Updating the Benthic Index of Biotic Integrity (B–IBI): Outcomes and Key Findings

November 2014

King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science and Technical Support Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104
206-477-4800 TTY Relay: 711
www.kingcounty.gov/EnvironmentalScience

Alternate Formats Available

Updating the Benthic Index of Biotic Integrity (B-IBI): Outcomes and Key Findings

Submitted by:

Elene Dorfmeier
King County Water and Land Resources Division
Department of Natural Resources and Parks

Leska Fore
Statistical Design

Jo Opdyke Wilhelm[1] and Deb Lester
King County Water and Land Resources Division
Department of Natural Resources and Parks

Funded by EPA Puget Sound Science and Technical Assistance Grant under the 2010 Puget Sound Initiative through grant number PC-00J28401 to King County, Department of Natural Resources and Parks: "Enhancement and Standardization of Benthic Macroinvertebrate Monitoring and Analysis Tools for the Puget Sound Region."

King County
Department of
Natural Resources and Parks
Water and Land Resources Division

[1] Corresponding author jo.wilhelm@kingcounty.gov

Acknowledgements

We thank all the managers and scientists who contributed their data to the regional database and who provided their perspective on the use of B-IBI for assessing and reporting the biological condition of their streams. We thank James Develle and Doug Henderson (King County Department of Information Technology) for adding functionality to the Puget Sound Stream Benthos website and database. We thank Karen Adams (formerly of Washington State Department of Ecology [Ecology]) for her engagement during the first two years of this project. We thank Peter Leinenbach (Environmental Protection Agency [EPA]) and Ken Rauscher (King County Department of Natural Resources and Parks [KCDNRP]) for GIS support that yielded landscape data fundamental to the recalibration analyses. We thank Chad Larson (Ecology), Mindy Fohn (Kitsap County), Gretchen Hayslip and Krista Mendelman (EPA), and Kate Macneale, Scott Stolnack, and Jim Simmonds (KCDNRP) for document review. We thank Tom Ventur (KCDNRP) for final document formatting.

The research in this report was funded by the EPA through grant number PC-J28401-0 to KCDNRP. This document has been subjected to peer-review and approved for publication; approval does not signify that the contents reflect the views or policy of King County or EPA.

Citation

King County. 2014. Updating the Benthic Index of Biotic Integrity (B-IBI): Outcomes and Key Findings. Prepared by Elene Dorfmeier (King County Water and Land Resources Division [WLRD]), Leska Fore (Statistical Design), Jo Opdyke Wilhelm (WLRD), and Deb Lester (WLRD). Seattle, Washington.

Table of Contents

1.0. Introduction ... 1
2.0. Grant Accomplishments ... 3
2.1 Improvements to B-IBI ... 3
B-IBI natural history information updated and revised ... 3
Recalibrated B-IBI to continuous 0-100 scale ... 4
Metrics adjusted for differences in taxonomic resolution ... 4
Macroinvertebrate collection methods yield comparable B-IBI ... 5
Natural site features have little influence on B-IBI scores ... 5
The impact of physical habitat and water quality stressors on B-IBI evaluated ... 6
2.2 Puget Sound Stream Benthos (PSSB) data management system expansion ... 7
2.3 Regional collaboration and reporting of B-IBI ... 7
3.0. Outcomes and Conclusions ... 9
3.1 Future steps ... 9
3.2 Conclusions ... 10
4.0. References ... 12

1.0. INTRODUCTION

The purpose of this document is to provide an overview of the various components of a recent effort to enhance benthic macroinvertebrate monitoring tools for the Puget Sound region. This document includes a brief summary of each project element. More detailed information can be found in the referenced technical documentation.

The Puget Lowland benthic index of biotic integrity (B-IBI) is a multi-metric index designed to assess the biological condition of a stream by sampling benthic macroinvertebrates and calculating metrics based on the community composition of taxa. B-IBI has been the primary assessment tool used to evaluate biological conditions in Puget Lowland streams since the early 1990s (Fore et al. 2001; Karr and Chu 1999; Kleindl 1995; Morley and Karr 2002). B-IBI is currently used by over 20 cities, counties, tribes, and state agencies in the Puget Sound region to assess and report stream health (King County 2009). Since its original development, B-IBI has been broadly applied in a variety of contexts in western Washington, including to establish baseline ecological conditions, track status and trends, and to measure the effectiveness of salmonid habitat restoration projects.

Interest in using B-IBI as a regional indicator of stream condition in Washington State has been strong since its original development and its use has continued to increase over the last 20 years. Biological monitoring data are now part of the Washington State water quality assessment and can lead to 303(d) impairment listings. In addition, B-IBI is used as one of the Vital Sign Indicators reported by the Puget Sound Partnership (PSP), an organization formed to develop a strategic framework for restoring the regional watershed (PSP 2013). PSP has identified two Action Agenda recovery targets based on B-IBI scores: (1) improve 30 streams from “fair” to “good” biological condition, as measured by B-IBI, and (2) protect and preserve streams in excellent biological condition. B-IBI data are currently being used to prioritize sites for both restoration and preservation in support of this effort (King County 2014a).

Successful assessment and subsequent protection of Puget Sound watersheds depends on benthic monitoring programs which utilize a reliable and precise metric to detect ecological degradation. In addition, to insure data are comparable among programs, collection protocols and data management tools must be standardized or important differences need to be identified, understood, and accounted for. In 2010, King County was awarded a grant from the Environmental Protection Agency (EPA) to build on the foundation laid by the development and launch of the Puget Sound Stream Benthos (PSSB), an open-access data management system developed to increase regional collaboration and decisions based on B-IBI (King County 2009). The PSSB provides secure benthic macroinvertebrate data storage, customizable data download options, capability for a variety of calculations, and allows data accessibility across political and watershed boundaries in the region. Continued multi-jurisdictional participation and collaboration has enabled the development of a streamlined and standardized macroinvertebrate field method and data sharing program for the Puget Sound region.

This project improved benthic invertebrate monitoring tools and coordination in the Puget Sound region in two ways: (1) by providing an updated index based on the best available science and, (2) by fostering multi-jurisdictional engagement and collaboration across the region. This report provides an overview of the key outcomes accomplished by this grant, an overview of the regional impact this project has made, and examines how this effort has promoted a larger dialog around the application of B-IBI throughout the Puget Sound region. The major accomplishments from this grant are summarized in six technical reports listed below. Summaries of the major findings of these documents are presented in Section 2.0 and are available in full on the PSSB.

Key accomplishments of this project include:

- Updated taxa attribute lists (long-lived, predator, clinger) with new scientific information; updated intolerant and tolerant taxa attributes with empirically-derived data from over 700 sites in the Puget Sound region (King County 2013).
- Adjusted B-IBI metric scores so that the final B-IBI is based on continuous scoring without gaps, has strong signal to noise discrimination, and is independent of taxonomic effort (King County 2014b).
- Confirmed comparability of regional macroinvertebrate data collected from different sampling surface area protocols used by various entities in the Puget Sound region (King County 2014c).
- Verified that natural site features do not add a consistent source of bias for B-IBI (King County 2014d).
- Evaluated the biological risks of common aquatic stressors, which revealed stressors related to substrate and water quality were the most influential to B-IBI scores (King County 2014e).
- Enhanced the analytical capabilities and functionality of the PSSB database management system by incorporating updated attributes, taxonomic levels, and B-IBI scoring; B-IBI data from new agencies and additional years added to the PSSB.
- Increased multi-agency participation and partnership within the Puget Sound region as demonstrated by attendance and participation in field and PSSB trainings and regional workshops.

2.0. GRANT ACCOMPLISHMENTS

2.1 Improvements to B-IBI

This effort resulted in a number of improvements to the B-IBI. These efforts and associated key outcomes are summarized below.

B-IBI natural history information updated and revised

Long lived, clinger, and predator taxa lists were updated by regional experts to reflect best available science for approximately 500 benthic taxa in Puget Sound. Intolerant and tolerant taxa lists were updated using Puget Sound data to evaluate taxa response to urbanization.

Five of the 10 individual B-IBI metrics are derived from specific taxa attributes, or natural history characteristics, of the benthic community. When B-IBI was developed in the early 1990s taxa attributes were based on information available at the time and the best professional judgment of regional taxonomic experts. In subsequent decades, new information describing invertebrate natural history has become available and thousands of benthic invertebrate site visits to Puget Sound streams have since been recorded. Data associated with specific biological attributes were evaluated to improve the ability of B-IBI metrics to assess biological condition and detect degradation due to anthropogenic influences. Taxa attributes for three of the 10 component metrics of B-IBI (clinger, predator, and long-lived) were updated using new scientific knowledge of natural history attributes. Taxa attributes for two additional metrics (tolerant and intolerant) were updated using observed response to watershed urbanization for the most common taxa. The objectives of these efforts were to improve the ability of each attribute-dependent metric, and B-IBI as a whole, to accurately measure biological condition in the Puget Sound region. None of the component B-IBI metrics were changed, only taxa attributes were updated.

Use of the updated attributes for intolerant taxa richness and percent tolerant metrics resulted in an increased correlation between these metrics and urbanization, demonstrating improved accuracy. Updates to the clinger taxa richness, long-lived taxa richness, and percent predator taxa attributes resulted in metrics showing similar strength in correlation to percent watershed urbanization compared to the original attribute lists. Validation datasets confirmed these results. Updated natural history information improves data confidence, allows for data comparability, and improves effective regional resource management while enhancing the integrity and regional applicability of nearly 20 years of macroinvertebrate data collected in the Puget Sound region.

For detailed information on the above summary refer to King County 2013: *Using natural history attributes of stream invertebrates to measure stream health*.

Recalibrated B-IBI to continuous 0–100 scale

Continuous metric scoring eliminated scoring gaps and yielded strong signal to noise discrimination.

The Puget Lowland B-IBI was originally developed as a set of 10 metrics with a discrete scoring system (1, 3, or 5) representing poor, fair, and good biological condition of stream sites. These metric scores are summed to calculate a total B-IBI score ranging from 10–50. Metric scoring was modified to a continuous scale, so that each of the 10 metrics was scored from 0–10, expanding total B-IBI range to 0–100. Standardizing metric scaling to a continuous, rather than discrete scale, eliminated scoring gaps and resulted in an index with a signal to noise ratio greater than 10 which is indicative of a strong indicator with a good ability to detect change in condition.

For detailed information for the above summary refer to King County 2014b: *Recalibration of the Puget Lowland Benthic Index of Biotic Integrity (B-IBI)*.

Metrics adjusted for differences in taxonomic resolution

B-IBI metric scores adjusted for three levels of standard taxonomic effort (STE).

Standard taxonomic effort (STE) refers to the level of effort used in the lab to identify the invertebrates collected. The level of STE used by regional jurisdictions and state agencies to analyze their benthic macroinvertebrate samples varies (e.g., family vs. genus for chironomids). Higher levels of taxonomic identification are described as "coarse" and more detailed levels referred to as "fine." In general there are three levels of identification used in Puget Sound: fine, medium, and coarse. B-IBI metric scores need to be adjusted to accommodate different levels of taxonomic effort to ensure that B-IBI values are comparable independent of taxonomic effort.

A data set of 186 site visits with data identified to the finest taxonomic level of resolution was used to compare metric scores and evaluate which metrics needed adjustment to correct for different taxonomic effort. Three of the 10 metrics (taxa richness, clinger richness, and percent dominant) differed according to STE and scores were adjusted. Adjusted scores were incorporated into the PSSB database so that users can simply enter their level of effort and the resulting calculations for metrics and overall B-IBI scores are corrected so that the B-IBI is comparable across the region, independent of STE.

For detailed information for the above summary refer to King County 2014b: *Recalibration of the Puget Lowland Benthic Index of Biotic Integrity (B-IBI)*.

Macroinvertebrate collection methods yield comparable B-IBI

B-IBI scores derived from 3 ft^2 or 8 ft^2 sampling areas can be compared with confidence and reported interchangeably.

Throughout the Puget Sound region, jurisdictions collect macroinvertebrate samples from different streambed surface areas. Samples are typically collected from 3-, 8-, or 9-ft^2. Washington State Department of Ecology (Ecology) and EPA both recommend sample collection from 8 ft^2. Local entities were reluctant to shift sampling protocols due to the risk of orphaning their existing long-term data sets collected from 3 ft^2 sample areas. There was concern that sample collection from a larger surface area would yield a greater variety of taxa and an increase in B-IBI making it challenging to compare data collected from different surface areas.

Side-by-side macroinvertebrate samples were collected from 55 sites using both the 3 and 8 ft^2 sampling protocols. Analyses showed no significant difference in mean B-IBI or B-IBI metric scores and taxonomic composition between the two sampling areas, and it is expected that results with the 9ft^2 would be similar. A minimum 500-count subsample is critical to the comparability between sampling protocols. Thus, no adjustments to metrics or the B-IBI are needed to make samples from different surface areas comparable if a target 500–count subsample is used.

Regional jurisdictions and agencies now have confidence that, once taxonomic effort is accounted for, historical data are comparable to current data even if surface area collection methods have changed. These results allowed some jurisdictions within the Puget Sound region to transition to collection of 8 ft^2 samples without losing the ability to track long-term trends based on historical data collected from 3 ft^2 areas. In addition, results of this work enable direct comparison of a larger pool of regional data and promote data integration to evaluate ecosystem conditions across jurisdictional boundaries.

For detailed information for the above summary refer to King County 2014c: Evaluation of Stream Benthic Macroinvertebrate Sampling Protocols: Comparison of 3 ft^2 and 8 ft^2.

Natural site features have little influence on B-IBI scores

B-IBI scores were not consistently associated with natural site features; human disturbance was identified as the strongest driver of B-IBI response.

B-IBI responds predictably to gradients of human impact, but not all variability in B-IBI response can be explained by measures of human disturbance. The association of natural site features (e.g., latitude, longitude, watershed area, precipitation, elevation, etc.) and B-IBI variability was evaluated using hierarchical multiple regression and regression trees with various predictor variables (i.e., macroinvertebrate organism count, site location, natural site features, and land cover) (King County 2014d). This analysis indicated that natural variability associated with site features added little to the predictability of B-IBI response. Although urbanization alone did not account for all of B-IBI response (49%), the additional variation explained by natural site features evaluated in this study was minimal (4%). Adjustments to B-IBI scoring to account for variability of natural site features were not necessary.

Variability in benthic macroinvertebrate communities likely results from a variety of specific factors such as pollutants, flow regime, water quality, habitat, or even random stochastic processes (e.g. natural disturbances). Many of these factors are incorporated into "urbanization"; however, they are not explicitly measured or data were not readily available for these analyses and their influence on B–IBI scores is likely to vary.

For detailed information for the above summary refer to King County 2014d: *Examining the influence of natural site features on B-IBI response*.

The impact of physical habitat and water quality stressors on B-IBI evaluated

Stressors associated with physical habitat, specifically fine substrate conditions, and water chemistry had the greatest influence on B-IBI scores and component metrics.

Relative risk is a statistical technique typically used with probabilistic (random) sampling designs to evaluate the relative importance of measured stressors. The output of the analysis is a comparison of various stressors and their relative importance to an indicator of biological health. Data from Ecology's Status and Trends Monitoring for Watershed Health and Salmon Recovery program for western Washington streams and small rivers was used to characterize major physical and chemical stressors that may impact B-IBI. Physical habitat, substrate composition, water quality, and sediment chemistry data for 146 western Washington survey sites were used to identify, characterize, and rank aquatic stressor risk to B-IBI scores. Each stressor was evaluated independently and risks were ranked by strength of association to biota response.

The results indicated that poor substrate quality parameters, specifically sedimentation (percent fines, small gravel and cobble, sand-fines) and embeddedness have a strong association with poor B-IBI scores. Results also illustrate that select water quality parameters (turbidity, dissolved oxygen, and phosphorous) strongly influenced B-IBI. This analysis suggests that targeting restoration of physical habitat, for example rebuilding riparian buffers and remediating excessive sources of sedimentation, could improve biotic condition. The results of this analysis will help assist Puget Sound area jurisdictions to focus key watershed restoration efforts associated with environmental stressors that impact B-IBI scores and help achieve the PSP B-IBI ecosystem recovery targets (King County 2014a).

For detailed information for the above summary refer to King County 2014e: *Identifying stressor risk to biological health in streams and small rivers of western Washington.*

2.2 Puget Sound Stream Benthos (PSSB) data management system expansion

PSSB enhancements resulted in improved data accessibility and increased ability to analyze, integrate, and interpret macroinvertebrate data for decision making across Puget Sound.

The PSSB is a regional clearinghouse for both storage and analysis of benthic macroinvertebrate data. Presently, the PSSB stores data from nearly 5000 site visits collected between 1994 and 2014 by 26 entities at over 1200 sites in the Puget Sound region. B-IBI adjustments summarized in this document have been incorporated into the PSSB, which include: recalibrated B-IBI scoring, updated taxa attribute lists, and taxonomic level scoring adjustments. These improvements greatly enhance the PSSB and increase its functionality and analytical capabilities. In addition, various land use and land cover attribute data, delineated basin boundaries for all sampling sites, and other landscape scale metrics for all delineated basins at various spatial scales are available for download. The PSSB now enables easier uploading of benthic macroinvertebrate data to Ecology's Environmental Information Management system. Expanding and updating this multi-entity regional database provides consistent data storage and analysis tools that allow for data flexibility and regional comparability.

To explore the improvements summarized above visit the web accessible *PSSB* (http://www.pugetsoundstreambenthos.org) and explore the geographic scope of the available data and the PSSB analysis capabilities.

2.3 Regional collaboration and reporting of B-IBI

Jurisdictions and agencies from the Puget Sound are working together more than ever before to discuss method standardization and communicate analytical results.

Regional collaboration was facilitated through multiple workshops, field and PSSB trainings, and dissemination of information via newsletters and emails. Regional partners are more active at the Puget Sound level (e.g., participation in the PSP Freshwater Work Group) and the broader Pacific Northwest (e.g., participation in the Pacific Northwest Aquatic Monitoring Partnership [PNAMP] workgroup and the Northwest chapter of the Society for Freshwater Science). Increased cross-jurisdictional coordination and method standardization allows regulatory groups to draw regionally based conclusions and begin to identify where and why biotic integrity is declining or improving in the region. B-IBI data are utilized for restoration planning and watershed protection in King County (King County 2014a) and statewide, measuring progress toward regional restoration of streams.

Collaborative outcomes from this grant include:

- Multi-regional participation in many aspects of this project helped support collaboration throughout the region (e.g., development of the Regional Stormwater

Monitoring Program sampling protocols for the Stormwater Workgroup; elevation of B-IBI as a PSP Vital Sign Indicator with associated recovery targets).

- Four *Puget Sound Stream Monitor* newsletters were prepared and distributed via email to over 180 individuals representing 72 organizations.
- Three regional workshops were held which facilitated dialog between jurisdictions and agencies regarding direction of monitoring programs and presented analytical results using macroinvertebrate data; workshops were attended by 76 participants from 37 organizations.
- Two PSSB user workshops were hosted which demonstrated PSSB data download options and offered website guidance; workshops were attended by 24 participants from 11 organizations.
- Three regional field trainings were led by Ecology to demonstrate field methods and to encourage standardization of field collection protocols; field trainings were attended by 54 attendees from 29 organizations.
- Samples were collected from 55 sites in collaboration with 9 partner organizations to test surface area collection methods and to better understand differences in general collection methods throughout the region (see King County 2014c for results).
- Communication through the partner network spread awareness of the invasive New Zealand mudsnail and taught decontamination techniques to field crews to help slow down and minimize spread of the species.

3.0. OUTCOMES AND CONCLUSIONS

3.1 Future steps

Measuring current ecological conditions and trends is a key step toward effective environmental management. This effort resulted in increased confidence that B-IBI can be used to establish a reliable and precise measure of biotic condition. A number of next steps have been identified to build on the work and momentum created by this project and are described here:

- Evaluate the sensitivity of B-IBI and its component metrics as measures of ecosystem recovery.
  - Connecting recovery actions to improvement in B-IBI and its Vital Sign targets should be a priority. An implementation strategy is necessary to meet restoration targets, specifically, the PSP Action Agenda goal of improving 30 subwatersheds from “fair” to “good” biological condition.
  - The list of possible actions available to improve B-IBI scores is shorter than the list of causes of impairment; only a few recovery actions are possible and their relative impacts need to be field tested. Removing urbanization in a watershed is not a realistic option; however, restricting development in buffer areas, planting trees in riparian areas, reducing sediment, and other habitat restoration actions need to be assessed for their ability to improve B-IBI scores.
- Successes and challenges need to be shared regionally as local jurisdictions implement restoration and management actions to recover wadeable streams.
  - Many participants at the regional workshops expressed strong interest in continuing to hold and participate in regional meetings to share B-IBI monitoring results and learn how to use and interpret B-IBI to guide management actions and inform if current actions are protective of stream function and health.
  - The PSSB website could serve as a mechanism to share monitoring results; however, additional funding is necessary to continue to organize and hold regular workshops to support continued collaboration around benthic monitoring.
- The rescaled B-IBI $_{0\text{-}100}$ should be adopted by PSP.
  - B-IBI$_{0\text{-}100}$ should be incorporated into the Vital Sign Indicator targets and the 2015 PSP State of the Sound report.
  - Some regional jurisdictions may have questions about how the B-IBI updates will impact their long-term data sets. To fully implement the changes, ongoing outreach and some follow-up with individual jurisdictions will be necessary.

- Biological impairment thresholds and regulatory decisions need to be effectively communicated.
    - Local jurisdictions need a defined process to work with Ecology regarding how biological impairment will be defined and regulatory decisions will be implemented. There are many lingering questions about how B-IBI data can be used, the implications of biological impairment listing of streams, requirements related to Total Maximum Daily Load (TMDL) allocations for B-IBI, and other regulatory questions as biological criteria for aquatic use are implemented.
    - The goal is to recover the biological health of Puget Sound streams, yet impairment listing of streams brings a myriad of complexities with it. Local jurisdictions need a voice in this process so that successful recovery is more likely.
    - The EPA has developed a biological condition gradient (BCG) framework to link Clean Water Act goals to the quantitative measures used in biological assessment (Davies and Jackson 2006; EPA 2013). It is recommended that EPA and Ecology work together with other scientists and water quality managers to develop a BCG for the Puget Sound region to address impairment thresholds and condition category descriptions. The need for a BCG has been highlighted during recent efforts to incorporate the use of B-IBI in the Soos Creek TMDL process (Plotnikoff and Blizard 2013).

3.2 Conclusions

This report summarizes the efforts that King County and the numerous partners involved with this project made to enhance and standardize benthic macroinvertebrate monitoring and analysis tools for the Puget Sound region, providing an overview of the key accomplishments of the process used to recalibrate B-IBI, strengthen the diagnostic capability of this index, and broaden data accessibility and analytical functionality of the PSSB. As the work associated with this grant comes to a close, one challenge will be to continue this work beyond jurisdictional boundaries to maintain regional collaboration, building on the strong foundation established by the efforts of this grant and the development of the PSSB. Outreach needs to continue with partners to further develop approaches for data-sharing, restoration strategy development, and communicating long-term monitoring results and outcomes.

The recalibrated B-IBI provides a quantitative tool to help focus restoration goals, measure effectiveness, and improve the overall ecological understanding of Puget Sound streams. The B-IBI provides a consistent and scientifically defensible quantitative tool necessary to identify ecological conditions in need of protection and restoration. Watershed prioritization is necessary before protection and restoration strategy development and implementation can be completed. The application of B-IBI for preserving biological integrity and planning future projects is underway. B-IBI's role as a PSP Vital Sign Indicator provides the region with the essential information needed to focus watershed restoration and preservation efforts and help evaluate the most effective strategies. The improvements in benthic monitoring tools supported by this project will enhance the ability of scientists and planners to improve restoration and preservation project design and better monitor effectiveness of these projects. All of these elements contribute to improved freshwater ecosystems, and ultimately a healthier Puget Sound.

4.0. REFERENCES

Davies, S. P., and S. K. Jackson. 2006. The biological condition gradient—A descriptive model for interpreting change in aquatic ecosystems. Ecological Applications 16: 1251-1266.

[EPA] United States Environmental Protection Agency. 2013. Biological Assessment Program Review: Assessing Level of Technical Rigor to Support Water Quality Management. Publication EPA 820-R-13-001. United States Environmental Protection Agency. Office of Science and Technology, Washington, D.C.

Fore, L. S., K. Paulsen, K. O'Laughlin. 2001. Assessing the performance of volunteers in monitoring streams. Freshwater Biology 46: 109-123.

Karr, J. R., and E. W. Chu. 1999. Restoring life in running waters: better biological monitoring. Island Press, Washington, D.C.

King County. 2009. Puget Sound Stream Benthos: Monitoring Status and Data Management. Prepared by Jenée Colton, Doug Henderson, Deb Lester and Jim Simmonds, Water and Land Resources Division. Seattle, Washington.

King County. 2013. Using Natural History Attributes of Stream Invertebrates to Measure Stream Health. Prepared by Leska Fore (Statistical Design), Bob Wisseman (Aquatic Biology Associates), Jo Opdyke Wilhelm (King County Water and Land Resources Division[WLRD]), Deb Lester (WLRD), Karen Adams (Washington State Department of Ecology), Gretchen Hayslip (US Environmental Protection Agency[EPA]), and Peter Leinenbach (EPA). Seattle, Washington.

King County. 2014a. B-IBI Restoration Decision Framework and Site Identification. Prepared by Jo Opdyke Wilhelm, Debra Bouchard, Chris Gregersen, Chris Knutson, and Kate Macneale. Water and Land Resources Division. Seattle, Washington.

King County. 2014b. Recalibration of the Puget Lowland Benthic Index of Biotic Integrity (B-IBI). Prepared by Jo Wilhelm (King County Water and Land Resources Division [WLRD]), Leska Fore (Statistical Design), Deb Lester (WLRD) and Elene Dorfmeier (WLRD). Seattle, Washington.

King County. 2014c. Evaluation of Stream Benthic Macroinvertebrate Sampling Protocols: Comparison of 3 ft^2 and 8 ft^2. Prepared by Jo Opdyke Wilhelm and Elene Dorfmeier, Water and Land Resources Division. Seattle, Washington.

King County. 2014d. Examining the Influence of Natural Site Features on B-IBI Response. Prepared by Elene Dorfmeier, King County Department of Natural Resources, Water and Land Resources Division. Seattle, Washington.

King County. 2014e. Identifying Stressor Risk to Biological Health in Streams and Small Rivers of Western Washington. Prepared by Elene Dorfmeier, King County Department of Natural Resources, Water and Land Resources Division. Seattle, Washington.

Kleindl, W. J. 1995. A Benthic Index of Biotic Integrity for Puget Sound Lowland Streams, Washington, USA. M.S. Thesis, University of Washington, Seattle, Washington.

Morley, S. A., and J. R. Karr. 2002. Assessing and restoring the health of urban streams in the Puget Sound basin. Conservation Biology. 16:1498-1509.

Plotnikoff, R. W. and J. A. Blizard. 2013. Squalicum Creek and Soos Creek: Bioassessment Monitoring and Analysis to Support Total Maximum Daily Load (TMDL) Development. Publication No. 13-03-017. Environmental Assessment Program. Washington State Department of Ecology, Olympia, WA.

[PSP] Puget Sound Partnership. 2013. 2013 State of the Sound: A Biennial Report on the Recovery of Puget Sound. Tacoma, Washington.