5	63.75
East Fork Mill Creek	REDWWQ05	61	3.41	4.39	81.9	75
Lost Man Creek	REDWWQ06	59	3.30	3.56	79.9	75
Cedar Creek	REDWWQ07	67	3.67	2.90	84.3	73.75
Bummer Lake Creek	REDWWQ08	56	2.02	4.30	73.3	72.5
Wilson Creek	REDWWQ09	45	3.30	2.90	89.5	70
Unnamed (Streelow Creek Trail)	REDWWQ10	52	3.07	3.32	72.1	66.25
West Branch Mill Creek	REDWWQ11	59	3.18	4.11	87.7	78.75
Little Lost Man Creek	REDWWQ12	63	3.44	2.97	80.3	73.75
Lost Man Creek	REDWWQ13	55	2.89	3.32	82.8	77.5
Rock Creek	REDWWQ14	66	3.14	3.43	83.8	72.5
Mill Creek	REDWWQ15	66	3.32	3.13	83.6	73.75
Redwood Creek	REDWWQ16	67	3.36	4.50	76.2	65
Peacock Creek	REDWWQ17	77	3.26	3.84	75.0	77.5
West Branch Mill Creek	REDWWQ19	59	3.27	4.66	77.4	73.75
Redwood Creek	REDWWQ20	46	2.36	3.02	72.5	50
Godwood Creek	REDWWQ21	65	3.47	2.99	76.7	70
West Branch Mill Creek	REDWWQ23	62	3.34	4.91	72.3	68.75
Lost Man Creek	REDWWQ24	71	3.17	4.14	86.9	80
Redwood Creek	REDWWQ25	49	2.45	2.92	70.0	55
Average		61	3.18	3.69	78.5	70.2
SD		8.3	0.40	0.69	6.5	7.4
Median		61	3.30	3.51	77.4	72.5
Range		45–77	2.02–3.67	2.90–4.91	69.0–89.5	50–80

Crater Lake National Park

Sampling began on August 7, 2012, following the arrival of the field crew from Redwood National and State Parks and continued until September 18, 2012, when field activities ceased. A total of 23 sites were sampled (Figure 7), from the original target of 25 to 30 sites. Many sites on the original sample list (Table 17) were unsampleable for a variety of reasons, including that some streams were dry, some too distant to sample safely, and at least one had access that was too steep to safely negotiate. Additionally, the crew was shortened down from 4 technicians to 3 technicians at the end of the season, necessitating the final selection of a site that was close enough to safely sample in a single day.

Most streams in Crater Lake originate on the outside caldera walls, especially the south and east portions. They drain volcanic soils and geology, especially basalt, and although many are steep gradient on the caldera, our sampling is limited to the safer gradients. The streams vary from wider subalpine meadow streams to narrow first order streams, all usually with large amounts of woody debris. Examples of sampled streams in Crater Lake are presented in Figure 8.

Physical Characteristics of Crater Lake Streams

Basic summary statistics of the monitoring streams are presented in Table 18. These are general geomorphological characteristics of the streams (e.g., elevation, slope, discharge) and do not impart any conditional information. An Unnamed tributary (CRLAWQ15) to Bybee Creek was the smallest stream sampled, with only an average width of 1.1 m and a discharge of $0.01 \text{ m}^3 \text{ s}^{-1}$. The Rogue River (CRLAWQ04) was the largest sampled, with an average width of 15.7 m and a discharge of $1.46 \text{ m}^3 \text{ s}^{-1}$.

Physical Condition Metrics of Crater Lake Streams

The four EPA physical condition metrics, along with substrate size and average embeddedness for Crater Lake are presented in Table 19. The median substrate size for a stream is a more common descriptor, since the average can be influenced by a few, very large pieces of substrate. Overall coarse gravel (median particle size = 38 mm) was the predominate substrate. One site, Lost Creek (CRLAWQ09), had the smallest diameter of substrate (median = 0.5 mm)—so that half of the particles measured in the stream reach were fine sediments. The largest substrates were on Sun Creek (CRLAWQ03) and Middle Fork Annie Creek (CRLAWQ10), with a median particle size of 114.8 mm—a large cobble size. Embeddedness, a measure of the amount of fine sediments entrapping gravel or large substrate averaged 48% across the park, with the highest embeddedness in Lost Creek (CRLAWQ09). The lowest embeddedness was in Sun Creek (CRLAWQ03).

Relative Bed Stability, the EPA metric that compares a geomorphically predicted median sediment size and compares it to the observed median sediment, was strongly negative for all Crater Lake streams. The negativity is interpreted as an excess of smaller, fine sediments that would be expected, generally suggesting an anthropogenic source (such as dirt roads). These negative values and resultant Intermediate and Most Disturbed condition assessments should be evaluated in the context of the natural geology of Crater Lake. See discussion for more in-depth analysis.

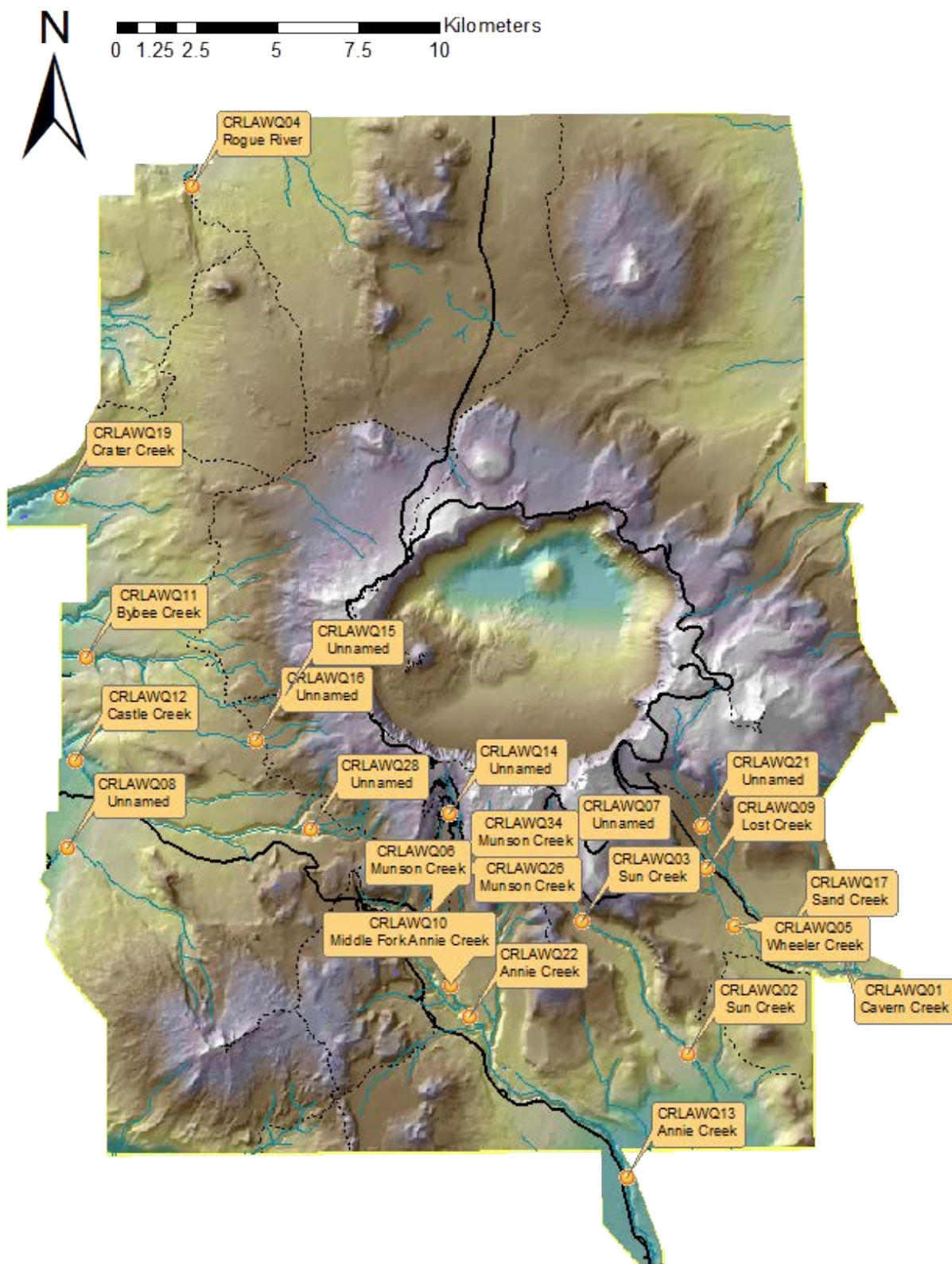


Figure 7. Stream sites sampled in Crater Lake National Park, 2012.

Table 17. Original site list for streams to be sampled in Crater Lake. Sites marked with * were not sampled due to a variety of reasons. Sites requiring more than 1.5 hours to access were deemed too far to safely sample in a single day.

Stream Name	Site Code	Date Sampled	Reason for Not Sampling
Cavern Creek	CRLAWQ01	8/7/2012	
Sun Creek	CRLAWQ02	8/27/2012	
Sun Creek	CRLAWQ03	8/28/2012	
Rogue River	CRLAWQ04	8/21/2012	
Wheeler Creek	CRLAWQ05	8/8/2012	
Munson Creek	CRLAWQ06	9/10/2012	
Unnamed (Trib to Vidae Creek)	CRLAWQ07	8/29/2012	
Unnamed (Trib to Union Creek)	CRLAWQ08	8/22/2013	
Lost Creek	CRLAWQ09	8/13/2012	
Middle Fork Annie Creek	CRLAWQ10	8/16/2012	
Bybee Creek	CRLAWQ11	8/30/2012	
Castle Creek	CRLAWQ12	8/14/2012	
Annie Creek	CRLAWQ13	9/4/2012	
Unnamed (Trib to Munson Creek)	CRLAWQ14	8/9/2012	
Unnamed (Trib to Bybee Creek)	CRLAWQ15	9/5/2012	
Unnamed (Trib to Bybee Creek)	CRLAWQ16	9/12/2012	
Sand Creek	CRLAWQ17	9/6/2012	
Unnamed (Trib to Goodbye Creek)	CRLAWQ18	*	Dry
Crater Creek	CRLAWQ19	9/13/2012	
Unnamed (Headwater to Red Blanket)	CRLAWQ20	*	Dry
Unnamed (Trib to Sand Creek)	CRLAWQ21	9/19/2012	
Annie Creek	CRLAWQ22	8/20/2012	
Copeland Creek	CRLAWQ23	*	Dry (only 30 m inundated reach)
Unnamed (Trib to Union Creek)	CRLAWQ24	*	Too distant from vehicle
Annie Creek	CRLAWQ25	*	Too distant/Steep access
Munson Creek	CRLAWQ26	9/11/2012	
Unnamed (Trib to Bybee Creek)	CRLAWQ27	*	Too distant from vehicle
Unnamed (Trib to Castle Creek)	CRLAWQ28	9/17/2012	
Sand Creek	CRLAWQ29	*	Due to time constraints and one crew leaving, these sites were passed over for a close, accessible site (#34)
Sun Creek	CRLAWQ30	*	
Sun Creek	CRLAWQ31	*	
Unnamed (Trib to Crater Creek)	CRLAWQ32	*	
Sand Creek	CRLAWQ33	*	
Munson Creek	CRLAWQ34	9/18/2012	



Figure 8. Examples of typical stream characteristics in Crater Lake National Park, 2012. A = Unnamed Stream (CRLAWQ14), B, C = Castle Creek (CRLAWQ12), D = Middle Fork Annie Creek (CRLAWQ10), E = Annie Creek (CRLAWQ22), and F = Rogue River (CRLAWQ04).

Table 18. Physical characteristics and location of streams sampled in Crater Lake, 2012. Coordinates in NAD 10983, Zone 10N. * Flow meter nonfunctioning for one site.

Stream Name	Site Code	Date Sampled	Coordinates		Elevation (m)	Reach Length (m)	Average Width (m)	Average Depth (cm)	Slope	Instantaneous Discharge	
			X	Y						m ³ s ⁻¹	ft ³ s ⁻¹
Cavern Creek	CRLAWQ01	8/7/2012	582663	4745151	1597	150	3.4	13.8	1.5%	0.11	3.8
Sun Creek	CRLAWQ02	8/27/2012	577902	4742140	1531	150	4.5	16.5	1.7%	0.46	16.3
Sun Creek	CRLAWQ03	8/28/2012	574605	4746208	1780	150	3.9	12.6	5.2%	0.21	7.5
Rogue River	CRLAWQ04	8/21/2012	562522	4768956	1565	320	15.7	24.0	2.8%	1.46	51.7
Wheeler Creek	CRLAWQ05	8/8/2012	579320	4746080	1742	150	1.7	10.7	1.9%	0.07	2.5
Munson Creek	CRLAWQ06	9/10/2012	569923	4746412	1841	160	4.3	14.1	1.9%	0.21	7.5
Unnamed to Vidae Creek) (Trib	CRLAWQ07	8/29/2012	573699	4747808	1971	150	2.8	10.1	4.9%	0.11	3.8
Unnamed to Union Creek) (Trib	CRLAWQ08	8/22/2013	558687	4748505	1508	150	2.4	14.3	3.1%	0.17	6.2
Lost Creek	CRLAWQ09	8/13/2012	578472	4747853	1819	150	1.3	7.1	1.6%	0.02	0.8
Middle Fork Annie Creek	CRLAWQ10	8/16/2012	570541	4744220	1708	150	2.3	14.2	4.6%	0.14	4.9
Bybee Creek	CRLAWQ11	8/30/2012	559256	4754347	1458	160	6.2	21.7	2.5%	0.78	27.6
Castle Creek	CRLAWQ12	8/14/2012	558929	4751202	1469	200	5.2	22.5	1.5%	0.49	17.2
Annie Creek	CRLAWQ13	9/4/2012	575986	4738322	1384	280	9.4	20.7	0.7%	*	*
Unnamed to Munson Creek) (Trib	CRLAWQ14	8/9/2012	570516	4749534	1965	150	1.2	9.0	3.7%	0.02	0.7
Unnamed to Bybee Creek) (Trib	CRLAWQ15	9/5/2012	565456	4753229	1890	150	1.1	5.8	5.4%	0.01	0.4
Unnamed to Bybee Creek) (Trib	CRLAWQ16	9/12/2012	564513	4751798	1787	150	1.8	7.6	3.2%	0.05	1.7
Sand Creek	CRLAWQ17	9/6/2012	580723	4745489	1617	200	4.7	18.4	2.0%	0.63	22.3
Crater Creek	CRLAWQ19	9/13/2012	558480	4759353	1420	150	4.5	22.1	2.4%	0.48	16.9
Unnamed to Sand Creek) (Trib	CRLAWQ21	9/19/2012	578299	4749178	1844	150	3.4	13.6	3.6%	0.31	10.9
Annie Creek	CRLAWQ22	8/20/2012	571126	4743255	1643	280	7.4	16.9	1.5%	1.11	39.1
Munson Creek	CRLAWQ26	9/11/2012	570469	4747761	1898	150	3.3	14.3	1.6%	0.19	6.7
Unnamed to Castle Creek) (Trib	CRLAWQ28	9/17/2012	566219	4749087	1795	150	1.3	4.7	6.1%	0.01	0.3
Munson Creek	CRLAWQ34	9/18/2012	570388	4747319	1886	150	2.9	14.7	0.7%	0.18	6.4
Average					1701	174	4.1	14.3	2.8%	0.33	11.6
SD					182	50	3.3	5.5	1.6%	0.38	13.4
Median					1742	150	3.4	14.2	2.4%	0.19	6.6
Range					1384–1971	150–320	1.1–15.7	4.7–24.0	0.7%–6.1%	0.01–1.46	0.3–51.7

Table 19. Physical condition metrics for Crater Lake streams sampled in 2012. Cells marked in sage (lightest shading) are sites for Least Disturbed, amber (medium shading) are sites meeting EPA threshold criteria for Intermediate, whereas cells marked in red (darkest shading) are sites meeting EPA criteria for Most Disturbed.

Stream Name	Site Code	Date Sampled	Stream Substrate diameter (mm)		Average Embeddedness (%)	Pool (%)	Riffle (%)	Physical Habitat Condition Metrics			
			Average	Median				In-stream Habitat Cover	Riparian Cover	Relative Bed Stability	Riparian Disturbance
Cavern Creek	CRLAWQ01	8/7/2012	6.4	6.2	50.8	15%	46%	1.15	0.80	-0.80	0.00
Sun Creek	CRLAWQ02	8/27/2012	8.2	38.0	43.5	24%	55%	0.99	0.78	-0.75	0.00
Sun Creek	CRLAWQ03	8/28/2012	48.3	114.8	24.5	5%	86%	0.58	0.25	-0.35	0.00
Rogue River	CRLAWQ04	8/21/2012	18.3	38.0	28.7	3%	71%	2.15	0.89	-0.82	0.44
Wheeler Creek	CRLAWQ05	8/8/2012	1.6	0.5	51.1	15%	38%	1.00	0.51	-1.44	0.00
Munson Creek	CRLAWQ06	9/10/2012	16.8	38.0	55.9	18%	36%	0.74	0.45	-0.37	0.00
Unnamed (Trib to Vidae Creek)	CRLAWQ07	8/29/2012	18.7	38.0	40.0	17%	59%	0.91	1.05	-0.55	0.00
Unnamed (Trib to Union Creek)	CRLAWQ08	8/22/2013	5.8	6.2	46.3	10%	80%	1.07	0.57	-1.09	0.00
Lost Creek	CRLAWQ09	8/13/2012	0.8	0.5	82.0	31%	17%	0.30	0.53	-1.40	1.29
Middle Fork Annie Creek	CRLAWQ10	8/16/2012	38.8	114.8	34.7	7%	87%	1.37	0.08	-0.42	0.00
Bybee Creek	CRLAWQ11	8/30/2012	7.5	38.0	44.1	18%	56%	1.41	0.87	-1.26	0.00
Castle Creek	CRLAWQ12	8/14/2012	3.1	6.2	49.5	8%	76%	1.23	0.87	-1.36	0.00
Annie Creek	CRLAWQ13	9/4/2012	5.6	6.2	55.1	32%	61%	0.90	0.46	-0.71	0.00
Unnamed (Trib to Munson Creek)	CRLAWQ14	8/9/2012	1.6	0.5	58.2	19%	53%	1.20	0.69	-1.45	1.37
Unnamed (Trib to Bybee Creek)	CRLAWQ15	9/5/2012	4.5	6.2	58.0	47%	41%	0.69	0.56	-0.92	0.17
Unnamed (Trib to Bybee Creek)	CRLAWQ16	9/12/2012	7.9	38.0	55.6	36%	53%	0.32	0.40	-0.69	0.00
Sand Creek	CRLAWQ17	9/6/2012	7.3	38.0	45.1	14%	86%	0.41	0.41	-0.86	0.00
Crater Creek	CRLAWQ19	9/13/2012	3.7	6.2	60.4	58%	15%	1.35	0.70	-1.38	0.00
Unnamed (Trib to Sand Creek)	CRLAWQ21	9/19/2012	13.3	38.0	46.9	27%	67%	1.18	0.42	-0.83	0.00
Annie Creek	CRLAWQ22	8/20/2012	8.6	38.0	40.4	10%	79%	1.52	0.55	-0.83	0.00
Munson Creek	CRLAWQ26	9/11/2012	16.3	38.0	31.6	6%	85%	0.51	0.30	-0.28	0.00
Unnamed (Trib to Castle Creek)	CRLAWQ28	9/17/2012	6.5	6.2	55.6	28%	70%	0.99	0.53	-0.92	0.00
Munson Creek	CRLAWQ34	9/18/2012	5.4	38.0	45.8	64%	28%	0.63	0.11	-0.44	0.00
Average			11.1	30.1	48.0	22%	59%	0.98	0.56	-0.87	0.14
SD			11.6	31.4	12.3	16%	22%	0.44	0.25	0.38	0.39
Median			7.3	38.0	46.9	18%	59%	0.99	0.53	-0.83	0.00
Range			0.8–48.3	0.5–114.8	24.5–82.0	3–64%	15–87%	0.3–2.15	0.08–1.05	-1.45 to -0.28	0–1.37

Due to the nature of these montane and subalpine streams, some of which meander in meadows, riparian cover is largely shrub or graminoid plants. Riparian Cover, a measure of the complexity of the riparian zone immediately on the stream banks, is naturally low in these meadow systems. Due to this, when using West-wide criteria for Intermediate or Most Disturbed, these natural streams are classified as degraded or impacted, despite the conditions being a natural character of the stream. Hence, two sites were Most Disturbed (Middle Fork Annie Creek, CRLAWQ10; Munson Creek CRLAWQ34) and another 13 were Intermediate.

In-stream Habitat Cover was high in all Crater Lake streams, with two being rated as Intermediate, Lost Creek (CRLAWQ09) and an Unnamed stream (CRLAWQ16). Riparian Disturbance was low in almost all sites, except two sites with Most Disturbed conditions: Lost Creek (CRLAWQ09) and an Unnamed stream (CRLAWQ14). Lost Creek is directly next to a campground, and CRLAWQ14 is located in a developed section of the park close to park headquarters. A third site, Rogue River (CRLAWQ04) was rated as Intermediate.

Chemical Characteristics and Condition Estimates of Crater Lake Streams

Selected water chemistry results are presented in Table 20. Parameters measure in-situ with a water probe (see methods) are listed under “Water Quality” and parameters measured in an analytical laboratory or with a stream-side assay (Acid Neutralizing Capacity) are presented as “Water Chemistry.”

pH was found to be circum-neutral (pH of 7 = neutral) to slightly alkaline, at an average of 7.68. All pH data attained the water quality criteria in Table 2 and the average pH was in the middle of the acceptable range. Only one site was under a pH of 7 (Unnamed, CRLAWQ15) and one was over 8 (Munson Creek, CRLAWQ34). **Acid Neutralizing Capacities** were all positive, indicating Least Disturbed.

Temperature is presented as a descriptor of conditions during sampling, but varies on a daily, monthly, and seasonal basis. As such, no status or condition should be inferred from temperature readings. However, the stream temperatures measured were on the cold side, with an average of 5.5 °C, typical for high elevation, montane, and subalpine streams. **Specific Conductivity** was uniformly low, and well under the EPA threshold criteria for Least Disturbed at all sites (used as a surrogate for salinity by the EPA). **Dissolved Oxygen** values were all high, and appear well within available regulatory thresholds for available water quality criteria (Table 2).

Only three sites had measureable **Turbidity**: Sun Creek, CRLAWQ02; Munson Creek, CRLAWQ06; and an Unnamed stream, CRLAWQ15. Although these sites were above the threshold for *drinking water*, they were well below the NPS threshold of 50 NTUs.

All **anion** and **cation** measurements were far below any available water quality criteria.

Only one site had a **Total Nitrogen** level above the EPA criteria for Least Disturbed, Unnamed stream, CRLAWQ16. It should also be noted that although Intermediate, it was only 0.005 mg L⁻¹ above the threshold.

Table 20. Water chemistry parameters for streams sampled in Crater Lake, 2012. Data collected with water probe are under “Water Quality,” whereas data from laboratory analyses are under “Water Chemistry.” Cells marked in sage (lightest shading) are sites for Least Disturbed, amber (medium shading) are sites meeting EPA threshold criteria for Intermediate, and cells marked in red (darkest shading) are sites meeting EPA criteria for Most Disturbed.

Stream Name	Site Code	Water Quality					Water Chemistry						
		pH	Temp (°C)	Specific Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Sodium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Acid Neutralizing Capacity	
												(µeq/L)	(mg/L)
Cavern Creek	CRLAWQ01	7.29	8.5	35	10.7	0.0	2.63	0.13	0.23	0.01	0.016	342	17.1
Sun Creek	CRLAWQ02	7.92	6.8	57	12.1	1.4	3.78	1.81	0.23	0.00	0.022	460	23.0
Sun Creek	CRLAWQ03	7.54	5.2	38	15.2	0.0	2.88	0.23	0.26	0.02	0.027	378	18.9
Rogue River	CRLAWQ04	7.93	3.6	61	16.3	0.0	4.02	0.18	0.39	0.02	0.060	800	40.0
Wheeler Creek	CRLAWQ05	7.77	4.6	63	12.4	0.0	3.33	1.27	0.23	0.03	0.035	580	29.0
Munson Creek	CRLAWQ06	7.84	9.4	45	9.3	4.0	3.02	0.56	0.27	0.06	0.035	416	20.8
Unnamed (Trib to Vidae Creek)	CRLAWQ07	7.06	2.4	34	14.9	0.0	2.46	0.27	0.38	0.02	0.021	328	16.4
Unnamed (Trib to Union Creek)	CRLAWQ08	7.64	3.4	62	16.3	0.0	3.12	0.06	0.31	0.02	0.053	600	30.0
Lost Creek	CRLAWQ09	7.65	5.6	42	15.7	0.0	2.61	0.07	0.17	0.05	0.020	430	21.5
Mid. F. Annie Creek	CRLAWQ10	7.60	7.2	62	12.6	0.0	3.98	1.88	0.36	0.02	0.038	482	24.1
Bybee Creek	CRLAWQ11	7.64	4.9	51	11.0	0.0	4.13	0.45	0.38	0.04	0.038	540	27.0
Castle Creek	CRLAWQ12	7.65	6.9	51	12.8	0.0	3.47	0.65	0.36	0.01	0.036	364	18.2
Annie Creek	CRLAWQ13	7.71	4.5	57	15.4	0.0	3.86	1.14	0.28	0.01	0.035	492	24.6
Unnamed (Trib to Munson Creek)	CRLAWQ14	7.23	4.9	23	13.9	0.0	1.74	0.17	0.15	0.03	0.011	214	10.7
Unnamed (Trib to Bybee Creek)	CRLAWQ15	6.91	4.4	27	16.6	1.4	1.73	0.04	0.32	0.05	0.007	254	12.7
Unnamed (Trib to Bybee Creek)	CRLAWQ16	7.81	5.1	32	10.4	0.0	2.35	0.10	0.34	0.13	0.020	300	15.0
Sand Creek	CRLAWQ17	7.79	5.8	63	14.4	0.0	3.79	1.26	0.18	0.02	0.034	580	29.0
Crater Creek	CRLAWQ19	7.83	5.2	46	10.5	0.0	3.58	0.11	0.36	0.02	0.036	502	25.1
Unnamed (Trib to Sand Creek)	CRLAWQ21	7.77	5.1	55	10.2	0.0	3.75	0.49	0.19	0.04	0.042	574	28.7
Annie Creek	CRLAWQ22	7.77	5.8	52	15.3	0.0	3.53	0.77	0.26	0.03	0.033	410	20.5
Munson Creek	CRLAWQ26	7.75	3.4	41	10.2	0.0	2.83	0.44	0.30	0.08	0.031	356	17.8
Unnamed (Trib to Castle Creek)	CRLAWQ28	7.88	6.6	35	9.5	0.0	2.46	0.11	0.22	0.02	0.017	338	16.9
Munson Creek	CRLAWQ34	8.68	7.7	41	8.7	0.0	2.86	0.46	0.28	0.10	0.033	338	16.9
Average		7.68	5.5	47	12.8	0.3	3.13	0.55	0.28	0.04	0.030	438	21.9
SD		0.35	1.7	12	2.6	0.9	0.71	0.55	0.07	0.03	0.013	134	6.7
Median		7.75	5.2	46	12.6	0.0	3.12	0.44	0.28	0.02	0.033	416	20.8
Range		6.9–8.68	2.4–9.4	23–63	8.7–16.6	0–4.0	1.73–4.13	0.04–1.88	0.15–0.39	0–0.13	0.007–0.060	214–800	10.7–40.0

Total Phosphorous levels were elevated at all but one park stream (Unnamed stream, CRLAWQ15). Three sites were above the Intermediate category and in the Most Disturbed condition: Rogue River, CRLAWQ04, and two Unnamed streams, CRLAWQ08 and CRLAWQ21. The widespread prevalence of high phosphorous levels suggests a natural landscape source and is a topic in the discussion.

Riparian Characteristics of Crater Lake Streams

The riparian zones of Crater Lake streams are dominated by coniferous canopy cover (Table 21), although the meadows abutting many of the streams limit the overall shading (average of 65% stream shading). Park-wide canopy cover is close to equal between big trees (>0.3 m dbh) and small trees (<0.3 m dbh), at 10% and 11% average respectively. However, per stream site, this was variable. Understory composition was more varied, with an increase in the prevalence of mixed and deciduous cover.

Vertebrate Assemblage and Condition of Crater Lake Streams

Results of electrofishing and visual encounters of vertebrate species, along with summaries of abundance, richness, and the EPA Vertebrate MMI are presented in Table 22. The most widespread vertebrate was the Brook Trout (*Salvelinus fontinalis*), at nine of the 23 sites surveyed. Brook Trout is an introduced nonnative, and its presence is a contributor to the rating of all but one site in the Intermediate condition according to the EPA Vertebrate MMI. All observed vertebrate species have been previously recorded in the park. Several sites were not electrofished due to reported presence of Bull Trout or being short-staffed at time of sampling.

The only site with a Least Disturbed rating was Sun Creek, (CRLAWQ02), where substantial restoration efforts to save the headwaters population of the endangered Bull Trout (*Salvelinus confluentus*) have occurred over the past decade.

Macroinvertebrate Assemblage and Condition of Crater Lake Streams

A total of 15,691 individual macroinvertebrates were collected, sorted, and identified from Crater Lake streams (a complete taxa list is given in Appendix D). A conservative estimate of the total species richness is 165 species (many taxa are only identified to family or genus level, hence the true species richness is likely higher; likewise there are instances where a specific individual was only able to be identified to family, but a separate individual was identified to genus or species, duplicating the “taxonomic units.” (See the full protocol [Dinger et al. 2013] or Cuffney et al. 2007 for more detail on ambiguous taxa). Summary statistics (Taxa Richness and measures of biological integrity) for each site are provided in Table 23. The most diverse site was Crater Creek (CRLAWQ19) with 65 total taxa, while the most depauperate site was an Unnamed stream (CRLAWQ21) with 32 taxa.

For calculating Hilsenhoff Biotic Index (HBI), tolerance values were available for 173 of the 174 taxonomic units (which include individuals only identified to higher taxonomic units due to poor keys, damaged specimens, or immature life stages). Taxa with no tolerance value were excluded from HBI calculations. The lowest HBI (indicating a preponderance of intolerant, clean-water

indicating organisms) was an Unnamed stream (CRLAWQ21), while the highest HBI (indicating more organisms tolerant of poor water quality) was Unnamed stream (CRLAWQ16).

Eight streams rated Intermediate under the EPA Invertebrate MMI condition rating, while the 15 other sites were all Least Disturbed. Eleven of the 23 sites were rated as “Slight impairment” under the Oregon Western Streams IBI condition assessment. The large number of stream reaches not under the most desirable conditions (i.e., Least Disturbed or “No impairment”) is probably a function of the geography and climate of Crater Lake and not from anthropogenic influences or disturbance.

Table 21. Riparian characteristics of Crater Lake streams, 2012. For composition: D = Deciduous, C = Coniferous, E = Broadleaf Evergreen, N = None, and M = Mixed (10% or more of multiple types).

Stream name	Site Code	Shading	Legacy Tree Height (m)	Canopy			Understory		
				Big Tree	Small Tree	Composition	Woody	Non-Woody	Composition
Cavern Creek	CRLAWQ01	88%	25.6	27%	15%	100% C	33%	20%	45% M, 27% C, 27% D
Sun Creek	CRLAWQ02	77%	42.4	3%	10%	64% N, 23% C, 14% D	66%	24%	100% D
Sun Creek	CRLAWQ03	43%	21.8	8%	10%	64% C, 36% N	7%	61%	59% N, 32% C, 9% M
Rogue River	CRLAWQ04	61%	32.2	15%	23%	100% C	47%	1%	50% C, 50% M
Wheeler Creek	CRLAWQ05	81%	27.1	19%	11%	82% C, 18% N	15%	48%	86% C, 9% M, 5% N
Munson Creek	CRLAWQ06	61%	28.4	11%	10%	59% C, 41% N	23%	10%	91% C, 9% M
Unnamed (Trib to Vidae Creek)	CRLAWQ07	80%	36.2	25%	10%	95% C, 5% N	48%	11%	82% M, 14% C, 5% D
Unnamed (Trib to Union Creek)	CRLAWQ08	70%	27.0	2%	13%	77% C, 23% N	35%	5%	73% M, 14% C, 14% N
Lost Creek	CRLAWQ09	84%	18.3	11%	14%	95% C, 5% D	21%	5%	55% M, 45% D
Middle Fork Annie Creek	CRLAWQ10	42%	37.4	4%	3%	82% N, 18% C	1%	83%	82% N, 18% C
Bybee Creek	CRLAWQ11	77%	38.5	17%	14%	77% C, 23% N	57%	20%	59% M, 27% D, 14% C
Castle Creek	CRLAWQ12	83%	29.1	12%	13%	77% C, 23% N	60%	13%	55% D, 36% M, 5% C, 5% N
Annie Creek	CRLAWQ13	51%	56.7	8%	4%	55% N, 45% C	33%	62%	77% D, 18% M, 5% N
Unnamed (Trib to Munson Creek)	CRLAWQ14	83%	17.0	9%	15%	82% C, 14% N, 5% D	43%	16%	50% C, 36% M, 14% D
Unnamed (Trib to Bybee Creek)	CRLAWQ15	73%	26.6	11%	13%	86% C, 14% N	21%	6%	84% C, 16% N
Unnamed (Trib to Bybee Creek)	CRLAWQ16	52%	23.1	8%	12%	68% C, 32% N	17%	0%	82% C, 18% N
Sand Creek	CRLAWQ17	59%	35.4	9%	5%	59% N, 41% C	26%	1%	45% D, 23% N, 18% C, 14% M
Crater Creek	CRLAWQ19	88%	42.5	12%	7%	68% C, 32% N	46%	8%	68% M, 18% C, 14% D
Unnamed (Trib to Sand Creek)	CRLAWQ21	63%	22.9	3%	18%	86% C, 14% N	21%	21%	100% C
Annie Creek	CRLAWQ22	54%	30.7	15%	23%	100% C	17%	71%	73% C, 18% N, 5% D, 5% M
Munson Creek	CRLAWQ26	34%	24.4	4%	7%	59% N, 41% C	19%	51%	91% C, 9% N
Unnamed (Trib to Castle Creek)	CRLAWQ28	76%	29.2	5%	10%	86% C, 14% N	33%	10%	100% C
Munson Creek	CRLAWQ34	23%	23.3	2%	1%	86% N, 14% C	8%	67%	77% C, 23% N
Average		65%	30.3	10%	11%		30%	27%	
SD		18%	9.1	7%	5%		18%	26%	
Median		70%	28.4	9%	11%		26%	16%	
Range		23–88%	17.0–56.7	2–27%	1–23%		1–66%	0–83%	

Table 22. Vertebrate species and metrics for Crater Lake streams, 2012. Cells colored amber (medium shading) indicate the site meets the numeric value for Intermediate condition assessment using EPA threshold values. Only one site, Sun Creek (CRLAWQ02), met the Least Disturbed threshold (in sage color—lightest shading). * indicates site not electrofished.

Stream Name	Site Code	Metrics			Amphibian				Fish	
		Total Abundance	Total Richness	EPA Vertebrate MMI	Tailed Frog (<i>Ascaphus truei</i>)	Cascade Frog (<i>Rana cascadae</i>)	Unidentified Frog	Tree Frog (<i>Pseudacris regilla</i>)	Brook Trout (<i>Salvelinus fontinalis</i>) Nonnative	Bull Trout (<i>Salvelinus confluentus</i>)
Cavern Creek	CRLAWQ01	13	1	52.1					13	
Sun Creek	CRLAWQ02	13	1	80.5						13
Sun Creek	CRLAWQ03	*	*	*						
Rogue River	CRLAWQ04	0	0							
Wheeler Creek	CRLAWQ05	1	1	42.6			1			
Munson Creek	CRLAWQ06	3	1	52.1					3	
Unnamed (Trib to Vidae Creek)	CRLAWQ07	0	0							
Unnamed (Trib to Union Creek)	CRLAWQ08	0	0							
Lost Creek	CRLAWQ09	*	*	*						
Middle Fork Annie Creek	CRLAWQ10	6	1	52.1					6	
Bybee Creek	CRLAWQ11	11	1	52.1					11	
Castle Creek	CRLAWQ12	4	2	55.7	1				3	
Annie Creek	CRLAWQ13	5	1	52.1					5	
Unnamed (Trib to Munson Creek)	CRLAWQ14	18	1	52.1					18	
Unnamed (Trib to Bybee Creek)	CRLAWQ15	1	1	42.6		1				
Unnamed (Trib to Bybee Creek)	CRLAWQ16	0	0							
Sand Creek	CRLAWQ17	5	1	52.1					5	
Crater Creek	CRLAWQ19	6	1	42.6		6				
Unnamed (Trib to Sand Creek)	CRLAWQ21	*	*	*						
Annie Creek	CRLAWQ22	0	0							
Munson Creek	CRLAWQ26	2	1	52.1					2	
Unnamed (Trib to Castle Creek)	CRLAWQ28	1	1	42.6				1		
Munson Creek	CRLAWQ34	*	*	*		4				
Average		6	1	51.1						
SD		5	0	9.5						
Median		5	1	52.1						
Range		0–18	0–2	42.6–80.5						

Table 23. Macroinvertebrate metrics for Crater Lake streams, 2012. Cells colored amber indicate EPA condition estimate of Intermediate. Cells colored sage (lightest shading) indicate Least Disturbed where EPA thresholds exist. For the Regional Oregon IBI, amber (medium shading) represent cells in the “slight impairment”—other rankings denote this as “good” as opposed to “very good” or “fair.”

Stream Name	Site Code	Total Taxa Richness	Shannon Diversity	Hilsenhoff Biotic Index	Regional	
					EPA West-Wide Macroinvertebrate MMI	Oregon Western Streams IBI
Cavern Creek	CRLAWQ01	49	2.87	3.33	71	68
Sun Creek	CRLAWQ02	51	3.13	2.31	89	92
Sun Creek	CRLAWQ03	48	2.83	2.19	78	88
Rogue River	CRLAWQ04	44	2.43	2.44	71	60
Wheeler Creek	CRLAWQ05	57	2.89	3.30	78	80
Munson Creek	CRLAWQ06	54	3.27	3.35	84	88
Unnamed (Trib to Vidae Creek)	CRLAWQ07	42	2.80	3.33	66	64
Unnamed (Trib to Union Creek)	CRLAWQ08	35	2.77	2.06	68	60
Lost Creek	CRLAWQ09	34	2.99	3.46	58	68
Middle Fork Annie Creek	CRLAWQ10	52	2.62	3.34	65	80
Bybee Creek	CRLAWQ11	36	2.33	3.72	72	80
Castle Creek	CRLAWQ12	34	2.05	3.13	67	60
Annie Creek	CRLAWQ13	42	2.65	3.70	70	80
Unnamed (Trib to Munson Creek)	CRLAWQ14	44	2.93	3.70	72	72
Unnamed (Trib to Bybee Creek)	CRLAWQ15	35	2.58	3.43	67	72
Unnamed (Trib to Bybee Creek)	CRLAWQ16	38	2.88	4.09	73	68
Sand Creek	CRLAWQ17	46	2.97	3.16	84	88
Crater Creek	CRLAWQ19	65	3.50	2.96	80	88
Unnamed (Trib to Sand Creek)	CRLAWQ21	32	1.86	1.15	69	68
Annie Creek	CRLAWQ22	46	2.49	3.23	80	76
Munson Creek	CRLAWQ26	48	2.74	2.20	78	80
Unnamed (Trib to Castle Creek)	CRLAWQ28	52	3.55	3.28	79	88
Munson Creek	CRLAWQ34	46	2.62	1.86	79	76
Average		45	2.77	2.99	74	76
SD		8	0.40	0.72	7	10
Median		46	2.80	3.28	72	76
Range		32–65	1.86–3.55	1.15–4.09	58–89	60–92

Discussion

General Issues

This was the second year of monitoring using the KLMN Wadeable Streams Monitoring protocol. Of primary note, the protocol has a goal of sampling 25–30 sites each at Redwood Parks and Crater Lake, but we were unable to meet this goal (23 sites were sampled in each of Redwood Parks and Crater Lake). Oregon Caves is set at three due to limited acreage. Reasons for undersampling were largely due to the logistical constraints of starting a new monitoring program and staffing problems outside of our control. Access to remote sites was difficult at both parks, and often the crew would drive/hike several hours only to find that the slope leading down to the stream was hazardous, or that the stream was ephemeral (drying out in the summer months). Ephemeral streams are not covered in this protocol due to the confounding factor that drying has in determining ecological integrity and anthropogenic impact. Future sampling seasons (2015 for Oregon Caves, Redwood Parks, and Crater Lake) will be more efficient and give us a higher probability of achieving our target goals. Additional issues that prevented fully completing sampling at the sites were 1) delays in hiring the field crew, and 2) one crew member departing early for other employment. Many of these constraints will be absent in future years (although new obstacles may arise), hopefully increasing the ability to reach 30 sites.

The immediate outcome of sampling fewer than 30 sites is a reduction of precision in the annual status assessments (i.e., increased error bars/standard deviations). Longer-term issues, if follow-up years are unable to increase the sample size, will be a reduction in power to detect trends in park aquatic resources, although a total sample size of 20 is the minimum to achieve the goals of the protocol.

This protocol makes use of EPA Wadeable Streams Assessment threshold criteria for assigning “condition” to assess ecological integrity using a diverse array of indicators (physical, chemical, and biological). From a management perspective, three main points should be emphasized:

1. The programmatic goal of the Wadeable Streams Assessment is to assess the amount of impairment in the sampling frame and not to identify the impairment at the site-specific level. Hence, within the EPA program, errors in site-specific condition do occur, are recognized to occur, and are hopefully minimized; however, region-wide averages have still driven the development of threshold criteria. Intermediate or Most Disturbed sites identified by this program should be investigated, but are not an immediate call for “crisis mode,” or an immediate management change.
2. Threshold criteria are based on regional reference conditions that were established for mountainous areas of the western United States, and localized values based on park reference sites may provide more accurate per-site and park-wide assessment. An example is the threshold criteria used for Total Phosphorous, where Crater Lake showed possible influence of local geology, exhibiting naturally higher phosphorous than the EPA derived values. When a majority of park sites show increased values in a single metric, and the park can

conclusively show that these sites should be rated as Least Disturbed, the creation of park-specific thresholds may be necessary through research programs or research partners.

3. The use of multiple indices allows for the potential of some indices to rate a stream condition as Least Disturbed whereas others might rate it as Most Disturbed—creating a perceived paradox in stream condition. Indeed, most sites in Crater Lake had one or more “flags” (“Intermediate or Most Disturbed”). Rather than view this as a paradox, managers should consider two points: (a) a weight of evidence approach, and (b) a specificity of impact approach. In the weight of evidence approach, a stream site that has multiple “flags” across multiple categories (e.g., biological, chemical, and biological) would suggest a truly imperiled stream. In the specificity of impact approach, a stream that is Intermediate in one category and not the others can be used to help pinpoint what the impact is that might be affecting water quality. As an example, a stream or lake that has elevated phosphorous and low nitrogen may be indicative of a system impacted by agriculture, whereas a system with low phosphorous and high nitrogen may be indicative of a system impacted by depositional pollution (although nitrogen is also associated with fertilizer runoff).

Oregon Caves National Monument and Preserve

The streams of Oregon Caves were classified as being in the Least Disturbed condition based on applying the metrics and thresholds of EPA and regional invertebrate metrics. One pattern that emerged in Oregon Caves is several flags (two per stream reach) in physical metrics (Table 24), although we were unable to electrofish two sites to measure the full complement of indicators.

Table 24. Condition summary for Oregon Caves streams, 2012. Flags indicate each incidence of Intermediate or Most Disturbed condition.

Stream Name	Site Code	Number of Flags			Sum
		Physical	Chemical	Biological	
Cave Creek	ORCAWQ01	2	1	0	3
Lake Creek	ORCAWQ02	2	0	0	2
No Name Creek	ORCAWQ03	2	1	0	3

The physical flags are in the categories of Riparian Cover and Relative Bed Stability (RBS). As a regionwide metric, the Riparian Cover is a combination of the estimated areal coverage of woody vegetation at the canopy, understory, and ground cover along the stream reach. However, much of the understory and ground cover in Oregon Caves (and Redwood Parks) is composed of ferns (probably Sword Fern, *Polystichum munitum*), which does not fall in the “woody vegetation” category, but rather is an herbaceous type of understory. Hence, despite lush and complex riparian vegetation in both the understory and ground cover, the stream reaches of Oregon Caves are ranked as having an underdeveloped riparian zone. This illustrates the necessity of follow-up interpretation on all EPA and other water quality metric scoring.

The second set of flags in the physical category was for RBS. This is a potentially valuable metric, in that the scoring can suggest causes of impairment in two opposite ends of a disturbance spectrum;

strong negative values indicate increased sedimentation, and strong positive values suggest a lack of sediments. Common to many impacted western streams, these disturbances arise from (1) timber and road impacts causing increased sediments, and (2) water withdrawal or diversion/dams that prevent natural sedimentation. Neither of these are identified stressors within Oregon Caves. On Lake Creek, (ORCAWQ02), water is diverted for the monument's water supply, but the sampled reach is *above* the withdrawal. What is clear is that the nature of these streams is different—Cave Creek (ORCAWQ01) is a narrow, forested stream with moderate hillslopes, and Lake Creek (ORCAWQ02) and No Name Creek (ORCAWQ03) are more open, with higher amounts of bedrock, more boulders, and steep hillslopes. Lastly, these RBS values are calculated using a rapid, quantitatively simplified measure that does not incorporate woody debris; the eventual incorporation of downed woody debris in the stream channel will impact the final numbers and provide more accurate assessments of the sediment surplus or paucity.

All measures of Riparian Disturbance were in the Least Disturbed category, however it should be noted that the highest measure was on Cave Creek (ORCAWQ01), which is proximal to several trails within the park. The observed impacts were the trails, and hence the lack of any other disturbance categories (e.g., trash) should alleviate any specific concern with this stream reach. However, turbidity and other measurements of potential impacts associated with trails should be watched over time.

The only additional flags were from Total Phosphorous levels being elevated in the Intermediate category. However, the sites with elevated TP levels (Cave Creek and No Name Creek) occur in areas of meta-basalt drainages (Figure 9; KellerLynn 2011). Igneous rock, like basalt, is a naturally high source of phosphorous (Cole 1994; Wetzel 2001).

Due to delays in obtaining a permit from the US Forest Service for sampling amphibians in the sites located outside the 2012 park boundary, we were unable to sample two of the three sites for aquatic vertebrates at Oregon Caves. Now that the expansion area has been officially added to Oregon Caves as a preserve, we will be able to conduct future sampling for a fuller inventory of the vertebrate community.

Although only three sites were sampled, the macroinvertebrate diversity at all three sites was remarkably high—between 64 and 73 taxa at each site—with particularly high amounts of stoneflies (Plecoptera) and caddis flies (Trichoptera). Using a species richness estimator (Chao1; Chao 1984) that uses the number of “singletons” and “doubletons,” (taxa that only occur in the sample set once or twice) to extrapolate to a potential “full inventory,” the total number of taxa in Oregon Caves is ~121 taxa, although caution should be used for estimates based on only three samples. Future sampling will add to this dataset and provide updated estimates of the macroinvertebrate species list for Oregon Caves.

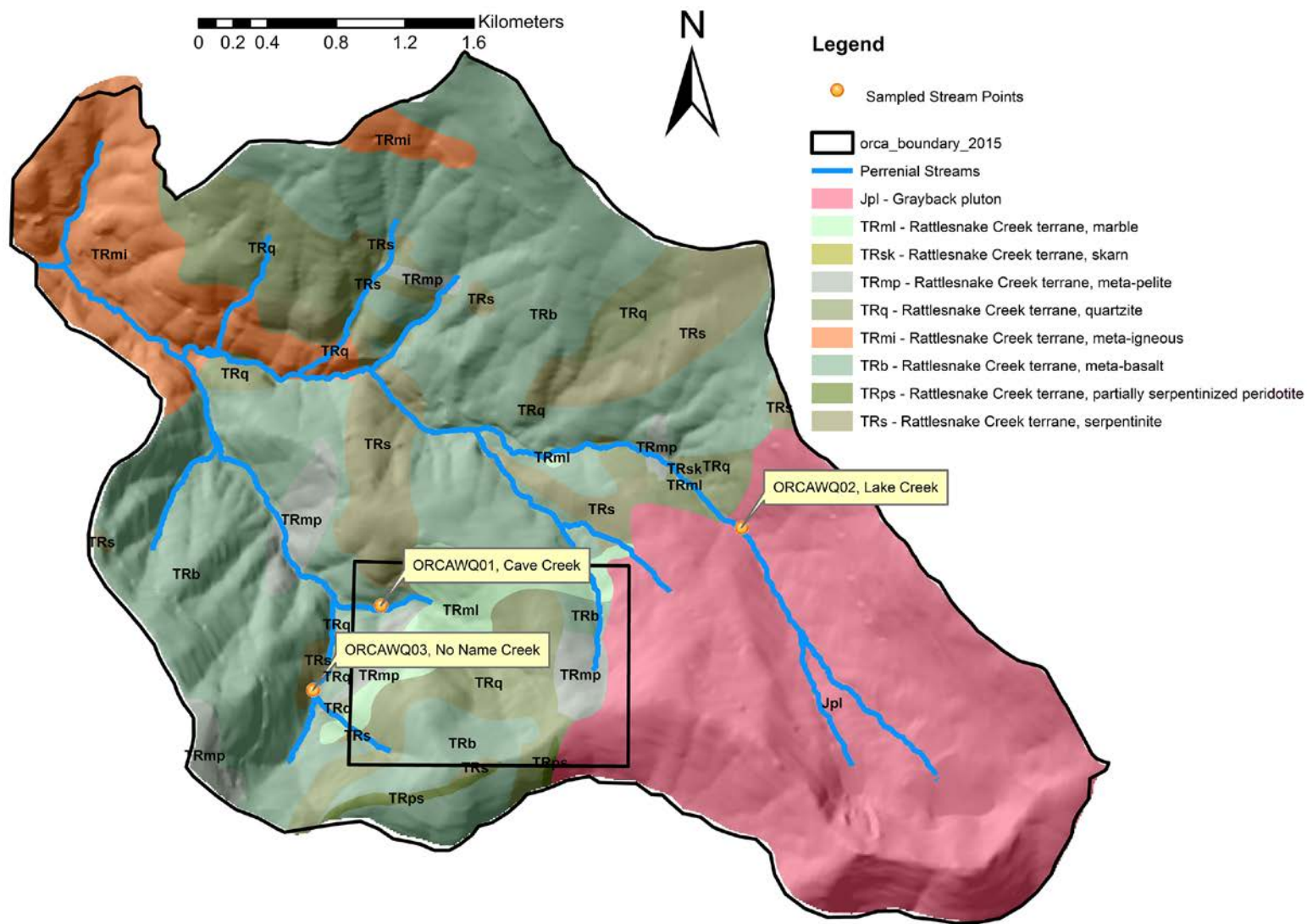


Figure 9. Geologic map of Oregon Caves National Monument and Preserve and 2012 stream sampling locations.

Redwood National and State Parks

Most stream sites at the Redwood Parks had at least one flag, although two sites were notable in the absence of any flags—these streams should be considered good examples of unimpaired ecological conditions (Table 25). These sites were Bummer Lake Creek (REDWWQ08) and Wilson Creek (REDWWQ09). Furthermore, there were another five sites with only one flag.

Notable too, is that the Redwood Parks had large amounts of fern understory, which is not counted as a “woody stem,” and as such does not contribute to Riparian Cover by the standards of the EPA metric (see description in Oregon Caves section above for more information). A full 15 sites were flagged due to this, but the regional reality of the Pacific Northwest is that these sites have well developed riparian zones, and should not be considered impaired. Riparian Cover at Redwood Creek (REDWWQ25) was flagged, but this site experiences large amounts of fluctuation in water levels in a season, and sampling commenced when much of the streamside zone was a previously inundated stream channel.

Only 16 sites had a complete dataset to allow for the measurement of Relative Bed Stability, a measure of the excess or lack of sediments in a stream. Of these, seven sites were Least Disturbed and eight sites were Intermediate, with a single site being Most Disturbed. The most disturbed site was McArthur Creek (REDWWQ01), with a large negative number, indicative of excess sediments based on its geomorphological conditions. The average sediment size in this creek was 0.1 mm, indicating that most substrate was fine sediments, silt, or clay. The rest of the sites in the Intermediate category had positive values, reflecting an excess of larger sized substrate. For a region with large concerns about sediment impacts relating to timber harvest (Rehn et al. 2005), higher amounts of these larger substrates can be indicative of successful mitigation techniques. One site on Redwood Creek (REDWWQ04), the highest elevation in the watershed that was sampled, had a larger sediment size than expected, possibly indicative of water withdrawal.

Turbidity across the park was low. Only two sites had registered a value above 0 NTUs (Nephelometric Turbidity Units), and these were McArthur Creek (REDWWQ01) and an Unnamed Creek (REDWWQ10). However, high sedimentation during high winter flows and flooding events remains a concern.

Conditions based on nutrients highlight three stream reaches of concern. First, overall amounts of Total Phosphorous were low, with most sites being Least Disturbed and only five sites ranking as Intermediate. Additionally, several of these Intermediate sites were just barely above the threshold for Least Disturbed (0.001 to 0.003 mg L⁻¹ above). Phosphorous does not appear to be a large stressor for the Redwood Parks. In contrast to Total Phosphorous levels, there were three sites that ranked Most Disturbed for Total Nitrogen. These were McArthur Creek (REDWWQ01—0.96 mg L⁻¹); Mill Creek (REDWWQ15—0.61 mg L⁻¹); and Peacock Creek (REDWWQ17—0.36 mg L⁻¹). Because many of the other stream sites (16 of 23) were in the Least Disturbed category, the possibility of these conditions being a result of background higher levels of nitrogen is excluded. These sites are candidates for further investigation and the search for a point-source pollution stressor.

Table 25. Condition summary for Redwood Parks streams, 2012 (ordered by Site Code). Flags indicate each incidence of Intermediate or Most Disturbed condition.

Stream Name	Site Code	Number of Flags			Sum
		Physical	Chemical	Biological	
McArthur Creek	REDWWQ01	2	1	1	4
Unnamed (Trib to Redwood Creek)	REDWWQ02	1	1	1	3
West Branch Mill Creek	REDWWQ03	2	1	0	3
Redwood Creek	REDWWQ04	2	0	0	2
East Fork Mill Creek	REDWWQ05	1	2	0	3
Lost Man Creek	REDWWQ06	1	0	0	1
Cedar Creek	REDWWQ07	1	0	0	1
Bummer Lake Creek	REDWWQ08	0	0	0	0
Wilson Creek	REDWWQ09	0	0	0	0
Unnamed (Streelow Creek Trail)	REDWWQ10	1	1	0	2
West Branch Mill Creek	REDWWQ11	2	1	0	3
Little Lost Man Creek	REDWWQ12	1	1	0	2
Lost Man Creek	REDWWQ13	1	0	0	1
Rock Creek	REDWWQ14	1	0	0	1
Mill Creek	REDWWQ15	1	1	0	2
Redwood Creek	REDWWQ16	2	0	0	2
Peacock Creek	REDWWQ17	0	1	0	1
West Branch Mill Creek	REDWWQ19	3	0	0	3
Redwood Creek	REDWWQ20	2	0	1	3
Godwood Creek	REDWWQ21	1	1	0	2
West Branch Mill Creek	REDWWQ23	1	1	0	2
Lost Man Creek	REDWWQ24	1	1	0	2
Redwood Creek	REDWWQ25	2	0	2	4

The vertebrate stream fauna of the Redwood Parks comprised some of the most diverse fish and amphibian assemblages sampled in any of the Klamath Network parks, and they all ranked as Least Disturbed according to the Aquatic Vertebrate MMI. Bummer Lake Creek (REDWWQ08), Cedar Creek (REDWWQ07), and Godwood Creek (REDWWQ21) stand out as unimpacted, with the vertebrate EPA MMI values all above 90. The Redwood Parks were characterized by a high overall diversity of aquatic macroinvertebrates (~ >285 taxa), which could potentially be due to the diversity of stream sizes sampled. Our sampling frame included both 1st order headwater streams, and larger order (4th and 5th) downstream reaches of substantial watersheds. This is in contrast to the other parks of the network, especially Crater Lake and Lassen Volcanic, where most of the streams are 1st and 2nd order headwaters. This introduces greater habitat variability and niches for a larger range of macroinvertebrates.

Using a species richness estimator (Chao1; Chao 1984) that uses the number of “singletons” and “doubletons,” (taxa that only occur in the sample set once or twice) to extrapolate to a potential “full inventory,” the total number of taxa in the Redwood Parks is ~323 taxa. Future sampling will add to this dataset and provide updated estimates of the macroinvertebrate species list for the Redwood Parks.

Although most sites were rated as Least Disturbed by either the West-wide Macroinvertebrate MMI or the North Coast CA MMI, a few patterns were evident: (1) The lowest West-wide MMI was at McArthur Creek, also identified to have Most Disturbed Total Nitrogen levels; (2) Redwood Creek (REDWWQ20 and REDWWQ25; and the further downstream reaches) had the only sites rated as Fair by the North Coast IBI, and is also identified as a 303(d) water quality impaired site for sediments and temperature (California Environmental Protection Agency State Water Resources Control Board 2010), and (3) Redwood Creek (REDWWQ04), despite other Redwood Creek sites having lower diversity, also had the second highest diversity, with 75 taxa. The results for McArthur Creek suggest the need for follow-up investigations on the nature of the stream to understand if observed results are from natural or anthropogenic influences. The results for Redwood Creek, albeit mixed, suggest several possible mechanisms: (1) temperature and sediment continue to impair macroinvertebrate assemblages; (2) the natural wider, slower character of downstream reaches of Redwood Creek have a naturally more tolerant assemblage of macroinvertebrates; and/or (3) seasonal expansion/contraction of the Redwood Creek waters may promote more tolerant communities due to drying (or rumored upstream water withdrawal/impacts from marijuana cultivation in the upper watershed) more common to desert southwest streams (Stanley et al. 1997).

Finally, using a weight of evidence approach the two streams receiving the most number of flags (4) were McArthur Creek (REDWWQ01) and Redwood Creek (REDWWQ25), already highlighted for specifics above. These creeks should be watched in future monitoring years for further signs of impacts and stressors. At least in the case of McArthur Creek, high numbers of flags may be the result of natural stressors, with several debris flows being recorded there in the past several decades.

Crater Lake National Park

All sites in Crater Lake had at least two flags in a combination of the physical, chemical, and biological stressor categories (Table 26). Similar to other parks of the network, the application of these West-wide thresholds for condition assessments must be viewed with follow-up analyses of natural, ambient conditions in the park.

Riparian Cover, a measure of complexity based on the areal coverage of woody canopy, woody understory, and woody ground cover, was flagged in a large percentage of sites (e.g., sites that were Intermediate or Most Disturbed). Similar to Lassen Volcanic NP (Dinger and Sarr 2014), the streams of Crater Lake move through montane meadows, with a large number of naturally occurring sedge and forb meadows. Although they are naturally occurring and unimpaired habitats, these meadow bordered streams still rank as Intermediate or Most Disturbed. Likewise, the heavy snow pack of Crater Lake in most years may also create conditions precluding a more developed riparian zone.

Table 26. Condition summary for Crater Lake streams, 2012 (ordered by Site Code). Flags indicate each incidence of Intermediate or Most Disturbed condition.

Stream Name	Site Code	Number of Flags			Sum
		Physical	Chemical	Biological	
Cavern Creek	CRLAWQ01	1	1	1	3
Sun Creek	CRLAWQ02	1	1	0	2
Sun Creek	CRLAWQ03	1	1	0	2
Rogue River	CRLAWQ04	2	1	1	4
Wheeler Creek	CRLAWQ05	2	1	1	4
Munson Creek	CRLAWQ06	1	1	3	5
Unnamed (Trib to Vidae Creek)	CRLAWQ07	0	1	2	3
Unnamed (Trib to Union Creek)	CRLAWQ08	2	1	2	5
Lost Creek	CRLAWQ09	4	1	2	7
Middle Fork Annie Creek	CRLAWQ10	1	1	2	4
Bybee Creek	CRLAWQ11	1	1	1	3
Castle Creek	CRLAWQ12	1	1	3	5
Annie Creek	CRLAWQ13	2	1	2	5
Unnamed (Trib to Munson Creek)	CRLAWQ14	2	1	2	5
Unnamed (Trib to Bybee Creek)	CRLAWQ15	2	0	3	5
Unnamed (Trib to Bybee Creek)	CRLAWQ16	2	2	1	5
Sand Creek	CRLAWQ17	2	1	1	4
Crater Creek	CRLAWQ19	1	1	1	3
Unnamed (Trib to Sand Creek)	CRLAWQ21	2	1	2	5
Annie Creek	CRLAWQ22	2	1	1	4
Munson Creek	CRLAWQ26	1	1	1	3
Unnamed (Trib to Castle Creek)	CRLAWQ28	2	1	1	4
Munson Creek	CRLAWQ34	1	1	2	4

The geology of Crater Lake also affected Relative Bed Stability, a measure of expected particle size for stream substrate versus the actual, observed particle size. For all the streams sampled in Crater Lake, this was strongly negative, indicating that substrate particle size was smaller than expected based on geomorphological features (like slope). The general interpretation based on this EPA condition metric would be that the streams of Crater Lake have an anthropogenic source of increased silt and sediment. The overall median substrate size for the combined pebble counts was 38 mm diameter, which is the size of coarse gravel (marble to tennis ball size). Rather than reflecting an input of small sediments, this pattern is likely a representation of the source material. Crater Lake and the Mount Mazama caldera were formed by a geologically recent (~7,700 years ago) volcanic

eruption, and much of the hillslope and terrain are dominated by volcanic, igneous rock (Figure 10). A high proportion of stream sampling sites are in “felsic pyroclastic” terrain, which is composed of large proportions of pumiceous lapilli (common to the Pumice Desert) that range in size from 2 to 64 mm in diameter (i.e., coarse gravel). Other streams sites lie in fine grain lithic- and crystal-rich ignimbrite (KellerLynn 2013). Hence, for the majority of sites, the strong negative readings do not indicate sediment pollution, but simply the source material.

Two sites in Crater Lake rank as Most Disturbed for Riparian Disturbance; these were Lost Creek (CRLAWQ09) and an Unnamed Stream (CRLAWQ14). Lost Creek is next to an NPS campground, and the observed disturbances included the campground itself, trash, and trails. The Unnamed stream (CRLAWQ14) is quite close to park facilities in the headquarters and visitor center area, and includes both disturbances from park buildings, pavement, pipes, and trash.

Water chemistry for Crater Lake reflected mostly Least Disturbed conditions, with the exception of Total Phosphorous, where many sites were Intermediate and Most Disturbed. Similar to Lassen Volcanic NP (Dinger and Sarr 2014) and Oregon Caves (this report), this is likely a reflection of the volcanic nature of the park unit, and not widespread nutrient pollution.

Only one site in Crater Lake that was sampled for vertebrates ranked as Least Disturbed, Sun Creek (CRLAWQ02), which is a site for Bull Trout (*Salvelinus confluentus*) restoration. All other sites with fish in Crater Lake (nine sites) were Intermediate due to the presence of Brook Trout (*Salvelinus fontinalis*). This is an unusual situation, where the occurrence of the Brook Trout, a cold water species requiring clean, fresh, relatively pristine water, would often be an indicator of good water quality, but the trout itself is a nonnative species and represents a strong stressor to native aquatic communities.

Aquatic macroinvertebrate diversity was limited to 165 species or taxa across the park, which is probably a function of several factors: (1) limited diversity of stream type (1st and 2nd order streams), (2) limited substrate diversity (mostly gravel), and (3) impact of the high snowpack/alpine climate of Crater Lake.

Using a species richness estimator (Chao1; Chao 1984) that uses the number of “singletons” and “doubletons,” (taxa that only occur in the sample set once or twice) to extrapolate to a potential “full inventory,” the total number of taxa in the Crater Lake sites is ~219 taxa. Future sampling will add to this dataset and provide updated estimates of the macroinvertebrate species list for Crater Lake.

Eight sites were ranked as Intermediate using the EPA MMI metric for macroinvertebrates, and the Oregon Western Streams IBI ranked 11 sites as “Good or Fair” (as opposed to “Very good”). Despite both of these indicators suggesting slightly impaired sites, the Hilsenhoff Biotic Index, a measure of the overall tolerance of the stream macroinvertebrates, was overall quite low (average of 2.99), suggestive of clean, high water quality streams. The discrepancy is likely due to the EPA MMI and Oregon Streams IBI being better calibrated to lower elevation, higher flow, more productive coastal or inland streams more typical of the region. Alpine and subalpine headwater stream

macroinvertebrate assemblages such as the ones in Crater Lake tend to be less diverse than forested, lower elevation streams (Vinson and Hawkins 1998).

Lastly, taking a weight of evidence approach to identifying impacted streams, one stream stands out as being a management concern, even with all the above caveats about the need for more park-based criteria thresholds for flags. This stream reach is Lost Creek (CRLAWQ09), which received seven total flags out of 11 possible. This stream is also next to a park campground, which suggests that it may receive higher impacts from visitation and should be watched for continued impacts.

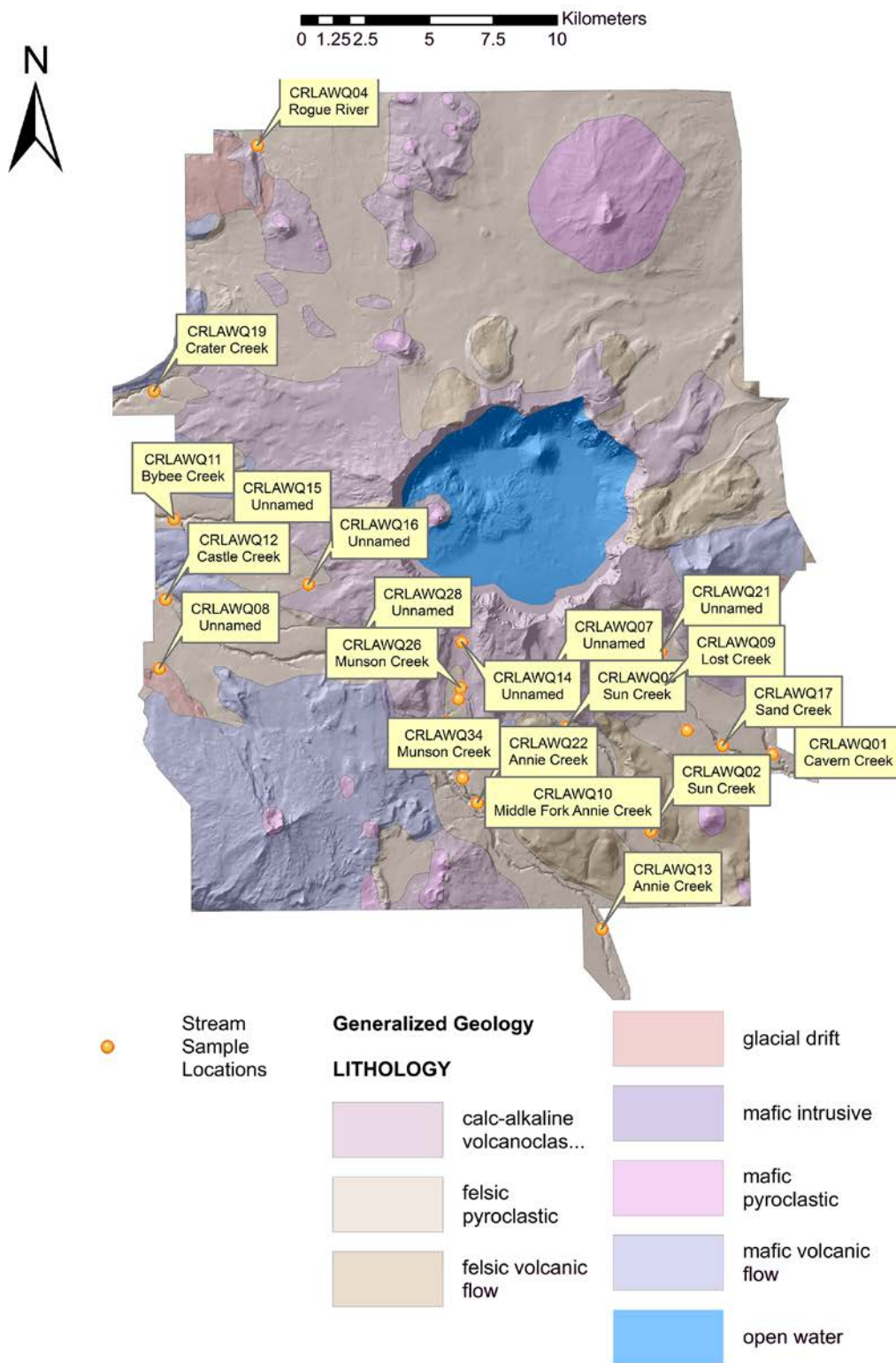


Figure 10. Simplified geologic map of Crater Lake National Park and 2012 sampling locations.

Conclusions

This was the second year of monitoring streams in the Klamath Network. Overall stream conditions in the three park service units that were surveyed appear to be in the Least Disturbed category, with specific concerns identified. No indications of large scale water quality criteria exceedances were observed (as in Table 2). Criteria set forth by the EPA Wadeable Streams Assessment (Table 1) provide some guidance and assessment for stream condition, but may need regional calibration owing to natural, localized reference conditions. Sampling will continue at these parks in 2015, with annual reports and more comprehensive Analysis and Synthesis reports completed thereafter.

In general, the application of broadly developed multimetric indices should be approached cautiously in these early years. Site-specific characteristics or distinctive disturbance histories may yield conflicting results. Interpretation should be cautious. In future years, a better understanding of the unique characteristics of the stream reaches in each park will hopefully allow us to better differentiate anthropogenic impacts from natural variation.

Additionally, two refinements will be made in the future as we incorporate more EPA reporting tools: (1) Future RBS values will incorporate woody debris and pool depth in calculating expected substrate size [current reported values are based on “rapid, quick assessment”], and (2) observed/expected ratios of biodiversity loss (for macroinvertebrates) will be calculated.

Literature Cited

- Brousseau, C. M., and R. G. Randall. 2008. Assessment of long-term trends in the littoral fish community of Hamilton Harbour using an Index of Biotic Integrity. Great Lakes Laboratory for Fisheries and Aquatic Sciences. Canadian Technical Report of Fisheries and Aquatic Sciences 2811. Burlington, Ontario, Canada.
- California Environmental Protection Agency State Water Resources Control Board. 2010. 2010 Integrated Report (Clean Water Act Section 303(d) List / 305(b) Report) – Statewide. Online report available at: http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml (accessed 22 April 2012).
- Chao, A. 1984. Non-parametric estimation of the number of classes in a population. *Scandinavian Journal of Statistics* 11:265-270.
- Cole, G. A. 1994. Textbook of Limnology, 4th edition. Waveland Press, Inc. Prospect Heights, Illinois.
- Cuffney, T. F., M. D. Bilger, and A. M. Haigler. 2007. Ambiguous taxa: Effects on the characterization and interpretation of invertebrate assemblages. *Journal of the North American Benthological Society* 36(2):286-307.
- Dinger, E. C., and D. A. Sarr. 2014. Integrated aquatic community and water quality monitoring of wadeable streams in the Klamath Network – Annual report: 2011 results from Whiskytown National Recreation Area and Lassen Volcanic National Park. Natural Resource Technical Report NPS/KLMN/NRTR—2014/904. National Park Service, Fort Collins, Colorado.
- Dinger, E. C., D. A. Sarr, S. R. Mohren, and R. L. Hoffman. 2012. Integrated aquatic community and water quality monitoring of mountain ponds and lakes in the Klamath Network. Natural Resource Report NPS/KLMN/NRR—2012/484. National Park Service, Fort Collins, Colorado.
- Dinger, E. C., D. A. Sarr, S. R. Mohren, C. E. Stanley, and K. M. Irvine. 2013. Integrated aquatic community and water quality monitoring of wadeable streams in the Klamath Network. Natural Resource Report NPS/KLMN/NRR—2013/669. National Park Service, Fort Collins, Colorado.
- Environmental Protection Agency (USEPA). 2006. Wadeable streams assessment: A collaborative survey of the nation's streams. EPA 841-B-06-002. Office of Research and Development, Office of Water, Washington, D.C.
- Environmental Protection Agency (USEPA). 2008. EPA's 2008 report on the environment. EPA/600/R-07/045F. National Center for Environmental Assessment, Washington, D.C.

- Environmental Protection Agency (USEPA). 2009. National rivers and streams assessment: Field operation manual. EPA-841-B-07-009. U.S. Environmental Protection Agency, Washington, D.C.
- Fetscher, A. E., L. Busse, and P. R. Ode. 2010. Standard operating procedures for collecting stream algae samples and associated physical habitat and chemical data for ambient bioassessments in California. California State Water Resources Control Board, Surface Water Ambient Monitoring Program (SWAMP), Bioassessment SOP 002. Available at: http://www.waterboards.ca.gov/water_issues/programs/swamp/docs/sop_algae.pdf.
- Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. *Great Lakes Entomology* 20:31-39.
- Hilsenhoff, W. L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society* 7:65-68.
- Hoffman, R. L., C. R. Currens, and M. A. Madej. 2005. Klamath Network water quality report (phase II). Klamath Inventory and Monitoring Network, Ashland, Oregon.
- Karr, J. R. and E. W. Chu. 1999. Restoring life in running waters: Better biological monitoring. Island Press, Washington, D.C.
- Kaufmann, P. R., P. Levine, E. G. Robison, C. Seeliger, and D. V. Peck. 1999. Quantifying physical habitat in wadeable streams. EPA/620/R-99/003. U.S. Environmental Protection Agency, Washington D.C.
- KellerLynn, K. 2011. Oregon Caves National Monument: Geological resources inventory report. Natural Resources Report NPS/NRSS/GRD/NRR—2011/457. National Park Service, Fort Collins, Colorado.
- KellerLynn, K. 2013. Crater Lake National Park: Geological resources inventory report. Natural Resources Report NPS/NRSS/GRD.NRR—2013/719. National Park Service, Fort Collins, Colorado.
- Kincaid, T. M. 2012. User guide for spsurvey, Version 2.4 – Probability survey design and analysis function. Available at: http://www.epa.gov/nheerl/arm/documents/design_doc/UserGuide.pdf (accessed 27 February 2013).
- Omernik, J. M. 1987. Ecoregions of the conterminous United States. Map (Scale 1:7,500,000). *Annals of the Association of American Geographers* 77(1):118-125.
- Oregon Watershed Enhancement Board. 1999. Water Quality Monitoring: Technical Guide Book. Salem, Oregon. Available at: http://www.oregon.gov/oweb/docs/pubs/wq_mon_guide.pdf
- Rehn, A. C., P. R. Ode, and J. T. May. 2005. Development of a Benthic Index of Biotic Integrity (B-IBI) for wadeable streams in northern coastal California and its application to regional 305(b)

- assessment. Final Technical Report. Surface Water Ambient Monitoring Program. California Department of Fish and Game Aquatic Bioassessment Laboratory, Rancho Cordova, California.
- Rosenberg, D. M., and V. H. Resh, editors. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York.
- Sarr, D. A., D. C. Odion, S. R. Mohren, E. E. Perry, R. L. Hoffman, L. K. Bridy, and A. A. Merton. 2007. Klamath Network vital signs monitoring plan. Natural Resource Report NPS/KLMN/NRR—2007/016. National Park Service, Fort Collins, Colorado.
- Stanley, E. H., S. G. Fisher, and N. B. Grimm. 1997. Ecosystem expansion and contraction in streams. *BioScience* 47:427-435.
- Stevens Jr., D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99:262-278.
- Stoddard, J. L., D. V. Peck, A. R. Olsen, D. P. Larsen, J. Van Sickle, C. P. Hawkins, R. M. Hughes, T. R. Whittier, G. Lomnický, A. T. Herlihy, P. R. Kaufmann, S. A. Peterson, P. L. Ringold, S. G. Paulsen, and R. Blair. 2005. Environmental Monitoring and Assessment Program (EMAP) western streams and rivers statistical summary. EPA 620/R-05/006. U.S. Environmental Protection Agency, Washington, D.C.
- Stoddard, J. L., D. V. Peck, S. G. Paulsen, J. Van Sickle, C. P. Hawkins, A. T. Herlihy, R. M. Hughes, P. R. Kaufmann, D. P. Larsen, G. Lomnický, A. R. Olsen, S. A. Peterson, P. L. Ringold, and T. R. Whittier. 2005. An ecological assessment of western streams and rivers. EPA/620/R-05/005. U.S. Environmental Protection Agency, Washington, D.C.
- Vinson, M. R., and C. P. Hawkins. 1998. Biodiversity of stream insects: Variation at local, basin, and regional scales. *Annual Review of Entomology* 43:271-293.
- Wetzel, R. G. 2001. *Limnology: Lake and river ecosystems*, 3rd edition. Elsevier Academic Press, San Diego, California.

Appendix A. Example of MMI Calculation and Scoring

To facilitate understanding of MMIs, below is an exposition on how a representative MMI, the California Northern Coastal Region Benthic Index of Biotic Integrity (Rehn et al. 2005), is calculated using data collected from Boulder Creek in Whiskeytown (WHISWQ02). Metric calculations begin using the species list provided by the contractor, Rhithron Associates, Inc.

Taxon	Count	Unique?	Taxon	Count	Unique?
Non-insect taxa			Trichoptera (Cont.)		
<i>Turbellaria</i>	1		<i>Polycentropus</i>	1	
<i>Sphaeriidae</i> - immature	1		<i>Rhyacophila</i> - early instar or damaged	4	
<i>Lebertia</i>	1		<i>Rhyacophila</i> Betteni Gr.	9	
<i>Torrenticola</i>	15		<i>Gumaga</i>	18	
<i>Mesenchytraeus</i>	2		<i>Sericostomatidae</i> - pupa	5	
<i>Lumbriculidae</i> - damaged	1		<i>Neophylax splendens</i>	9	
<i>Spirosperma</i>	4		Coleoptera		
Ephemeroptera			<i>Ampumixis dispar</i>	3	
<i>Ameletus</i>	16		<i>Cleptelmis addenda</i>	1	
<i>Baetis tricaudatus</i>	23		<i>Elmidae</i> - early instar or damaged	5	no
<i>Dipheter hageni</i>	43		<i>Optioservus</i>	2	
<i>Caudatella</i> - early instar or damaged	4	no	<i>Zaitzevia parvula</i>	1	
<i>Caudatella heterocaudata</i>	7		<i>Eubrianax edwardsi</i>	72	
<i>Drunella</i> - early instar	7	no	Diptera		
<i>Drunella doddssii</i>	4		<i>Ceratopogoninae</i> - early instar	3	
<i>Drunella flavilinea</i>	3		<i>Empididae</i> - early instar, damaged, or pupa	1	
<i>Drunella pelosa</i>	1		<i>Antocha monticola</i>	3	
<i>Ephemerella excrucians</i>	5		<i>Cryptolabis</i>	14	
<i>Ephemerellidae</i> - early instar or damaged	4	no	<i>Dicranota</i>	3	
<i>Epeorus</i>	42		<i>Hexatoma</i>	1	
<i>Ironodes</i>	2		<i>Tipulidae</i> - damaged or pupa	2	no
<i>Rhithrogena</i>	1		Diptera (Chironomidae)		
<i>Paraleptophlebia</i>	3		<i>Brillia</i>	4	
Plecoptera			<i>Cricotopus (Nostococladus) nostocicola</i>	3	
<i>Suwallia</i>	4		<i>Cryptochironomus</i>	1	
<i>Moselia infuscata</i>	1		<i>Demicryptochironomus</i>	6	
<i>Zapada cinctipes</i>	2		<i>Eukiefferiella Brevicalcar</i> Gr.	1	
<i>Calineuria californica</i>	2		<i>Lopescladius</i>	1	
<i>Perlidae</i> - early instar	1	no	<i>Micropsectra</i>	5	
Trichoptera			<i>Monodiamesa</i>	2	
<i>Amiocentrus aspilus</i>	1		<i>Pagastia</i>	5	
<i>Micrasema</i>	5		<i>Paratendipes</i>	3	
<i>Heteroplectron californicum</i>	4		<i>Polypedilum</i>	10	
<i>Glossosoma</i>	3		<i>Prodiamesa</i>	2	
<i>Glossosomatidae</i> - damaged or pupa	9	no	<i>Rheotanytarsus</i>	5	
<i>Helicopsyche</i>	140		<i>Stempellinella</i>	7	
<i>Hydropsyche</i>	14		<i>Tanypodinae</i> - early instar or damaged	1	no
<i>Parapsyche</i>	6		<i>Tanytarsini</i> - early instar or damaged	3	no
<i>Lepidostoma</i>	9		<i>Tanytarsus</i>	2	
<i>Allocosmoecus partitus</i>	1		<i>Thienemannimyia</i> Gr.	6	
<i>Limnephilidae</i> - early instar or damaged	5		<i>Tvetenia Bavarica</i> Gr.	1	

The values for the eight metrics that comprise the MMI are then calculated. The first metric is EPT taxa richness (Ephemeroptera, Plecoptera, and Trichoptera). In this example, a quick count of the number of taxa in these three insect orders is 37; but this must be adjusted for non-unique taxa. There are often incomplete taxonomic determinations by the taxonomist, but who can determine that they do not represent other unique taxa. For EPT, there are 5 non-unique taxa, so the final EPT taxa richness is 32. Once the values for each eight metrics are calculated, they are scored according to the metric creation (either on a scale from the original authors or linearly interpreted):

Component Metric	Boulder Creek Value	Score
EPT Richness	32	10
Coleoptera Richness	6	10
Diptera Richness	6	6
% Intolerant Individuals	63.90%	10
%Non-gastropod Individuals	35%	10
% Predator Individuals	7.1%	3
% Shredder Taxa	13.4%	8
% Non-insect Taxa	6.0%	10
	Sum	67
	Scaled to 100	83.75

The final step is to scale it to a 0–100 range for interpretation. In this example, the summed score is multiplied by 1.25 for a final score of “83.75.”

Interpretation is then based on a traditional scale; 100 = pristine; 10 = severely degraded. Furthermore, scores from 10 to 20 can be considered “very poor,” 20–40 are “poor,” 40–60 are “fair,” 60–80 are “good,” and 80–100 are “very good.” Secondly, scores below 52 are considered “impaired.”

Appendix B. Benthic Macroinvertebrates of Oregon Caves National Monument and Preserve

The following table is an accounting of all macroinvertebrate taxonomic units reported by the contract laboratory. The Interagency Taxonomic Information System (ITIS) Serial Number is provided for each taxon when available.

Note that due to taxonomic ambiguity, taxa used in analyses may differ from the taxa presented here. See the full protocol for more on dealing with taxonomic ambiguity.

Table B-1. Taxonomic units of benthic macroinvertebrates encountered in Oregon Caves National Monument and Preserve, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was three.

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Coleoptera	Elmidae	<i>Bryelmis siskiyou</i>	114093	7	1	33%
Coleoptera	Elmidae	Elmidae	114093	2	2	67%
Coleoptera	Elmidae	<i>Heterolimnius corpulentus</i>	114169	61	3	100%
Coleoptera	Elmidae	<i>Lara</i>	114137	2	2	67%
Coleoptera	Hydrophilidae	<i>Ametor scabrosus</i>	112892	2	2	67%
Coleoptera	Psephenidae	<i>Acneus</i>	114082	1	1	33%
Diptera	Blephariceridae	<i>Agathon</i>	121230	2	2	67%
Diptera	Ceratopogonidae	<i>Atrichopogon</i>	127113	3	2	67%
Diptera	Ceratopogonidae	<i>Bezzia / Palpomyia</i>	*	2	1	33%
Diptera	Chironomidae	<i>Brillia</i>	128477	15	3	100%
Diptera	Chironomidae	<i>Chaetocladius</i>	128520	1	1	33%
Diptera	Chironomidae	<i>Cricotopus (Nostococladus) nostocicola</i>	128628	2	1	33%
Diptera	Chironomidae	<i>Eukiefferiella</i>	128689	4	2	67%
Diptera	Chironomidae	<i>Eukiefferiella brehmi</i> Gr.	128704	11	3	100%
Diptera	Chironomidae	<i>Eukiefferiella brevicar</i> Gr.	128703	5	2	67%
Diptera	Chironomidae	<i>Eukiefferiella devonica</i> Gr.	128695	17	3	100%
Diptera	Chironomidae	<i>Heleniella</i>	128730	1	1	33%
Diptera	Chironomidae	<i>Krenopelopia</i>	128170	3	1	33%
Diptera	Chironomidae	<i>Macropelopia</i>	128034	1	1	33%
Diptera	Chironomidae	<i>Micropsectra</i>	129890	65	3	100%
Diptera	Chironomidae	Orthoclaadiinae	128457	1	1	33%
Diptera	Chironomidae	Orthoclaadiinae sp. (RAI Taxon # 0001)	*	20	2	67%
Diptera	Chironomidae	<i>Orthocladus</i>	128874	59	3	100%
Diptera	Chironomidae	<i>Pagastia</i>	128401	2	1	33%
Diptera	Chironomidae	<i>Parachaetocladius</i>	128951	10	3	100%
Diptera	Chironomidae	<i>Parakiefferiella</i>	128968	2	1	33%
Diptera	Chironomidae	<i>Parametriocnemus</i>	128978	8	3	100%
Diptera	Chironomidae	<i>Rheocricotopus</i>	129086	6	3	100%
Diptera	Chironomidae	<i>Rheotanytarsus</i>	129952	4	1	33%
Diptera	Chironomidae	<i>Stempellina</i>	129962	10	1	33%
Diptera	Chironomidae	<i>Stempellinella</i>	129969	8	3	100%
Diptera	Chironomidae	<i>Thienemanniella</i>	129182	4	2	67%
Diptera	Chironomidae	<i>Tvetenia</i>	129197	1	1	33%
Diptera	Chironomidae	<i>Tvetenia bavarica</i> Gr.	129205	2	1	33%
Diptera	Dixidae	<i>Dixa</i>	125810	1	1	33%
Diptera	Dixidae	Dixidae	125809	1	1	33%

Table B-1. Taxonomic units of benthic macroinvertebrates encountered in Oregon Caves National Monument and Preserve, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was three. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Diptera	Dolichopodidae	Dolichopodidae	136824	1	1	33%
Diptera	Empididae	<i>Chelifera / Metachela</i>	*	5	2	67%
Diptera	Empididae	<i>Clinocera</i>	135849	7	2	67%
Diptera	Empididae	Empididae sp. (RAI Taxon # 0001)	*	5	1	33%
Diptera	Empididae	<i>Neoplasta</i>	136352	4	2	67%
Diptera	Empididae	<i>Oreogeton</i>	136377	4	2	67%
Diptera	Pelecorhynchidae	<i>Glutops</i>	130915	6	3	100%
Diptera	Psychodidae	<i>Pericoma / Telmatoscopus</i>	*	1	1	33%
Diptera	Simuliidae	<i>Prosimulium</i>	126703	33	3	100%
Diptera	Tipulidae	<i>Dicranota</i>	121027	3	2	67%
Diptera	Tipulidae	<i>Hexatoma</i>	120094	4	1	33%
Diptera	Tipulidae	<i>Limnophila</i>	120164	1	1	33%
Ephemeroptera	Ameletidae	<i>Ameletus</i>	100996	14	3	100%
Ephemeroptera	Baetidae	<i>Baetis</i>	100800	20	2	67%
Ephemeroptera	Baetidae	<i>Baetis bicaudatus</i>	100823	211	3	100%
Ephemeroptera	Baetidae	<i>Dipheter hageni</i>	568598	8	3	100%
Ephemeroptera	Ephemerellidae	<i>Caudatella</i>	101347	6	2	67%
Ephemeroptera	Ephemerellidae	<i>Caudatella hystrix</i>	101348	89	3	100%
Ephemeroptera	Ephemerellidae	<i>Drunella coloradensis</i>	101389	34	3	100%
Ephemeroptera	Ephemerellidae	<i>Drunella doddsii</i>	698494	13	1	33%
Ephemeroptera	Ephemerellidae	<i>Drunella pelosa</i>	568634	3	1	33%
Ephemeroptera	Ephemerellidae	<i>Drunella spinifera</i>	101385	2	2	67%
Ephemeroptera	Ephemerellidae	Ephemerellidae	101232	21	3	100%
Ephemeroptera	Ephemerellidae	<i>Serratella levis</i>	568638	3	1	33%
Ephemeroptera	Heptageniidae	<i>Cinygma</i>	100598	1	1	33%
Ephemeroptera	Heptageniidae	<i>Cinygmula</i>	100557	41	2	67%
Ephemeroptera	Heptageniidae	<i>Epeorus</i>	100626	85	3	100%
Ephemeroptera	Heptageniidae	Heptageniidae	100504	8	2	67%
Ephemeroptera	Heptageniidae	<i>Ironodes</i>	100666	77	3	100%
Ephemeroptera	Heptageniidae	<i>Rhithrogena</i>	100572	4	1	33%
Ephemeroptera	Leptophlebiidae	Leptophlebiidae	101095	11	1	33%
Ephemeroptera	Leptophlebiidae	<i>Paraleptophlebia</i>	101187	8	2	67%
Ephemeroptera		Ephemeroptera	100502	2	1	33%
Haplotaenidia	Enchytraeidae	<i>Enchytraeus</i>	68531	9	2	67%
Haplotaenidia	Enchytraeidae	<i>Fridericia</i>	204785	12	2	67%
Haplotaenidia	Enchytraeidae	<i>Mesenchytraeus</i>	68544	44	3	100%

Table B-1. Taxonomic units of benthic macroinvertebrates encountered in Oregon Caves National Monument and Preserve, 2012. TSN = Taxonomic Serial Number; see www.its.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was three. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Megaloptera	Corydalidae	Corydalidae	115023	1	1	33%
Plecoptera	Chloroperlidae	<i>Kathroperla</i>	103236	4	1	33%
Plecoptera	Chloroperlidae	<i>Sweltsa</i>	103273	26	3	100%
Plecoptera	Leuctridae	Leuctridae	102840	8	2	67%
Plecoptera	Leuctridae	<i>Moselia infuscata</i>	102910	13	3	100%
Plecoptera	Nemouridae	<i>Malenka</i>	102567	15	3	100%
Plecoptera	Nemouridae	Nemouridae	102517	5	1	33%
Plecoptera	Nemouridae	<i>Soyedina</i>	102556	1	1	33%
Plecoptera	Nemouridae	<i>Visoka cataractae</i>	102615	13	1	33%
Plecoptera	Nemouridae	<i>Zapada columbiana</i>	102596	45	3	100%
Plecoptera	Nemouridae	<i>Zapada oregonensis</i> Gr.	102597	5	2	67%
Plecoptera	Peltoperlidae	<i>Sierraperla cora</i>	102515	27	3	100%
Plecoptera	Peltoperlidae	<i>Soliperla</i>	103142	2	1	33%
Plecoptera	Peltoperlidae	<i>Yoraperla nigrisoma</i>	568730	163	3	100%
Plecoptera	Perlidae	<i>Doroneuria baumanni</i>	103123	32	3	100%
Plecoptera	Perlidae	Perlidae	102914	11	3	100%
Plecoptera	Perlodidae	<i>Diura knowltoni</i>	103096	2	2	67%
Plecoptera	Perlodidae	<i>Kogotus nonus</i>	103150	1	1	33%
Plecoptera	Perlodidae	<i>Megarcys</i>	103110	3	2	67%
Plecoptera	Perlodidae	Perlodidae	102994	16	3	100%
Plecoptera	Perlodidae	<i>Salmoperla sylvanica</i>	103192	3	2	67%
Trichoptera	Brachycentridae	<i>Micrasema</i>	116958	93	2	67%
Trichoptera	Glossosomatidae	<i>Anagapetus</i>	117154	2	1	33%
Trichoptera	Goeridae	<i>Goeracea</i>	116298	8	2	67%
Trichoptera	Hydropsychidae	<i>Parapsyche</i>	115556	32	3	100%
Trichoptera	Lepidostomatidae	<i>Lepidostoma</i>	116794	7	3	100%
Trichoptera	Limnephilidae	Limnephilidae	115933	4	1	33%
Trichoptera	Philopotamidae	<i>Wormaldia</i>	115258	2	2	67%
Trichoptera	Rhyacophilidae	<i>Rhyacophila</i>	115097	20	3	100%
Trichoptera	Rhyacophilidae	<i>Rhyacophila angelita</i> Gr.	115099	1	1	33%
Trichoptera	Rhyacophilidae	<i>Rhyacophila arnaudi</i>	115165	1	1	33%
Trichoptera	Rhyacophilidae	<i>Rhyacophila betteni</i> Gr.	115101	4	2	67%
Trichoptera	Rhyacophilidae	<i>Rhyacophila brunnea/vemna</i> Gr.	*	5	3	100%
Trichoptera	Rhyacophilidae	<i>Rhyacophila coloradensis</i> Gr.	115156	1	1	33%
Trichoptera	Rhyacophilidae	<i>Rhyacophila grandis</i> Gr.	115105	4	2	67%
Trichoptera	Rhyacophilidae	<i>Rhyacophila sibirica</i> Gr.	568811	9	2	67%
Trichoptera	Rhyacophilidae	<i>Rhyacophila vagrita</i> Gr.	115152	3	1	33%

Table B-1. Taxonomic units of benthic macroinvertebrates encountered in Oregon Caves National Monument and Preserve, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a "species group," or a recently redescribed taxon with no number yet designated. Total number of sites sampled was three. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Trichoptera	Rhyacophilidae	<i>Rhyacophila verrula</i> Gr.	115125	10	2	67%
Trichoptera	Rhyacophilidae	<i>Rhyacophila vofixa</i> Gr.	115197	22	3	100%
Trichoptera	Rhyacophilidae	Rhyacophilidae	115096	3	3	100%
Trichoptera	Uenoidae	<i>Neophylax</i>	116046	22	2	67%
Trichoptera	Uenoidae	Uenoidae	568757	4	1	33%
Trichoptera		Trichoptera	115095	4	1	33%
Trombidiformes	Hydrovolziidae	<i>Hydrovolzia</i>	83119	2	1	33%
Trombidiformes	Lebertiidae	<i>Lebertia</i>	83034	1	1	33%
Trombidiformes	Protziidae	<i>Protzia</i>	83170	27	3	100%
Trombidiformes	Sperchontidae	<i>Sperchon</i>	83006	7	3	100%
Turbellaria		Turbellaria	53964	7	2	67%

Appendix C. Benthic Macroinvertebrates of Redwood National and State Parks

The following table is an accounting of all macroinvertebrate taxonomic units reported by the contract laboratory. The Interagency Taxonomic Information System (ITIS) Serial Number is provided for each taxon when available.

Note that due to taxonomic ambiguity, taxa used in analyses may differ from the taxa presented here. See the full protocol for more on dealing with taxonomic ambiguity.

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23.

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Acari		Acari	733321	11	6	26%
Amphipoda	Anisogammaridae	<i>Ramellogammarus</i>	93953	552	9	39%
Amphipoda	Crangonyctidae	<i>Stygobromus</i>	93861	1	1	4%
Amphipoda		Amphipoda	93294	174	5	22%
Basommatophora	Planorbidae	<i>Menetus dilatatus</i>	205210	8	1	4%
Coleoptera	Dytiscidae	<i>Agabus</i>	111966	2	1	4%
Coleoptera	Dytiscidae	Dytiscidae	111963	4	4	17%
Coleoptera	Dytiscidae	Hydroporinae	678402	11	4	17%
Coleoptera	Dytiscidae	Hydroporini	728229	1	1	4%
Coleoptera	Dytiscidae	<i>Liodessus</i>	112580	1	1	4%
Coleoptera	Dytiscidae	<i>Oreodytes</i>	112314	20	5	22%
Coleoptera	Dytiscidae	<i>Oreodytes crassulus</i>	728440	3	2	9%
Coleoptera	Dytiscidae	<i>Oreodytes obesus</i>	112316	10	5	22%
Coleoptera	Dytiscidae	<i>Uvarus subtilis</i>	193571	4	2	9%
Coleoptera	Elmidae	<i>Ampumixis dispar</i>	114197	37	8	35%
Coleoptera	Elmidae	<i>Bryelmis siskiyou</i>	114093	11	1	4%
Coleoptera	Elmidae	<i>Cleptelmis addenda</i>	114166	3	2	9%
Coleoptera	Elmidae	Elmidae	114093	104	19	83%
Coleoptera	Elmidae	<i>Heterlimnius corpulentus</i>	114169	354	23	100%
Coleoptera	Elmidae	<i>Lara</i>	114137	36	6	26%
Coleoptera	Elmidae	<i>Narpus</i>	114142	27	15	65%
Coleoptera	Elmidae	<i>Narpus angustus</i>	114143	4	3	13%
Coleoptera	Elmidae	<i>Narpus concolor</i>	114144	23	8	35%
Coleoptera	Elmidae	<i>Optioservus</i>	114177	405	17	74%
Coleoptera	Elmidae	<i>Optioservus divergens</i>	114178	38	6	26%
Coleoptera	Elmidae	<i>Optioservus quadrimaculatus</i>	114180	46	7	30%
Coleoptera	Elmidae	<i>Optioservus seriatus</i>	114181	39	5	22%
Coleoptera	Elmidae	<i>Ordobrevia nubifera</i>	114236	49	10	43%
Coleoptera	Elmidae	<i>Zaitzevia</i>	114205	92	17	74%
Coleoptera	Elmidae	<i>Zaitzevia parvula</i>	945801	110	10	43%
Coleoptera	Gyrinidae	<i>Gyrinus</i>	112654	3	2	9%
Coleoptera	Hydraenidae	<i>Hydraena</i>	112757	3	3	13%
Coleoptera	Hydrophilidae	<i>Ametor</i>	112890	3	3	13%
Coleoptera	Hydrophilidae	<i>Ametor scabrosus</i>	112892	1	1	4%
Coleoptera	Psephenidae	<i>Acneus</i>	114082	12	6	26%
Coleoptera	Psephenidae	<i>Eubrianax edwardsi</i>	114086	9	3	13%
Coleoptera	Psephenidae	Psephenus	114070	1	1	4%

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Diptera	Ceratopogonidae	<i>Atrichopogon</i>	127113	3	1	4%
Diptera	Ceratopogonidae	<i>Bezzia / Palpomyia</i>	*	2	2	9%
Diptera	Ceratopogonidae	Ceratopogonidae	127076	3	3	13%
Diptera	Ceratopogonidae	Ceratopogoninae	127338	22	10	43%
Diptera	Chironomidae	<i>Ablabesmyia</i>	128079	2	2	9%
Diptera	Chironomidae	<i>Boreochlus</i>	127954	4	2	9%
Diptera	Chironomidae	<i>Brillia</i>	128477	842	23	100%
Diptera	Chironomidae	<i>Brundiniella eumorpha</i>	128028	1	1	4%
Diptera	Chironomidae	Chironomini	129229	4	3	13%
Diptera	Chironomidae	<i>Cladotanytarsus</i>	129873	13	4	17%
Diptera	Chironomidae	<i>Corynoneura</i>	128563	23	8	35%
Diptera	Chironomidae	<i>Cricotopus</i>	128575	70	9	39%
Diptera	Chironomidae	<i>Cricotopus trifascia</i> Gr.	128659	1	1	4%
Diptera	Chironomidae	<i>Cryptochironomus</i>	129368	1	1	4%
Diptera	Chironomidae	<i>Eukiefferiella</i>	128689	10	7	30%
Diptera	Chironomidae	<i>Eukiefferiella brehmi</i> Gr.	128704	19	8	35%
Diptera	Chironomidae	<i>Eukiefferiella brevicar</i> Gr.	128703	23	7	30%
Diptera	Chironomidae	<i>Eukiefferiella claripennis</i> Gr.	128693	29	13	57%
Diptera	Chironomidae	<i>Eukiefferiella devonica</i> Gr.	128695	19	7	30%
Diptera	Chironomidae	<i>Eukiefferiella pseudomontana</i> Gr.	128706	13	2	9%
Diptera	Chironomidae	<i>Heleniella</i>	128730	1	1	4%
Diptera	Chironomidae	<i>Heterotanytarsus</i>	128734	29	3	13%
Diptera	Chironomidae	<i>Heterotrissocladius marcidus</i> Gr.	128744	10	3	13%
Diptera	Chironomidae	<i>Krenopelopia</i>	128170	1	1	4%
Diptera	Chironomidae	<i>Krenosmittia</i>	128771	1	1	4%
Diptera	Chironomidae	<i>Larsia</i>	128183	58	9	39%
Diptera	Chironomidae	<i>Limnophyes</i>	128776	5	5	22%
Diptera	Chironomidae	<i>Lopescladius</i>	128811	2	1	4%
Diptera	Chironomidae	<i>Macropelopia</i>	128034	16	3	13%
Diptera	Chironomidae	<i>Meropelopia</i>	128132	1	1	4%
Diptera	Chironomidae	<i>Metriocnemus</i>	128821	1	1	4%
Diptera	Chironomidae	<i>Micropsectra</i>	129890	465	23	100%
Diptera	Chironomidae	<i>Microtendipes pedellus</i> Gr.	129541	6	3	13%
Diptera	Chironomidae	<i>Microtendipes rydalensis</i> Gr.	129547	32	7	30%
Diptera	Chironomidae	<i>Natarsia</i>	128070	12	7	30%
Diptera	Chironomidae	<i>Nilotanypus</i>	128202	12	12	52%
Diptera	Chironomidae	Orthoclaadiinae	128457	30	19	83%

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Diptera	Chironomidae	Orthoclaadiinae sp. (RAI Taxon # 0001)	*	16	2	9%
Diptera	Chironomidae	Orthoclaadiinae sp. (RAI Taxon # 0004)	*	2	1	4%
Diptera	Chironomidae	<i>Orthocladus</i>	128874	200	21	91%
Diptera	Chironomidae	<i>Orthocladus lignicola</i>	128913	3	3	13%
Diptera	Chironomidae	<i>Parachaetocladus</i>	128951	5	4	17%
Diptera	Chironomidae	<i>Paracladopelma</i>	129597	4	4	17%
Diptera	Chironomidae	<i>Parakiefferiella</i>	128968	3	2	9%
Diptera	Chironomidae	<i>Parametriocnemus</i>	128978	75	22	96%
Diptera	Chironomidae	<i>Paratanytarsus</i>	129935	13	4	17%
Diptera	Chironomidae	<i>Paratendipes</i>	129623	2	2	9%
Diptera	Chironomidae	<i>Parorthocladus</i>	129011	8	4	17%
Diptera	Chironomidae	<i>Phaenopsectra</i>	129637	36	4	17%
Diptera	Chironomidae	<i>Polypedilum</i>	129657	338	22	96%
Diptera	Chironomidae	<i>Potthastia gaedii</i> Gr.	128409	21	5	22%
Diptera	Chironomidae	<i>Pseudodiamesa</i>	128416	2	2	9%
Diptera	Chironomidae	<i>Psilometriocnemus</i>	129083	2	2	9%
Diptera	Chironomidae	<i>Rheocricotopus</i>	129086	17	13	57%
Diptera	Chironomidae	<i>Rheotanytarsus</i>	129952	86	9	39%
Diptera	Chironomidae	<i>Stempellinella</i>	129969	337	23	100%
Diptera	Chironomidae	<i>Stenochironomus</i>	129746	1	1	4%
Diptera	Chironomidae	Tanypodinae	127994	8	4	17%
Diptera	Chironomidae	Tanytarsini	129872	26	9	39%
Diptera	Chironomidae	<i>Tanytarsus</i>	129978	125	18	78%
Diptera	Chironomidae	<i>Thienemanniella</i>	129182	24	9	39%
Diptera	Chironomidae	<i>Thienemannimyia</i> Gr.	128236	72	20	87%
Diptera	Chironomidae	<i>Tvetenia</i>	129197	1	1	4%
Diptera	Chironomidae	<i>Tvetenia bavarica</i> Gr.	129205	161	17	74%
Diptera	Chironomidae	<i>Zavrelimyia</i>	128259	24	14	61%
Diptera	Dixidae	<i>Dixa</i>	125810	11	6	26%
Diptera	Dixidae	<i>Meringodixa chalonensis</i>	125874	7	4	17%
Diptera	Dolichopodidae	Dolichopodidae	136824	1	1	4%
Diptera	Empididae	<i>Chelifera / Metachela</i>	*	15	4	17%
Diptera	Empididae	<i>Clinocera</i>	135849	4	3	13%
Diptera	Empididae	Empididae	135830	2	2	9%
Diptera	Empididae	<i>Neoplasta</i>	136352	6	5	22%
Diptera	Empididae	<i>Oreogeton</i>	136377	24	4	17%
Diptera	Pelecorhynchidae	<i>Glutops</i>	130915	16	7	30%

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Diptera	Psychodidae	<i>Pericoma / Telmatoscopus</i>	*	1	1	4%
Diptera	Ptychopteridae	<i>Ptychoptera</i>	125786	4	1	4%
Diptera	Simuliidae	<i>Prosimulium</i>	126703	1	1	4%
Diptera	Simuliidae	<i>Simulium</i>	126774	171	19	83%
Diptera	Stratiomyidae	<i>Caloparyphus</i>	130409	7	3	13%
Diptera	Stratiomyidae	<i>Euparyphus</i>	130436	4	3	13%
Diptera	Stratiomyidae	Stratiomyidae	130150	1	1	4%
Diptera	Tipulidae	<i>Antocha monticola</i>	119660	46	8	35%
Diptera	Tipulidae	<i>Dicranota</i>	121027	10	6	26%
Diptera	Tipulidae	<i>Hexatoma</i>	120094	12	8	35%
Diptera	Tipulidae	<i>Limnophila</i>	120164	4	3	13%
Diptera	Tipulidae	<i>Pedicia</i>	121118	2	2	9%
Diptera	Tipulidae	<i>Tipula</i>	119037	5	3	13%
Diptera	Tipulidae	Tipulidae	118840	20	14	61%
Ephemeroptera	Ameletidae	<i>Ameletus</i>	100996	219	23	100%
Ephemeroptera	Baetidae	<i>Acentrella turbida</i>	568574	21	4	17%
Ephemeroptera	Baetidae	Baetidae	100755	9	3	13%
Ephemeroptera	Baetidae	<i>Baetis</i>	100800	364	19	83%
Ephemeroptera	Baetidae	<i>Baetis bicaudatus</i>	100823	32	3	13%
Ephemeroptera	Baetidae	<i>Baetis flavistriga</i>	100835	142	8	35%
Ephemeroptera	Baetidae	<i>Baetis tricaudatus</i>	100817	576	18	78%
Ephemeroptera	Baetidae	<i>Centroptilum</i>	100873	43	7	30%
Ephemeroptera	Baetidae	<i>Diphetor hageni</i>	568598	216	19	83%
Ephemeroptera	Baetidae	<i>Procloeon</i>	206622	2	1	4%
Ephemeroptera	Ephemerellidae	<i>Attenella margarita</i>	101343	1	1	4%
Ephemeroptera	Ephemerellidae	<i>Caudatella</i>	101347	1	1	4%
Ephemeroptera	Ephemerellidae	<i>Caudatella heterocaudata</i>	101351	1	1	4%
Ephemeroptera	Ephemerellidae	<i>Drunella</i>	101365	21	7	30%
Ephemeroptera	Ephemerellidae	<i>Drunella coloradensis</i>	101389	69	7	30%
Ephemeroptera	Ephemerellidae	<i>Drunella doddsii</i>	698494	122	16	70%
Ephemeroptera	Ephemerellidae	<i>Drunella flavilinea</i>	101392	18	8	35%
Ephemeroptera	Ephemerellidae	<i>Drunella spinifera</i>	101385	12	2	9%
Ephemeroptera	Ephemerellidae	Ephemerella	101233	7	1	4%
Ephemeroptera	Ephemerellidae	<i>Ephemerella tibialis</i>	101401	82	13	57%
Ephemeroptera	Ephemerellidae	Ephemerellidae	101232	109	13	57%
Ephemeroptera	Ephemerellidae	<i>Matriella teresa</i>	776979	5	3	13%
Ephemeroptera	Ephemerellidae	<i>Serratella</i>	101395	2	1	4%
Ephemeroptera	Ephemerellidae	<i>Serratella levis</i>	568638	538	4	17%

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Ephemeroptera	Ephemerellidae	<i>Serratella micheneri</i>	568639	3	3	13%
Ephemeroptera	Ephemerellidae	<i>Timpanoga hecuba</i>	101318	52	11	48%
Ephemeroptera	Heptageniidae	<i>Cinygma</i>	100598	153	14	61%
Ephemeroptera	Heptageniidae	<i>Cinygmula</i>	100557	79	12	52%
Ephemeroptera	Heptageniidae	<i>Ecdyonurus</i>	697960	5	2	9%
Ephemeroptera	Heptageniidae	<i>Epeorus</i>	100626	130	14	61%
Ephemeroptera	Heptageniidae	Heptageniidae	100504	42	9	39%
Ephemeroptera	Heptageniidae	<i>Ironodes</i>	100666	204	17	74%
Ephemeroptera	Heptageniidae	<i>Rhithrogena</i>	100572	1	1	4%
Ephemeroptera	Isonychiidae	<i>Isonychia</i>	101041	1	1	4%
Ephemeroptera	Leptohyphidae	<i>Tricorythodes</i>	101405	18	3	13%
Ephemeroptera	Leptophlebiidae	Leptophlebiidae	101095	2	1	4%
Ephemeroptera	Leptophlebiidae	<i>Paraleptophlebia</i>	101187	468	23	100%
Ephemeroptera	Siphonuridae	Siphonuridae	100951	1	1	4%
Ephemeroptera	Siphonuridae	<i>Siphonurus</i>	100953	1	1	4%
Haplotaaxida	Enchytraeidae	<i>Enchytraeus</i>	68531	7	5	22%
Haplotaaxida	Enchytraeidae	<i>Fridericia</i>	204785	3	2	9%
Haplotaaxida	Enchytraeidae	<i>Mesenchytraeus</i>	68544	56	12	52%
Haplotaaxida	Haplotaaxidae	<i>Haplotaaxis</i>	68505	1	1	4%
Haplotaaxida	Naididae	<i>Nais</i>	68946	53	6	26%
Haplotaaxida	Naididae	<i>Spirosperma</i>	68780	6	4	17%
Haplotaaxida	Naididae	tubificoid Naididae with hair chaetae	*	13	4	17%
Haplotaaxida	Naididae	tubificoid Naididae without hair chaetae	*	1	1	4%
Hemiptera	Corixidae	Corixidae	103364	15	3	13%
Hemiptera	Gerridae	Gerridae	103801	1	1	4%
Isopoda	Asellidae	Asellidae	92657	3	2	9%
Isopoda	Asellidae	<i>Caecidotea</i>	92686	27	1	4%
Lumbriculida	Lumbriculidae	<i>Kincaidiana hexatheca</i>	68471	44	5	22%
Lumbriculida	Lumbriculidae	Lumbriculidae	68440	1	1	4%
Lumbriculida	Lumbriculidae	<i>Rhynchelmis</i>	68463	1	1	4%
Megaloptera	Corydalidae	Corydalidae	115023	4	1	4%
Megaloptera	Corydalidae	<i>Orohermes crepusculus</i>	115045	15	7	30%
Megaloptera	Sialidae	<i>Sialis</i>	115002	22	8	35%
Nemata		Nemata	563956	2	2	9%
Neotaenioglossa	Hydrobiidae	Hydrobiidae	70493	9	6	26%
Neotaenioglossa	Pleuroceridae	<i>Juga</i>	71570	89	6	26%
Neotaenioglossa	Pleuroceridae	<i>Juga bulbosa</i>	71584	79	10	43%

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Odonata	Gomphidae	Gomphidae	101664	4	4	17%
Odonata	Gomphidae	<i>Octogomphus specularis</i>	101737	7	4	17%
Plecoptera	Chloroperlidae	<i>Alloperla</i>	103203	9	2	9%
Plecoptera	Chloroperlidae	Chloroperlidae	103202	125	21	91%
Plecoptera	Chloroperlidae	<i>Kathroperla</i>	103236	16	7	30%
Plecoptera	Chloroperlidae	<i>Paraperla</i>	103233	15	8	35%
Plecoptera	Chloroperlidae	Paraperlinae	609856	1	1	4%
Plecoptera	Chloroperlidae	<i>Suwallia</i>	103254	179	12	52%
Plecoptera	Chloroperlidae	<i>Sweltsa</i>	103273	184	21	91%
Plecoptera	Leuctridae	<i>Despaxia augusta</i>	102842	37	9	39%
Plecoptera	Leuctridae	Leuctridae	102840	93	17	74%
Plecoptera	Leuctridae	<i>Moselia infuscata</i>	102910	80	12	52%
Plecoptera	Nemouridae	<i>Malenka</i>	102567	397	22	96%
Plecoptera	Nemouridae	Nemouridae	102517	35	9	39%
Plecoptera	Nemouridae	<i>Soyedina</i>	102556	2	1	4%
Plecoptera	Nemouridae	<i>Zapada</i>	102591	8	3	13%
Plecoptera	Nemouridae	<i>Zapada cinctipes</i>	102594	62	6	26%
Plecoptera	Nemouridae	<i>Zapada columbiana</i>	102596	13	1	4%
Plecoptera	Nemouridae	<i>Zapada frigida</i>	102601	5	3	13%
Plecoptera	Nemouridae	<i>Zapada oregonensis</i> Gr.	102597	17	6	26%
Plecoptera	Peltoperlidae	Peltoperlidae	102488	29	5	22%
Plecoptera	Peltoperlidae	<i>Sierraperla cora</i>	102515	7	3	13%
Plecoptera	Peltoperlidae	<i>Soliperla</i>	103142	20	8	35%
Plecoptera	Peltoperlidae	<i>Yoraperla</i>	102510	242	13	57%
Plecoptera	Peltoperlidae	<i>Yoraperla nigrisoma</i>	568730	84	2	9%
Plecoptera	Perlidae	<i>Calineuria californica</i>	102986	207	19	83%
Plecoptera	Perlidae	<i>Doroneuria baumanni</i>	103123	49	12	52%
Plecoptera	Perlidae	<i>Hesperoperla pacifica</i>	102972	21	7	30%
Plecoptera	Perlidae	Perlidae	102914	514	22	96%
Plecoptera	Perlodidae	<i>Diura knowltoni</i>	103096	9	3	13%
Plecoptera	Perlodidae	<i>Kogotus nonus</i>	103150	2	1	4%
Plecoptera	Perlodidae	Perlodidae	102994	193	12	52%
Plecoptera	Perlodidae	<i>Salmoperla sylvanica</i>	103192	10	1	4%
Plecoptera	Pteronarcyidae	<i>Pteronarcella</i>	102485	21	3	13%
Plecoptera	Pteronarcyidae	<i>Pteronarcys</i>	102471	9	4	17%
Plecoptera	Pteronarcyidae	<i>Pteronarcys princeps</i>	102484	1	1	4%
Rhynchobdellida	Piscicolidae	Piscicolidae	69296	1	1	4%
Trichoptera	Apataniidae	<i>Apatania</i>	115935	93	16	70%

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Trichoptera	Apataniidae	Apataniidae	598182	2	1	4%
Trichoptera	Brachycentridae	<i>Micrasema</i>	116958	71	9	39%
Trichoptera	Calamoceratidae	Calamoceratidae	116529	1	1	4%
Trichoptera	Calamoceratidae	<i>Heteroplectron californicum</i>	116538	37	11	48%
Trichoptera	Glossosomatidae	<i>Agapetus</i>	117121	29	8	35%
Trichoptera	Glossosomatidae	<i>Anagapetus</i>	117154	5	1	4%
Trichoptera	Glossosomatidae	<i>Glossosoma</i>	117159	35	14	61%
Trichoptera	Glossosomatidae	Glossosomatidae	117120	17	8	35%
Trichoptera	Hydropsychidae	Arctopsychinae	568763	9	1	4%
Trichoptera	Hydropsychidae	<i>Hydropsyche</i>	115453	12	3	13%
Trichoptera	Hydropsychidae	Hydropsychidae	115398	35	9	39%
Trichoptera	Hydropsychidae	<i>Parapsyche</i>	115556	18	7	30%
Trichoptera	Hydroptilidae	Hydroptilidae	115629	1	1	4%
Trichoptera	Hydroptilidae	<i>Mayatrichia</i>	115811	1	1	4%
Trichoptera	Hydroptilidae	<i>Ochrotrichia</i>	115714	11	4	17%
Trichoptera	Lepidostomatidae	<i>Lepidostoma</i>	116794	264	22	96%
Trichoptera	Leptoceridae	Leptoceridae	116547	1	1	4%
Trichoptera	Limnephilidae	<i>Chyrandra centralis</i>	116018	2	1	4%
Trichoptera	Limnephilidae	<i>Dicosmoecus atripes</i>	116266	2	2	9%
Trichoptera	Limnephilidae	<i>Dicosmoecus gilvipes</i>	116268	9	1	4%
Trichoptera	Limnephilidae	<i>Ecclisomyia</i>	116025	13	1	4%
Trichoptera	Limnephilidae	<i>Hydatophylax hesperus</i>	115998	1	1	4%
Trichoptera	Limnephilidae	Limnephilidae	115933	27	6	26%
Trichoptera	Limnephilidae	<i>Onocosmoecus</i>	116315	1	1	4%
Trichoptera	Limnephilidae	<i>Psychoglypha</i>	115974	7	3	13%
Trichoptera	Philopotamidae	Philopotamidae	115257	9	5	22%
Trichoptera	Philopotamidae	<i>Wormaldia</i>	115258	131	14	61%
Trichoptera	Polycentropodidae	<i>Polycentropus</i>	117044	3	2	9%
Trichoptera	Rhyacophilidae	<i>Rhyacophila</i>	115097	33	16	70%
Trichoptera	Rhyacophilidae	<i>Rhyacophila angelita</i> Gr.	115099	19	11	48%
Trichoptera	Rhyacophilidae	<i>Rhyacophila betteni</i> Gr.	115101	143	23	100%
Trichoptera	Rhyacophilidae	<i>Rhyacophila brunnea/vemna</i> Gr.	*	21	11	48%
Trichoptera	Rhyacophilidae	<i>Rhyacophila grandis</i> Gr.	115105	18	6	26%
Trichoptera	Rhyacophilidae	<i>Rhyacophila sibirica</i> Gr.	568811	17	3	13%
Trichoptera	Rhyacophilidae	<i>Rhyacophila vofixa</i> Gr.	115197	12	2	9%
Trichoptera	Rhyacophilidae	Rhyacophilidae	115096	15	10	43%
Trichoptera	Sericostomatidae	<i>Gumaga</i>	117003	44	13	57%

Table C-1. Taxonomic units of benthic macroinvertebrates encountered in Redwood National and State Parks, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Trichoptera	Uenoidae	<i>Farula</i>	116331	30	4	17%
Trichoptera	Uenoidae	<i>Neophylax</i>	116046	1	1	4%
Trichoptera	Uenoidae	<i>Neophylax rickeri</i>	116054	22	6	26%
Trichoptera	Uenoidae	<i>Neophylax splendens</i>	116063	9	4	17%
Trichoptera	Uenoidae	Uenoidae	568757	10	4	17%
Trichoptera		Trichoptera	115095	20	9	39%
Trombidiformes	Hydrodromidae	<i>Hydrodroma</i>	83225	2	1	4%
Trombidiformes	Hydrovolziidae	<i>Hydrovolzia</i>	83119	2	2	9%
Trombidiformes	Hydryphantidae	Hydryphantidae	83212	3	1	4%
Trombidiformes	Hygrobatidae	<i>Atractides</i>	83282	29	10	43%
Trombidiformes	Hygrobatidae	<i>Hygrobates</i>	83297	26	6	26%
Trombidiformes	Lebertiidae	<i>Estelloxus californiensis</i>	83049	1	1	4%
Trombidiformes	Lebertiidae	<i>Lebertia</i>	83034	55	18	78%
Trombidiformes	Limnocharidae	<i>Limnochares</i>	83146	2	2	9%
Trombidiformes	Mideopsidae	Mideopsidae	83476	1	1	4%
Trombidiformes	Mideopsidae	<i>Mideopsis</i>	83479	116	12	52%
Trombidiformes	Oxidae	<i>Oxus</i>	83244	3	2	9%
Trombidiformes	Protziidae	<i>Protzia</i>	83170	22	9	39%
Trombidiformes	Protziidae	<i>Wandesia</i>	83172	1	1	4%
Trombidiformes	Sperchontidae	<i>Sperchon</i>	83006	39	9	39%
Trombidiformes	Sperchontidae	<i>Sperchonopsis</i>	83029	20	9	39%
Trombidiformes	Torrenticolidae	<i>Torrenticola</i>	83254	388	23	100%
Turbellaria		Turbellaria	53964	46	13	57%
Veneroida	Pisidiidae	<i>Pisidium</i>	81400	35	2	9%

Appendix D. Benthic Macroinvertebrates of Crater Lake National Park

The following table is an accounting of all macroinvertebrate taxonomic units reported by the contract laboratory. The Interagency Taxonomic Information System (ITIS) Serial Number is provided for each taxon when available.

Note that due to taxonomic ambiguity, taxa used in analyses may differ from the taxa presented here. See the full protocol for more on dealing with taxonomic ambiguity.

Table D-1. Taxonomic units of benthic macroinvertebrates encountered in Crater Lake National Park, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23.

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Acari		Acari	733321	6	3	13%
Coleoptera	Elmidae	<i>Lara</i>	114137	1	1	4%
Coleoptera	Elmidae	<i>Optioservus quadrimaculatus</i>	114180	1	1	4%
Coleoptera	Hydraenidae	<i>Hydraena</i>	112757	1	1	4%
Coleoptera	Hydrophilidae	<i>Ametor</i>	112890	1	1	4%
Coleoptera	Hydrophilidae	<i>Ametor scabrosus</i>	112892	5	4	17%
Coleoptera	Hydrophilidae	Hydrophilidae	112811	1	1	4%
Copepoda		Copepoda	85257	6	1	4%
Diptera	Blephariceridae	<i>Agathon</i>	121230	1	1	4%
Diptera	Ceratopogonidae	Ceratopogoninae	127338	3	2	9%
Diptera	Chironomidae	<i>Brillia</i>	128477	160	31	135%
Diptera	Chironomidae	<i>Chaetocladius</i>	128520	123	23	100%
Diptera	Chironomidae	Chironomini	129229	1	1	4%
Diptera	Chironomidae	<i>Corynoneura</i>	128563	37	14	61%
Diptera	Chironomidae	<i>Cricotopus</i>	128575	3	1	4%
Diptera	Chironomidae	<i>Cricotopus nostocicola</i>	128628	94	7	30%
Diptera	Chironomidae	<i>Diamesa</i>	128355	12	3	13%
Diptera	Chironomidae	<i>Eukiefferiella</i>	128689	111	23	100%
Diptera	Chironomidae	<i>Eukiefferiella brehmi</i> Gr.	128704	46	4	17%
Diptera	Chironomidae	<i>Eukiefferiella claripennis</i> Gr.	128693	61	10	43%
Diptera	Chironomidae	<i>Eukiefferiella coerulescens</i> Gr.	128701	9	2	9%
Diptera	Chironomidae	<i>Eukiefferiella devonica</i> Gr.	128695	97	13	57%
Diptera	Chironomidae	<i>Eukiefferiella gracei</i> Gr.	128705	186	16	70%
Diptera	Chironomidae	<i>Heleniella</i>	128730	10	3	13%
Diptera	Chironomidae	<i>Heterotrissocladius</i>	128737	9	2	9%
Diptera	Chironomidae	<i>Hydrobaenus</i>	128750	30	6	26%
Diptera	Chironomidae	<i>Krenosmittia</i>	128771	31	19	83%
Diptera	Chironomidae	<i>Larsia</i>	128183	3	2	9%
Diptera	Chironomidae	<i>Limnophyes</i>	128776	4	2	9%
Diptera	Chironomidae	<i>Macropelopia</i>	128034	16	5	22%
Diptera	Chironomidae	<i>Metriocnemus</i>	128821	6	5	22%
Diptera	Chironomidae	<i>Micropsectra</i>	129890	220	23	100%
Diptera	Chironomidae	Orthocladiinae	128457	27	17	74%
Diptera	Chironomidae	Orthocladiinae sp. (RAI Taxon # 0001)	*	51	7	30%
Diptera	Chironomidae	<i>Orthocladus</i>	128874	355	23	100%
Diptera	Chironomidae	<i>Orthocladus lignicola</i>	128913	3	2	9%

Table D-1. Taxonomic units of benthic macroinvertebrates encountered in Crater Lake National Park, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (Continued).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Diptera	Chironomidae	<i>Pagastia</i>	128401	445	21	91%
Diptera	Chironomidae	<i>Parachaetocladius</i>	128951	3	2	9%
Diptera	Chironomidae	<i>Parakiefferiella</i>	128968	5	2	9%
Diptera	Chironomidae	<i>Parametriocnemus</i>	128978	57	16	70%
Diptera	Chironomidae	<i>Parorthocladius</i>	129011	80	14	61%
Diptera	Chironomidae	<i>Prodiamesa</i>	128452	1	1	4%
Diptera	Chironomidae	<i>Pseudodiamesa</i>	128416	12	5	22%
Diptera	Chironomidae	<i>Psilometriocnemus</i>	129083	1	1	4%
Diptera	Chironomidae	<i>Rheocricotopus</i>	129086	65	23	100%
Diptera	Chironomidae	<i>Rheosmittia</i>	129107	3	2	9%
Diptera	Chironomidae	<i>Stempellina</i>	129962	1	1	4%
Diptera	Chironomidae	<i>Stempellinella</i>	129969	35	5	22%
Diptera	Chironomidae	<i>Stilocladius</i>	129152	25	10	43%
Diptera	Chironomidae	Tanypodinae	127994	2	2	9%
Diptera	Chironomidae	Tanytarsini	129872	4	3	13%
Diptera	Chironomidae	<i>Thienemanniella</i>	129182	17	6	26%
Diptera	Chironomidae	<i>Tvetenia</i>	129197	50	11	48%
Diptera	Chironomidae	<i>Tvetenia bavarica</i> Gr.	129205	261	23	100%
Diptera	Chironomidae	<i>Tvetenia discoloripes</i> Gr.	129197	3	2	9%
Diptera	Dixidae	<i>Dixa</i>	125810	3	1	4%
Diptera	Dixidae	Dixidae	125809	1	1	4%
Diptera	Empididae	<i>Clinocera</i>	135849	72	14	61%
Diptera	Empididae	Empididae	135830	9	5	22%
Diptera	Empididae	Empididae sp. (RAI Taxon # 0001)	*	1	1	4%
Diptera	Empididae	<i>Neoplasta</i>	136352	64	10	43%
Diptera	Empididae	<i>Oreogeton</i>	136377	34	6	26%
Diptera	Pelecorhynchidae	<i>Glutops</i>	130915	41	12	52%
Diptera	Psychodidae	<i>Pericoma</i> / <i>Telmatoscopus</i>	*	10	3	13%
Diptera	Ptychopteridae	<i>Bittacomorpha</i>	125765	1	1	4%
Diptera	Simuliidae	<i>Helodon</i>	*	128	19	83%
Diptera	Simuliidae	<i>Prosimulium</i>	126703	28	4	17%
Diptera	Simuliidae	Simuliidae	126640	43	7	30%
Diptera	Simuliidae	<i>Simulium</i>	126774	7	3	13%
Diptera	Thaumaleidae	Thaumaleidae	126624	1	1	4%
Diptera	Tipulidae	<i>Dicranota</i>	121027	20	5	22%
Diptera	Tipulidae	<i>Hesperoconopa</i>	120732	19	9	39%
Diptera	Tipulidae	<i>Limnophila</i>	120164	5	3	13%

Table D-1. Taxonomic units of benthic macroinvertebrates encountered in Crater Lake National Park, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Diptera	Tipulidae	<i>Pedicia</i>	121118	1	1	4%
Diptera	Tipulidae	Tipulidae	118840	14	11	48%
Ephemeroptera	Ameletidae	<i>Ameletus</i>	100996	65	19	83%
Ephemeroptera	Baetidae	<i>Baetis</i>	100800	729	16	70%
Ephemeroptera	Baetidae	<i>Baetis bicaudatus</i>	100823	1218	21	91%
Ephemeroptera	Baetidae	<i>Baetis tricaudatus</i>	100817	488	16	70%
Ephemeroptera	Ephemerellidae	<i>Caudatella</i>	101347	675	20	87%
Ephemeroptera	Ephemerellidae	<i>Caudatella hystrix</i>	101348	19	6	26%
Ephemeroptera	Ephemerellidae	<i>Caudatella jacobi</i>	568632	14	6	26%
Ephemeroptera	Ephemerellidae	<i>Drunella</i>	101365	159	10	43%
Ephemeroptera	Ephemerellidae	<i>Drunella coloradensis</i>	101389	93	15	65%
Ephemeroptera	Ephemerellidae	<i>Drunella doddsii</i>	698494	117	17	74%
Ephemeroptera	Ephemerellidae	<i>Drunella spinifera</i>	101385	3	2	9%
Ephemeroptera	Ephemerellidae	<i>Ephemerella</i>	101233	72	11	48%
Ephemeroptera	Ephemerellidae	<i>Ephemerella alleni</i>	101251	8	3	13%
Ephemeroptera	Ephemerellidae	<i>Ephemerella tibialis</i>	101401	2	2	9%
Ephemeroptera	Ephemerellidae	Ephemerellidae	101232	123	9	39%
Ephemeroptera	Heptageniidae	<i>Cinygma</i>	100598	118	10	43%
Ephemeroptera	Heptageniidae	<i>Cinygmula</i>	100557	411	23	100%
Ephemeroptera	Heptageniidae	<i>Epeorus</i>	100626	632	22	96%
Ephemeroptera	Heptageniidae	Heptageniidae	100504	88	6	26%
Ephemeroptera	Heptageniidae	<i>Ironodes</i>	100666	6	2	9%
Ephemeroptera	Heptageniidae	<i>Rhithrogena</i>	100572	143	12	52%
Ephemeroptera	Leptophlebiidae	<i>Paraleptophlebia</i>	101187	57	10	43%
Haplotaaxida	Enchytraeidae	<i>Enchytraeus</i>	68531	30	11	48%
Haplotaaxida	Enchytraeidae	<i>Fridericia</i>	204785	14	10	43%
Haplotaaxida	Enchytraeidae	<i>Mesenchytraeus</i>	68544	492	22	96%
Haplotaaxida	Naididae	<i>Nais</i>	68946	1	1	4%
Haplotaaxida	Naididae	<i>Telmatodrilus vej dovskyi</i>	68760	1	1	4%
Haplotaaxida	Naididae	tubificoid Naididae with hair chaetae	*	12	4	17%
Haplotaaxida	Naididae	tubificoid Naididae without hair chaetae	*	8	3	13%
Lumbriculida	Lumbriculidae	Lumbriculidae	68440	1	1	4%
Nemata		Nemata	563956	117	14	61%
Ostracoda		Ostracoda	84195	74	11	48%
Plecoptera	Capniidae	Capniidae	102643	23	8	35%
Plecoptera	Chloroperlidae	Chloroperlidae	103202	45	9	39%
Plecoptera	Chloroperlidae	Chloroperlinae	609855	2	2	9%

Table D-1. Taxonomic units of benthic macroinvertebrates encountered in Crater Lake National Park, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Plecoptera	Chloroperlidae	<i>Kathroperla</i>	103236	10	6	26%
Plecoptera	Chloroperlidae	<i>Paraperla</i>	103233	11	3	13%
Plecoptera	Chloroperlidae	Paraperlinae	609856	2	1	4%
Plecoptera	Chloroperlidae	<i>Suwallia</i>	103254	1	1	4%
Plecoptera	Chloroperlidae	<i>Sweltsa</i>	103273	80	13	57%
Plecoptera	Leuctridae	<i>Despaxia augusta</i>	102842	1	1	4%
Plecoptera	Leuctridae	Leuctridae	102840	24	12	52%
Plecoptera	Leuctridae	<i>Moselia infuscata</i>	102910	46	9	39%
Plecoptera	Nemouridae	Nemouridae	102517	13	6	26%
Plecoptera	Nemouridae	<i>Visoka cataractae</i>	102615	104	18	78%
Plecoptera	Nemouridae	<i>Zapada</i>	102591	25	5	22%
Plecoptera	Nemouridae	<i>Zapada columbiana</i>	102596	1193	23	100%
Plecoptera	Nemouridae	<i>Zapada frigida</i>	102601	5	3	13%
Plecoptera	Nemouridae	<i>Zapada oregonensis</i> Gr.	102597	39	6	26%
Plecoptera	Peltoperlidae	<i>Yoraperla</i>	102510	319	9	39%
Plecoptera	Peltoperlidae	<i>Yoraperla brevis</i>	102512	886	20	87%
Plecoptera	Peltoperlidae	<i>Yoraperla nigrisoma</i>	568730	927	13	57%
Plecoptera	Perlidae	<i>Doroneuria</i>	103121	4	1	4%
Plecoptera	Perlodidae	<i>Isoperla</i>	102995	82	11	48%
Plecoptera	Perlodidae	<i>Megarcys</i>	103110	92	16	70%
Plecoptera	Perlodidae	Perlodidae	102994	152	17	74%
Plecoptera	Perlodidae	<i>Salmoperla sylvanica</i>	103192	1	1	4%
Plecoptera	Pteronarcyidae	<i>Pteronarcys</i>	102471	6	3	13%
Plecoptera	Taeniopterygidae	Taeniopterygidae	102788	22	7	30%
Plecoptera		Plecoptera	102467	10	3	13%
Trichoptera	Apataniidae	<i>Apatania</i>	115935	50	6	26%
Trichoptera	Apataniidae	Apataniidae	598182	1	1	4%
Trichoptera	Apataniidae	<i>Pedomoecus sierra</i>	115973	22	7	30%
Trichoptera	Brachycentridae	<i>Micrasema</i>	116958	64	7	30%
Trichoptera	Glossosomatidae	<i>Anagapetus</i>	117154	15	4	17%
Trichoptera	Glossosomatidae	<i>Glossosoma</i>	117159	54	8	35%
Trichoptera	Glossosomatidae	Glossosomatidae	117120	4	3	13%
Trichoptera	Hydropsychidae	Arctopsychinae	568763	3	2	9%
Trichoptera	Hydropsychidae	Hydropsychidae	115398	6	3	13%
Trichoptera	Hydropsychidae	<i>Parapsyche</i>	115556	46	12	52%
Trichoptera	Lepidostomatidae	<i>Lepidostoma</i>	116794	4	2	9%
Trichoptera	Limnephilidae	<i>Cryptochia</i>	115907	26	8	35%
Trichoptera	Limnephilidae	<i>Ecclisocosmoecus scylla</i>	116342	8	6	26%

Table D-1. Taxonomic units of benthic macroinvertebrates encountered in Crater Lake National Park, 2012. TSN = Taxonomic Serial Number; see www.itis.gov for full taxonomy. * indicates cases where no TSN exists, either due to it being a “species group,” or a recently redescribed taxon with no number yet designated. Total number of sites sampled was 23. (*Continued*).

Order (or higher)	Family	Taxon (lowest unit identified)	TSN	Total No.	No. of sites	Percent of sites
Trichoptera	Limnephilidae	<i>Ecclisomyia</i>	116025	72	8	35%
Trichoptera	Limnephilidae	Limnephilidae	115933	79	15	65%
Trichoptera	Limnephilidae	<i>Psychoglypha</i>	115974	31	4	17%
Trichoptera	Philopotamidae	<i>Dolophilodes</i>	115319	1	1	4%
Trichoptera	Philopotamidae	<i>Wormaldia</i>	115258	2	1	4%
Trichoptera	Rhyacophilidae	<i>Rhyacophila</i>	115097	18	6	26%
Trichoptera	Rhyacophilidae	<i>Rhyacophila alberta</i> Gr.	115163	2	1	4%
Trichoptera	Rhyacophilidae	<i>Rhyacophila betteni</i> Gr.	115101	69	15	65%
Trichoptera	Rhyacophilidae	<i>Rhyacophila brunnea/vemna</i> Gr.	*	28	14	61%
Trichoptera	Rhyacophilidae	<i>Rhyacophila hyalinata</i> Gr.	115159	27	6	26%
Trichoptera	Rhyacophilidae	<i>Rhyacophila sibirica</i> Gr.	568811	90	16	70%
Trichoptera	Rhyacophilidae	<i>Rhyacophila vagrita</i> Gr.	115152	9	5	22%
Trichoptera	Rhyacophilidae	<i>Rhyacophila verrula</i> Gr.	115125	17	7	30%
Trichoptera	Rhyacophilidae	<i>Rhyacophila vofixa</i> Gr.	115197	161	16	70%
Trichoptera	Rhyacophilidae	Rhyacophilidae	115096	11	6	26%
Trichoptera	Uenoidae	<i>Neothremma</i>	116388	871	20	87%
Trichoptera	Uenoidae	Uenoidae	568757	22	5	22%
Trichoptera		Trichoptera	115095	9	5	22%
Trombidiformes	Aturidae	<i>Aturus</i>	82974	4	1	4%
Trombidiformes	Hygrobatidae	<i>Atractides</i>	83282	8	6	26%
Trombidiformes	Lebertiidae	<i>Lebertia</i>	83034	57	19	83%
Trombidiformes	Mideopsidae	<i>Mideopsis</i>	83479	1	1	4%
Trombidiformes	Protziidae	<i>Protzia</i>	83170	1	1	4%
Trombidiformes	Sperchontidae	<i>Sperchon</i>	83006	171	23	100%
Trombidiformes	Sperchontidae	<i>Sperchonopsis</i>	83029	5	2	9%
Trombidiformes	Torrenticolidae	<i>Testudacarus</i>	83250	9	4	17%
Turbellaria		Turbellaria	53964	137	18	78%
Veneroida	Pisidiidae	<i>Pisidium</i>	81400	1	1	4%
Veneroida	Sphaeriidae	Sphaeriidae	81389	56	8	35%

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 150/129614, 167/129614, 106/129614, September 2015

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA TM