Recalibration of the Puget Lowland Benthic Index of Biotic Integrity (B-IBI)

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King County

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Citation

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[1] Reports, presentations, and relevant documents are available on the B-IBI Recalibration Documents and Materials project page of the PSSB: http://www.pugetsoundstreambenthos.org/Projects/BIBI-Recalibration-Documentation.aspx.

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EXECUTIVE SUMMARY

The Puget Lowland benthic index of biotic integrity (B-IBI) was developed in the 1990s as an integrative measure of the biological health of wadeable streams in the Pacific Northwest. B-IBI is an index composed of 10 metrics that characterize aquatic macroinvertebrate communities by measuring taxa richness, relative abundance, and other ecological characteristics of stream macroinvertebrates. Since its original development, B-IBI has been broadly applied in a variety of contexts in western Washington including status and trend assessment of regional and local conditions and effectiveness monitoring of habitat restoration projects. More recently, B-IBI has been designated as a Vital Sign indicator of freshwater health for Puget Sound watersheds. To achieve restoration targets for watersheds set by the Leadership Council of the Puget Sound Partnership, B-IBI is used to identify watersheds for restoration and protection. The Department of Ecology uses B-IBI to determine biological impairment of streams for the Washington State water quality assessment and reporting under the Clean Water Act.

Approximately twenty years have passed since the Puget Lowland B-IBI was developed and calibrated in the early 1990s using data from approximately 200 stream site visits from western Oregon and Washington. B-IBI was originally developed as a set of 10 metrics with a discrete scaling system of values (1, 3, or 5) that are summed to calculate a B-IBI score ranging from 10–50 (referred to as B-IBI$_{10\text{-}50}$) where high scores reflect excellent stream health. This report summarizes B-IBI recalibration efforts motivated by a desire to take advantage of improvements in data quantity (nearly 5,000 Puget Sound site visits), taxa attribute classifications, and scoring techniques to refine B-IBI metric scoring and improve precision and accuracy of the component metrics and B-IBI to assess biological condition.

B-IBI recalibration

Benthic macroinvertebrate data stored in the Puget Sound Stream Benthos data management system (PSSB) were used to rescore component metrics and compare the influence of taxonomic effort on metric scoring. Data were limited to sites located in the Puget Sound basin at elevations less than 500 m, sampled between July and October with a surface collection area of 3, 8, or 9 ft^2 and that had associated landscape data obtained by GIS analysis (856 total sites).

The 10th and 90th percentiles of values for each metric were used to define the upper and lower bounds of each metric score. The metric score is the linear interpolation between the upper (90th percentile) and lower (10th percentile) thresholds so that each metric score ranges from 0–10 with a score of 10 always indicative of the best condition. The ten recalibrated component metrics are summed together for a B-IBI score ranging from 0–100 (referred to as B-IBI$_{0\text{-}100}$).

The level of taxonomic effort used to identify invertebrates in a sample influences the B-IBI score. Therefore, a data set from 186 site visits was used to evaluate and correct B-IBI$_{0\text{-}100}$ for different levels of taxonomic effort. These site visits were selected because the original taxonomic identification was conducted to the lowest practical level and could therefore be collapsed to coarser levels of taxonomic resolution allowing for a comparison of the effect of taxonomic effort. Taxonomic scoring adjustments derived from the 10th and 90th percentile for three levels of taxonomic effort were necessary for three metrics (taxa richness, clinger richness, and percent dominant). Scoring adjustments effectively account for taxonomic effort differences so that overall B-IBI scores and biological condition classification are comparable regardless of taxonomic effort level. Thus, scoring adjustments provide consistent assessments and comparability across watersheds, programs, and time.

The signal to noise ratio for B-$IBI_{0\text{-}100}$ was 10.76 and is an estimate of precision. In general, a signal to noise ratio greater than 10 is considered a precise indicator with a good ability to detect change in condition.

B-IBI comparison

B-$IBI_{10\text{-}50}$ and B-$IBI_{0\text{-}100}$ are highly correlated with each other and with human disturbance, decreasing with percent urbanization in the watershed. This correlation with watershed urbanization, which is slightly stronger for B-$IBI_{0\text{-}100}$, represents the ability to discriminate changes in biological communities resulting from human impacts and is one of the most important qualities of a reliable biological index.

B-$IBI_{0\text{-}100}$ has the statistical precision to detect five or more condition categories for many standard statistical designs. To report B-$IBI_{0\text{-}100}$ values in a narrative format, the recalibrated B-$IBI_{0\text{-}100}$ scores were divided evenly across the existing five condition categories also used for B-$IBI_{10\text{-}50}$: Excellent, Good, Fair, Poor and Very Poor. B-$IBI_{0\text{-}100}$ scores are more evenly distributed across the condition categories compared to B-$IBI_{10\text{-}50}$ with fewer sites binned into the poor and fair condition categories and more sites into the two extreme conditions (very poor and excellent). For the majority of sites (71%) there was no change in condition category for both B-$IBI_{10\text{-}50}$ and B-$IBI_{0\text{-}100}$. However, 29% of sites shifted condition category, of which 17% shifted up one condition category to a higher quality condition category (e.g., from fair to good) while 12% shifted down one condition category (e.g., from poor to very poor).

Conclusions

This report summarizes the methods and analyses used to standardize benthic macroinvertebrate monitoring by recalibrating the primary analysis tool used to assess stream health in the Puget Sound region (B-IBI). The recalibrated B-$IBI_{0\text{-}100}$ is a robust and sensitive tool that can be applied to assess the ecological condition of Puget Lowland streams, where urbanization is a major stressor on water resources. B-$IBI_{0\text{-}100}$ can be used for management and restoration of water resources and provides an accurate tool for evaluating anthropogenic impacts on streams.

The major improvements to B-IBI include continuous scoring that eliminated scoring gaps, development of three levels of standard taxonomic effort to reduce taxonomy-related variability, metric scoring adjustments that account for taxonomic level differences, and updates to the taxonomic lists for tolerant, intolerant, predator, long-lived, and clinger taxa. These improvements have been incorporated into the PSSB. Increased cross-jurisdictional cooperation, verification of method comparability, development of more precise and accurate analysis tools, and improved ease of data access and manipulation evolved from the B-IBI recalibration process. These tools enable improved regional evaluation of biological health and increased confidence in the ability to evaluate changes in biotic integrity, especially due to urbanization.

1.0. Introduction

What is B-IBI?

The Puget Lowland benthic index of biotic integrity (B-IBI) was developed in the 1990s as an integrative measure of the biological health of wadeable streams in the Pacific Northwest (Karr 1998; Fore et al. 2001, Karr & Chu 1999, Kleindl 1995, Morley & Karr 2002). B-IBI is an index composed of 10 metrics that characterize aquatic macroinvertebrate communities by measuring taxa richness, relative abundance, and other ecological characteristics of stream macroinvertebrates (Appendix A). Aquatic macroinvertebrate communities are effective biological indicators of stream condition because they reflect the cumulative impacts of multiple stressors in a watershed (McDonald et al. 1991; Walsh 2006). Indices based on macroinvertebrate taxa assemblages are widely applied for conservation and management of aquatic resources since they can assist in determining linkages between observed ecological effects and environmental stress.

How is B-IBI used?

B-IBI was developed to address the legislative mandates of the Clean Water Act (Karr 1998). States are required to assess the condition of their water resources and report whether they are meeting water quality standards (Davies and Jackson 2006). Since its original development, B-IBI has been broadly applied in a variety of contexts in western Washington including status and trend assessment of regional and local conditions and effectiveness monitoring of habitat restoration projects. Interest in using B-IBI as a regional indicator of stream condition in Washington State has been strong since its development in the mid-1990s. Use of B-IBI continues to increase with over 20 agencies in the Puget Sound basin relying on B-IBI as a bioindicator of stream health (King County 2009). There is also growing interest amongst these agencies to use B-IBI results to set funding and stream enhancement priorities.

Recently, B-IBI was designated as one of the three Vital Signs indicators for freshwater used to report the health of Puget Sound by the Puget Sound Partnership (PSP), an organization formed to develop a strategic framework for restoring the Puget Sound watershed (PSP 2012). As a Vital Signs indicator, B-IBI has two regional recovery targets to (1) protect all excellent streams and (2) restore 30 streams from fair to good. These targets provide a mechanism for using biological data to prioritize where to conduct stream and watershed restoration and preservation efforts and for evaluating the strategies that may be most effective.

B-IBI data are being used to evaluate biological impairment of streams for the Washington State water quality assessment (Ecology 2012), which has historically been focused on water quality data (chemistry). Waterbodies classified as impaired based on B-IBI data are listed on Washington State's 303(d) list and may be considered for stressor identification or total maximum daily load (TMDL) studies to improve biotic condition. Because benthic macroinvertebrate communities reflect water quality, habitat, and flow conditions, use of

B-IBI in the water quality assessment and the 303(d) listing process provides an important tool for better characterizing environmental conditions and potential stressors.

Scoring the original B-IBI

The Puget Lowland B-IBI was developed and calibrated in the early 1990s using data from approximately 200 stream site visits in Puget Sound; Clackamas River, Oregon; and the Olympic Peninsula (Karr 1998, Fore unpublished data). B-IBI was originally developed as a set of 10 metrics with a discrete scaling system of values (1, 3, or 5) to quantitatively describe the biological condition of stream health (poor, fair, excellent), similar to the original Index of Biotic Integrity approach established by Karr (1981). Using this method, metric scores are summed to calculate a B-IBI score ranging from 10–50.

B-IBI recalibration

The component metrics of B-IBI have been repeatedly demonstrated to be strong indicators of human disturbance and site condition (see Appendix A, Kerans and Karr 1994, Kleindl 1995, Fore et al. 1996, Karr and Chu 1999, Karr et al. 1986, Fore et al. 2001, Morley and Karr 2002). B-IBI recalibration efforts summarized here were motivated by a desire to re-evaluate index performance, increase confidence in bioassessment results, and to take advantage of improvements in data quantity, taxa attribute classifications, and scoring techniques. Working with multiple partners, the objective of this project was to update certain metrics, refine B-IBI metric scoring and improve the precision and accuracy of the component metrics and B-IBI to assess biological condition.

Macroinvertebrate data now exist in the Puget Sound Stream Benthos data management system (PSSB; www.pugetsoundstreambenthos.org) for almost 5,000 site visits scattered broadly across the Puget Sound basin. Taxa attributes used to calculate five of the ten B-IBI component metrics were recently updated (King County 2013a). Improved continuous scoring approaches have emerged for scoring component metrics which reduce index variability and eliminate gaps in index scoring (Minns et al. 1994, Hughes et al. 1998, Blocksom 2003, Stoddard et al. 2008).

This report describes the process used to update B-IBI based on new information about individual taxa attributes and national guidance for constructing multimetric indices.

2.0. B-IBI Recalibration

This document describes recalibration of component metrics using continuous scaling and adjustment of metric scores for three levels of taxonomic effort. Five of the ten B-IBI metric calculations rely on taxa attribute lists. See King County (2013a) for a description of taxonomic updates for clinger taxa richness, percent predator, long-lived taxa richness, percent tolerant, and intolerant taxa richness and for development of a human disturbance gradient (percent watershed urbanization) used in evaluating the recalibrated and original B-IBI. The component metrics have a variety of units including the number or percentage of taxa in particular groups. In order to combine metrics into a single B-IBI score, each metric value must first be converted into a unitless number (Karr et al. 1986, Barbour et al. 1995).

To differentiate between the two B-IBI indices derived from the two metric scoring methods, the original B-IBI will be denoted as B-IBI$_{10\text{-}50}$ and the recalibrated B-IBI as B-IBI$_{0\text{-}100}$. When results apply to both versions of B-IBI, just B-IBI will be used. The following sections provide an overview of the process used to recalibrate B-IBI$_{10\text{-}50.}$

2.1 Update scoring of B-IBI component metrics

Benthic macroinvertebrate data stored in the PSSB were used to rescore component metrics and compare the influence of taxonomic effort on metric scoring. Data were limited to sites located in the Puget Sound basin (Water Resource Inventory Areas [WRIA] 1–19) at elevations less than 500 m, sampled between July and October with a surface collection area of 3, 8, or 9 ft^2 and that had associated landscape data obtained by GIS analysis (King County 2013b). The following PSSB user-defined options were selected to download stream data: (1) replicates combined, (2) taxonomic resolution as defined by project metadata, (3) 500 organism maximum count (i.e., subsampled when organism count is greater than 500). The final dataset included the most recent site visit from 856 sites visited between 2000 and 2012 (see Appendix B for summary statistics for these sites).

The Puget Lowland B-IBI$_{10\text{-}50}$ was originally developed as a set of 10 metrics with a discrete scaling system of scores (1, 3, 5) summed to calculate a total B-IBI score ranging from 10-50. B-IBI measures the biological condition based on stream macroinvertebrates and provides a scale of condition from very poor (10) to excellent (50) (Table 1). Scoring metrics using continuous rather than discrete scores is expected to improve B-IBI precision, distinguish more categories of biological condition, decrease index variability, and eliminate gaps in index scoring (Minns et al. 1994, Hughes et al. 1998, Blocksom 2003, Stoddard et al. 2008). The methods described here outline the procedures of scoring each metric on a continuous scale (0–10), leading to a composite index having scores ranging from 0–100.

Table 1. Qualitative categories of biological condition.
Modified from Karr (1981) and Karr et al. (1986) by Morley (2000) and updated with B-IBI$_{0\text{-}100}$ scoring. Closed brackets [ ] include endpoints; open brackets ( ) exclude endpoints.

Biological Condition	Description	B-IBI$_{10\text{-}50}$	B-IBI$_{0\text{-}100}$
Excellent	Comparable to least disturbed reference condition; overall high taxa diversity, particularly of Ephemeroptera (mayfly), Plecoptera (stonefly), Trichoptera (caddisfly), long-lived, clinger, and intolerant taxa. Relative abundance of predators high.	[46, 50]	[80, 100]
Good	Slightly divergent from least disturbed condition; absence of some long-lived and intolerant taxa; slight decline in richness of Ephemeroptera, Plecoptera, and Trichoptera; proportion of tolerant individuals increases.	[38, 44]	[60, 80)
Fair	Total taxa richness reduced – particularly intolerant, long-lived, Plecoptera, and clinger taxa; relative abundance of predators declines; proportion of tolerant individuals continues to increase.	[28, 36]	[40, 60)
Poor	Overall taxa diversity depressed; proportion of predators greatly reduced as is long-lived taxa richness; few Plecoptera or intolerant taxa present; dominance by three most abundant taxa often very high.	[18, 26]	[20, 40)
Very Poor	Overall taxa diversity very low and dominated by a few highly tolerant taxa; Ephemeroptera, Plecoptera, caddisfly, clinger, long-lived, and intolerant taxa largely absent; relative abundance of predators very low.	[10, 16]	[0, 20)

Metric scoring results

The ten B-IBI component metric values were plotted against watershed urbanization to verify response to the disturbance gradient. Metric values refer to the richness count or percent calculated from the macroinvertebrate data. For example, the metric value for Ephemeroptera richness is the count of unique mayfly taxa at a site. Metric values are the same for B-IBI$_{10\text{-}50}$ and B-IBI$_{0\text{-}100}$. The metric score is the standardized interpretation of that count or percent (1, 3, 5 or 0–10). Percent watershed urbanization was selected as the human disturbance gradient to calibrate metric response because it was highly correlated with B-IBI$_{10\text{-}50}$ and it is a simple and effective measure for summarizing site condition that is easy to apply and interpret (see King County 2013a for details). Metrics were generally well distributed across the range of disturbance, reasonably monotonic, and not highly skewed (Appendix C). Thus, no statistical transformation was necessary before they were scored.

Component metric summary statistics were calculated (Table 2) and the 10th and 90th percentiles of each metric value are used to define scoring equations by setting upper and lower bounds of each metric score (Blocksom 2003, Stoddard et al. 2005, Stoddard et al. 2008). The metric score is the linear interpolation between the upper (90th percentile) and lower (10th percentile) thresholds (Minns et al. 1994, Hughes et al. 1998).

Table 2. B-IBI component metric summary statistics for 856 sites. Underlined metrics indicate metrics that increase, rather than decrease with increasing human disturbance.

Metric name	Mean	Minimum	Maximum	10th Percentile	90th Percentile
Total taxa richness	29	3	70	16	41
Ephemeroptera richness	4.3	0	13	1	8
Plecoptera richness	4.6	0	14	1	8
Trichoptera richness	5.1	0	13	1	9
Long-lived richness	5.8	0	17	2	10
Intolerant richness	2.9	0	14	0	7
% Tolerant individuals	14.5	0	88	0	43
% Predator individuals	9.9	0	55	1	21
Clinger richness	13.9	0	31	5	22
% Dominance	60.5	23	99	42	82

Equations for converting component metric values onto a continuous scale are shown in Table 3. For the eight metrics that decline as human disturbance increases, metric values above the 90th percentile are scored as a 10 and metric values below the 10th percentile are scored as 0. For metrics that increase as disturbance increases (percent tolerant and dominance), metric scoring is inverted so that a score of 10 always indicates the best condition; metric values below the 10th percentile are scored as 10 and above the 90th percentile are scored as 0. The ten recalibrated component metrics are summed together for a B-IBI score ranging from 0–100 (see Appendix D for example calculations). Metric score calculations are rounded to the nearest tenth of a decimal point on the PSSB.

Table 3. B-IBI$_{0\text{-}100}$ component metric scoring formulas. See Table 6 for all ten metric scoring formulas.

Metric Response with Disturbance	Score for Values < 10th Percentile	Score for Values > 90th Percentile	Scoring Formula
Decrease with Human Disturbance	0	10	$= \frac{10 \times (\text{Observed Value} - \text{10th Percentile})}{(\text{90th Percentile} - \text{10th Percentile})}$
Increase with Human Disturbance	10	0	$= 10 - \left[\frac{10 \times (\text{Observed Value} - \text{10th Percentile})}{(\text{90th Perecentile} - \text{10th Percentile})}\right]$

2.2 Taxonomic resolution adjustments

The level of taxonomic effort used to identify invertebrates impacts some metrics and the overall B-IBI score. Comparing B-IBI across projects and over time requires some level of taxonomic standardization or scoring adjustments to ensure that a difference in B-IBI scores and metrics is due to biological condition and not differences in taxonomic effort. Greater taxonomic effort increases the number of taxa identified as the level of taxonomic resolution increases from family to genus to species. This section provides an overview of the process used to develop appropriate scoring adjustments for B-IBI$_{0\text{-}100}$ metrics due to different levels of taxonomic effort[2].

A data set from 186 site visits was used to evaluate and correct B-IBI$_{0\text{-}100}$ for different levels of taxonomic effort. These site visits were selected because the original taxonomic identification was conducted to the lowest practical level and could therefore be collapsed to coarser levels of taxonomic resolution allowing for a comparison of the effect of taxonomic effort. With help from Rhithron Associates, Inc., a company that specializes in taxonomic identification of freshwater invertebrates, three levels of standard taxonomic effort (STE) were developed that represent coarse, medium, and fine taxonomic effort. The STE can be specified in the criteria panel of the PSSB for each sample taxa list stored in the PSSB (Table 4). These were created to represent a broad range of taxonomic effort levels and the most commonly specified classifications utilized by Puget Sound macroinvertebrate monitoring agencies. The finest resolution is the STE level specified by Ecology (see Appendices G and H in Adams 2010), the coarsest resolution is the STE level specified by King County for the ambient biological monitoring program prior to 2012[3], and the medium resolution is an intermediate level.

[2] B-IBI$_{10\text{-}50}$ includes scoring adjustments for three of the ten metrics (total taxa richness, clinger richness, and percent dominant) to account for taxa richness differences resulting from the level of taxonomic identification of Chironomidae (family versus genus) (Appendix E). Analysis of B-IBI$_{10\text{-}50}$ data determined that these scoring adjustments were successful in consistently categorizing biological condition regardless of the taxonomic effort used for identifying chironomids (Wilhelm 2012).
[3] Beginning in 2012, King County switched to having invertebrates identified to Ecology's specifications for lowest practical level (Adams 2010).

Table 4. Level of taxonomic effort for various taxa groups for three levels of standard taxonomic effort (STE; fine, medium, and coarse).

Taxa Group	Common Name	Fine STE	Medium STE	Coarse STE
Oligochaeta	segmented worms	Subfamily/Genus	Family	Subclass ("Oligochaeta")
Acari	mites	Genus	Subclass ("Acari")	Subclass ("Acari")
Gastropoda	snails	Genus	Genus	Family
Dytiscidae	predaceous diving beetles	Genus (adults and larvae)	Genus (adults) Family (larvae)	Family (adults and larvae)
Simuliidae	blackflies	Genus (larvae and pupae)	Genus (larvae) Family (pupae)	Family (larvae and pupae)
Chironomidae (larvae and pupae)	midges	Genus/species/ species group	Subfamily/tribe	Family
Trichoptera	caddisflies	Genus/species/ species group	Genus (larvae) Family (pupae)	Genus (larvae) Order (pupae)
All other taxonomic groups	various	Lowest practical level: typically genus or species	Lowest practical level: typically genus or species	Lowest practical level: typically genus or species

Taxonomic effort results

Metric values and continuous scores were downloaded from the PSSB for the three STE levels without any taxonomic scoring adjustments. To test whether corrections to metric scoring were necessary, correlations of B-IBI$_{0\text{-}100}$ scores for medium and fine STE were compared against B-IBI$_{0\text{-}100}$ scores for coarse STE (Figure 1). B-IBI$_{0\text{-}100}$ scores differed according to taxonomic effort averaging 7.5 points higher for fine STE compared to coarse STE and 3.4 points higher for medium STE compared to coarse STE. The consistently higher B-IBI$_{0\text{-}100}$ scores for samples with finer taxonomic effort indicate that taxonomic scoring adjustments are necessary to make B-IBI$_{0\text{-}100}$ scores derived from different levels of taxonomic effort comparable.

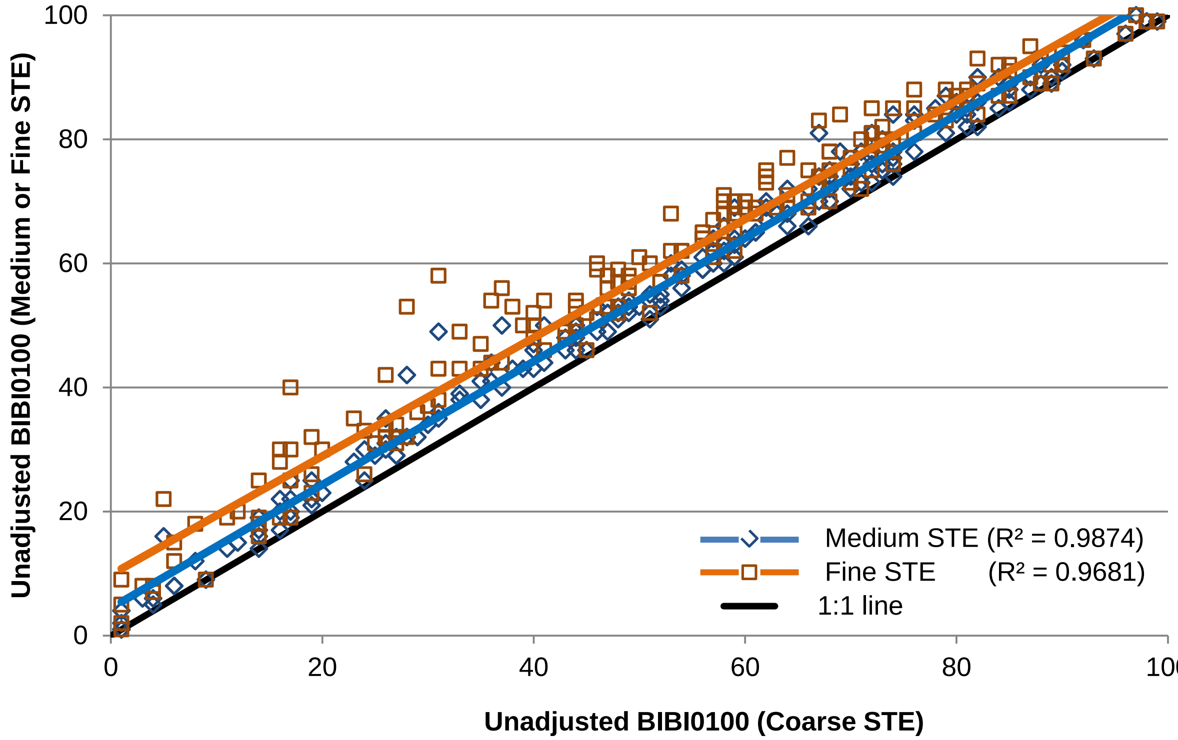

Figure 1. Correlation graphs of unadjusted B-IBI$_{0\text{-}100}$ scores at three levels of standard taxonomic effort (STE).
The unadjusted B-IBI$_{0\text{-}100}$ scores are calculated with the same metric scoring formulas regardless of STE level. B-IBI$_{0\text{-}100}$ scores for fine and medium level STE were higher indicating the need for taxonomic scoring adjustments.

The mean, minimum and maximum metric values were compared across the three STE levels for each of the ten metrics to identify the metrics contributing to the observed differences in B-IBI$_{0\text{-}100}$ scores derived from different taxonomic levels. As predicted, three of the ten metrics (taxa richness, clinger richness, and percent dominant) differed according to taxonomic effort (Table 5).

Table 5. Summary statistics for the three metrics requiring scoring adjustments based on taxonomic effort level.
Different levels of taxonomic effort were applied to each site visit for comparison (n = 186). 10^{th} and 90^{th} percentiles are used for metric scoring formulas.

Metric	STE Level	Mean	Minimum	Maximum	10th Percentile	90th Percentile
Taxa Richness	Coarse	28	9	47	16	37
	Medium	32	11	53	20	43
	Fine	41	13	70	27	56
Percent Dominant	Coarse	61	32	93	44	82
	Medium	55	26	93	39	75
	Fine	50	18	93	32	69
Clinger Richness	Coarse	14	2	27	5	22
	Medium	15	2	28	7	23
	Fine	16	2	34	7	24

Scoring adjustments for these three metrics were derived from the 10^{th} and 90^{th} percentile results for each STE level as previously described. The adjusted B-IBI$_{0\text{-}100}$ scores were compared at all three STE levels (Figure 2). After scores for the three metrics were adjusted, there was no difference in B-IBI$_{0\text{-}100}$ scores as illustrated by the overlapping regression lines in Figure 2. Adjusted B-IBI$_{0\text{-}100}$ scores averaged 0.07 points lower for fine STE compared to coarse STE and only 0.52 points lower for medium STE compared to coarse STE which are negligible differences across a scale of 0-100.

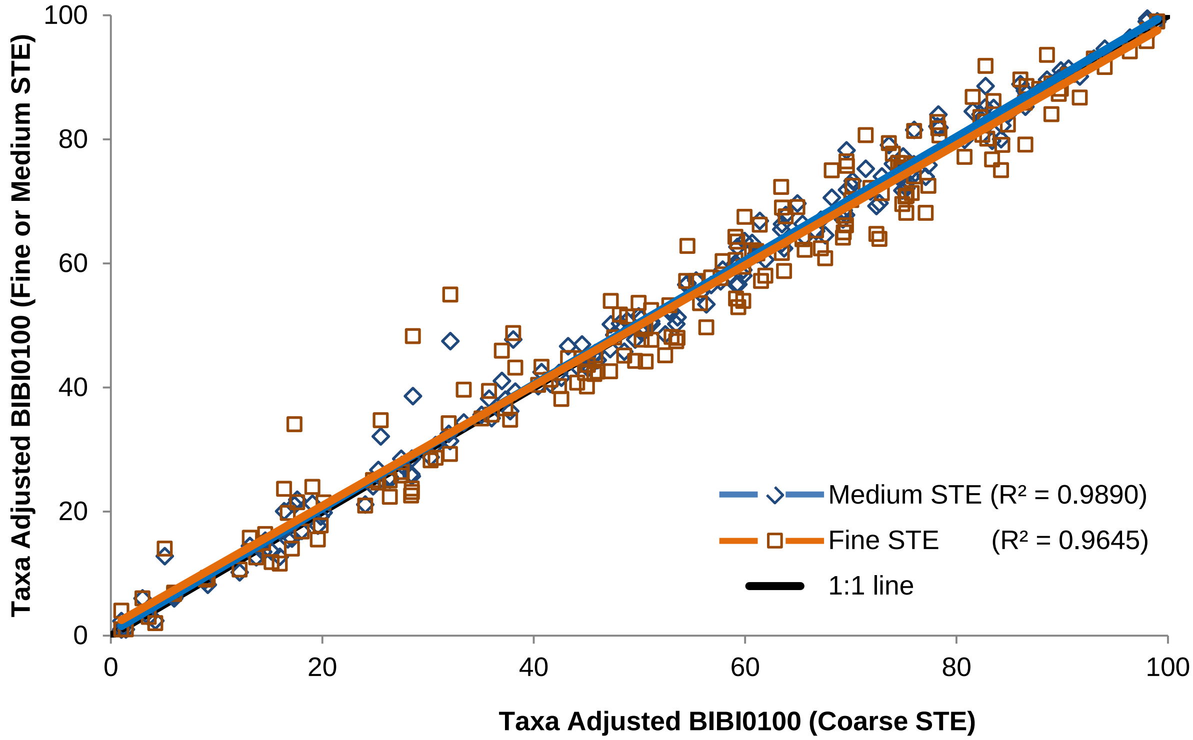

Figure 2. Correlation graphs of taxa adjusted B-IBI$_{0\text{-}100}$ scores at three levels of standard taxonomic effort (STE).
The adjusted B-IBI$_{0\text{-}100}$ scores are calculated with different formulas for three metrics (taxonomic and clinger richness and percent dominant) based on STE level. The three lines plot on top of each other indicating agreement and that metric adjustment were sufficient to make B-IBI comparable for different levels of taxonomic effort.

Scoring adjustments effectively account for taxonomic effort differences so that overall B-IBI$_{0\text{-}100}$ scores and biological condition classification are comparable regardless of taxonomic effort level. To make sure that the appropriate taxonomic adjustments are applied, it is necessary that the data stored in the PSSB are appropriately classified into one of the three levels of STE. King County reviewed data in the PSSB in fall 2013 and edited the STE settings for all site visits; project defaults were set to the STE level reflected for the most recent year of data. Going forward, it is the responsibility of project stewards for individual PSSB projects to assure these settings are correct. Three taxonomic groups have the largest influence on the changes observed in B-IBI scores due to the level of taxonomic effort: Chironomidae (midges), Oligochaeta (segmented worms), and Acari (mites). The coarse STE taxa richness for Chironomidae, Oligochaeta, and Acari by definition is 1. However, at fine STE the average (and maximum) richness for Chironomidae is 11 (26), Oligochaeta 3 (7), and Acari 2 (8) (Figure 3). When taxonomy data do not fit exactly into one of the three predetermined effort levels, the taxonomic effort for Chironomidae is given the most weight due to the high species richness of this group and its influence on B-IBI scoring. For example, if Chironomidae are identified to genus-species (which falls into the fine STE – see Table 4), but Acari are identified to subclass (which falls into the coarse STE), the overall sample should be identified as fine STE in the PSSB metadata[4].

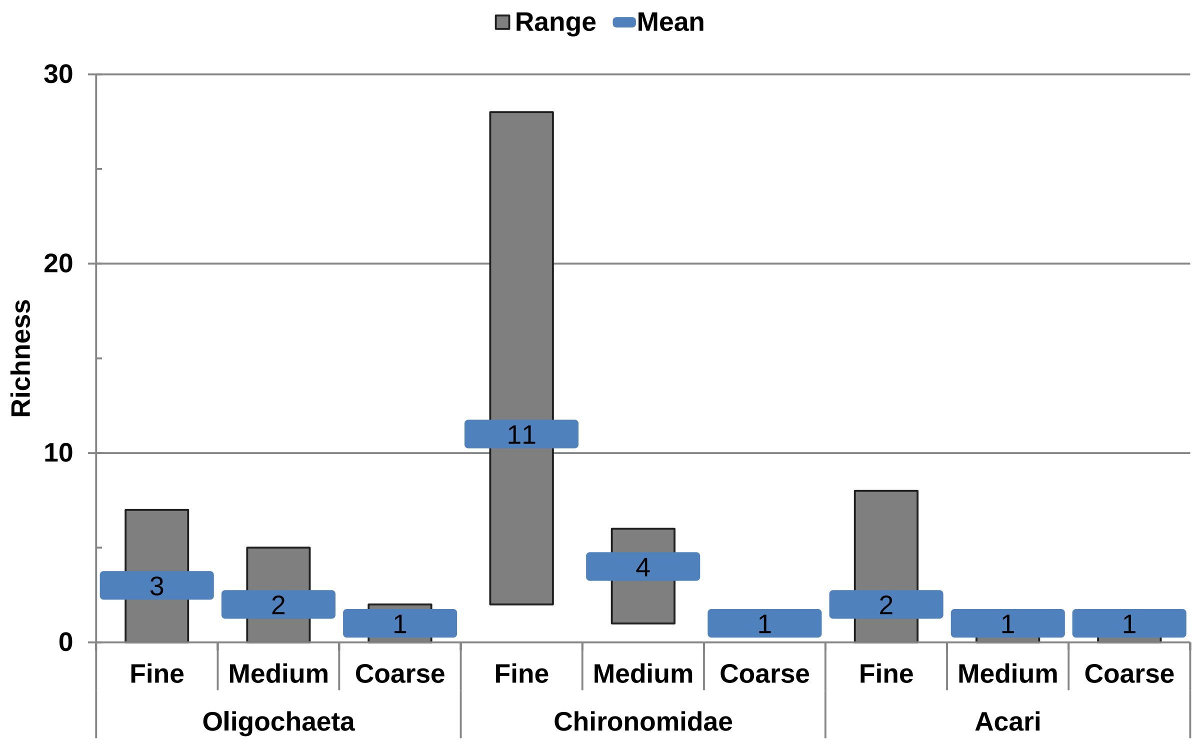

Figure 3. Range (gray bars) and mean (blue) of taxonomic richness for Oligochaeta, Chironomidae, and Acari for three levels of standard taxonomic effort (STE). See Table 4 for a description of the fine, medium, and coarse STE levels.

In conclusion, the level of taxonomic effort has a direct influence on three B-IBI metrics and these were adjusted to make B-IBI comparable regardless of taxonomic effort. In this way, stream biological condition can be consistently assessed and compared across watersheds, programs, or time because scoring adjustments compensate for different levels of taxonomic effort. These scoring adjustments are programmed into the PSSB.

Agencies need to weigh the purpose of their monitoring program in addition to cost when determining what level of taxonomic effort to specify. Finer taxonomic resolution enables more accurate assignment of taxon attributes, allows for greater insight in stressor identification, and builds a more robust dataset that may contribute to increased understanding of how macroinvertebrate communities reflect certain stressors. Ecology specifies that the fine STE be used for data to be considered for the state water quality assessment (Ecology 2012). The primary disadvantage for fine STE are increased costs due

[4] If data across years or project have different STE levels, PSSB users can opt to calculate B-IBI based on either (1) the coarse STE so that fine and medium STE data are collapsed to coarse STE levels and B-IBI will be calculated based on the resulting metric values or (2) STE designated in the metadata and B-IBI will be calculated using the scoring adjustments for the different STEs as appropriate.

to the greater time and effort required. Sample archiving may be an advantageous approach that keeps current costs low, but enables future, finer resolution taxa identification that may be valuable in stressor identification or prioritization of management actions.

2.3 Recalibrated metric calculations

To calculate the new B-IBI, metrics are now continuously scored and adjusted for the level of taxonomic effort. Table 6 is the summary table for calculating B-IBI$_{0\text{-}100}$ scores for each of the ten B-IBI component metrics including taxonomic effort adjustments. The PSSB now calculates B-IBI$_{0\text{-}100}$ and offers users a variety of options to fine tune the desired analyses including options for STE, attribute lists, and subsampling. See Appendix F for a B-IBI$_{0\text{-}100}$ scoring table showing the approximate observed values for each metric score.

Table 6. Formulas used to rescale and rescore component metrics. When the result is less than zero, zero is used; if greater than ten, ten is used so that each metric ranges from 0-10. Scoring was adjusted for three metrics based on level of taxonomic effort.

Metric	Metric Scoring Equation	10th Percentile	90th Percentile
Total taxa richness			
Coarse	10 x (Observed value – 16) / (37 – 16)	16	37
Medium	10 x (Observed value – 20) / (43 – 20)	20	43
Fine	10 x (Observed value – 27) / (56 – 27)	27	56
Ephemeroptera richness	10 x (Observed value – 1) / (8 – 1)	1	8
Plecoptera richness	10 x (Observed value – 1) / (8 – 1)	1	8
Trichoptera richness	10 x (Observed value – 1) / (9 – 1)	1	9
Long-lived richness	10 x (Observed value – 2) / (10 – 2)	2	10
Intolerant richness	10 x (Observed value – 0) / (7 – 0)	0	7
Percent tolerant	10 – [10 x (Observed value – 0) / (43 – 0)]	0	43
Percent predator	10 x (Observed value – 1) / (21 – 1)	1	21
Clinger richness			
Coarse	10 x (Observed value – 5) / (22 – 5)	5	22
Medium	10 x (Observed value – 7) / (23 – 7)	7	23
Fine	10 x (Observed value – 7) / (24 – 7)	7	24
Percent dominant			
Coarse	10 – [10 x (Observed value – 44) / (82 – 44)]	44	82
Medium	10 – [10 x (Observed value – 39) / (75 – 39)]	39	75
Fine	10 – [10 x (Observed value – 32) / (69 – 32)]	32	69

No other scoring adjustments needed

The influence of collection area (3 ft^2 versus 8 ft^2) and several natural factors (e.g., elevation, watershed area, precipitation, surficial geology permeability, and wetland landcover) on B-IBI were tested. These were not related to metrics in a consistent way and so no metric scoring adjustments were needed for collection area or natural factors (King County 2014a, King County 2014b). Other information or data could come to light that may necessitate adjustment in the future.

2.4 Variance and precision of B-IBI

Continuous metric scoring for B-IBI provides a more accurate representation of the data and avoids gaps in index scores (Minns et al. 1994; Hughes et al. 1998; Blocksom 2003). B-IBI variance was estimated from quality control (QC) replicates collected in the field. Several Puget Sound jurisdictions collect replicate samples from 5-10% of their annual sampling locations to estimate within site variability. These replicate samples are typically collected on the same day as the primary B-IBI sample. B-IBI_{0-100} metrics and index scores were calculated for Puget Sound site visits that collected benthic macroinvertebrates from at least a 3 ft^2 area and identified a minimum of 400 organisms. Minimum sample size avoided introduction of an additional source of variance associated with calculating taxa richness metrics from small sample sizes; 164 site visits in the PSSB met these criteria.

Variance of B-IBI was estimated using a random effects model of ANOVA with replicates nested within sites. The mean squared error (MSE) for the replicates was used as an estimate of the variance associated with repeat sampling at a site. This measure of variance corresponds to the error associated with slight differences in the physical location of the sample collection, likely due to substrate heterogeneity and associated differences in the invertebrates collected.

In addition to estimating variance, ANOVA also tests for statistical significance of differences in the factors (site and replicate). The results for hypothesis testing (under the null hypothesis the means of all groups are equal) are included as part of the standard ANOVA output. Not surprisingly, B-IBI scores at some sites were significantly different.

The estimate of variance for repeat same-day samples of B-IBI_{0-100} was 51.84 (Table 7). The variance for B-IBI_{0-100} was estimated from the two replicate samples collected from 164 same day site visits. Thus, a relatively large sample size provides confidence that this estimate of variance is reliable. The variance estimate can be used to determine the statistical power to detect change in alternative sampling designs, to calculate the number of replicates needed to detect a preferred amount of difference between sites, or to estimate the amount of change that can be detected over time (Fore et al. 1994; Fore et al., 2001).

Table 7. ANOVA results table for B-IBI$_{0\text{-}100}$ variance.

B-IBI$_{0\text{-}100}$	Effect	Effect df	Sums of Squares	Mean Squares	F	P
Site	Random	163	190264	1167.26	22.52	0.00
Replicate	Random	164	8503	**51.84**		

df = degrees of freedom

2.4.1 Estimating precision of B-IBI

One approach to measure precision uses the signal to noise ratio (S/N). S/N compares the variance of the indicator across all sites (the "signal") to the variance of the indicator within a site or time period (the "noise"). The higher the S/N the greater the precision of the indicator. Greater precision means the indicator has an increased ability to detect trends or changes because the measurement error is relatively low compared to the potential differences observed across stream sites (Kauffman et al. 1999). One advantage associated with measuring precision in this way is that values for S/N are unitless and can be compared across indicators. Because variance for site and replicates are compared as a ratio, the range of indicator values does not affect the values of S/N.

Variance for sites and replicates can be estimated from the ANOVA output as:

$$s_{Site}^2 = \frac{MS_{\ Site} - MS_{\ Rep}}{c}$$

$$s_{Site}^2 = \frac{1167.26 - 51.84}{2} = 557.71$$

$$s_{Rep}^2 = 51.84$$

S/N can be calculated as:

$$\frac{S}{N} = \frac{s_{Site}^2}{s_{Rep}^2} = \frac{557.71}{51.84} = 10.76$$

The S/N for B-IBI for these data is 10.76. In general, any value of S/N that is greater than 10 is considered a strong indicator with a good ability to detect change in condition (Kaufmann et al. 1999). Thus, results for B-IBI$_{0\text{-}100}$ indicate that it has good precision for detecting change or trend.

2.4.2 Minimum detectable change

Using the estimate of variance for B-IBI$_{0\text{-}100}$, the minimum change that would represent a statistically significant difference at a site can be calculated. The minimum detectable difference (MDD) can be calculated as (Blocksom and Flotemersch 2008):

$$MDD = \sqrt{\frac{s^2}{n}} * 1.96 = \sqrt{\frac{51.84}{1}} * 1.96 = 7.2 * 1.96 = 14.11$$

Where s^2 = 51.84, estimated B-IBI variance
n = 1, number of visits to the site
1.96 = the critical value from a standard normal distribution corresponding to a two-tailed Type I error of 0.05

The z-statistic from the normal distribution was used to calculate the MDD rather than t values from the Student's t distribution because the estimate of variance was derived from a large sample of 164 site visits; thus, the small-sample correction of the Student's t distribution was not needed. Results of the calculation provide an estimate of 14.11 for the MDD based on a single site visit. Dividing the range of B-IBI$_{0\text{-}100}$ by the MDD (100/14.11) yields 7.09 categories of biological condition that could be detected for this simple statistical sampling design based on a single visit to one site. The MDD results and number of categories that can be detected are similar to those reported for a multimetric index in California (Ode et al. 2005).

3.0. Comparing B-IBI

This section compares B-IBI$_{10-50}$ to B-IBI$_{0-100}$ by verifying the ability to discriminate site condition and examining shifts in biological condition. B-IBI$_{10-50}$ and B-IBI$_{0-100}$ are highly correlated (Figure 4, Spearman's Rho = 0.97, p = <0.001) and a linear model of B-IBI$_{0-100}$ versus B-IBI$_{10-50}$ predicts an average 2.5 point increase in B-IBI$_{0-100}$ for each point increase in B-IBI$_{10-50}$ (*B-IBI$_{0-100}$ = 2.5347*B-IBI$_{10-50}$ - 29.269*, $R^2 = 0.947$). This increase is as expected and is associated with the expanded range of values for B-IBI$_{0-100}$.

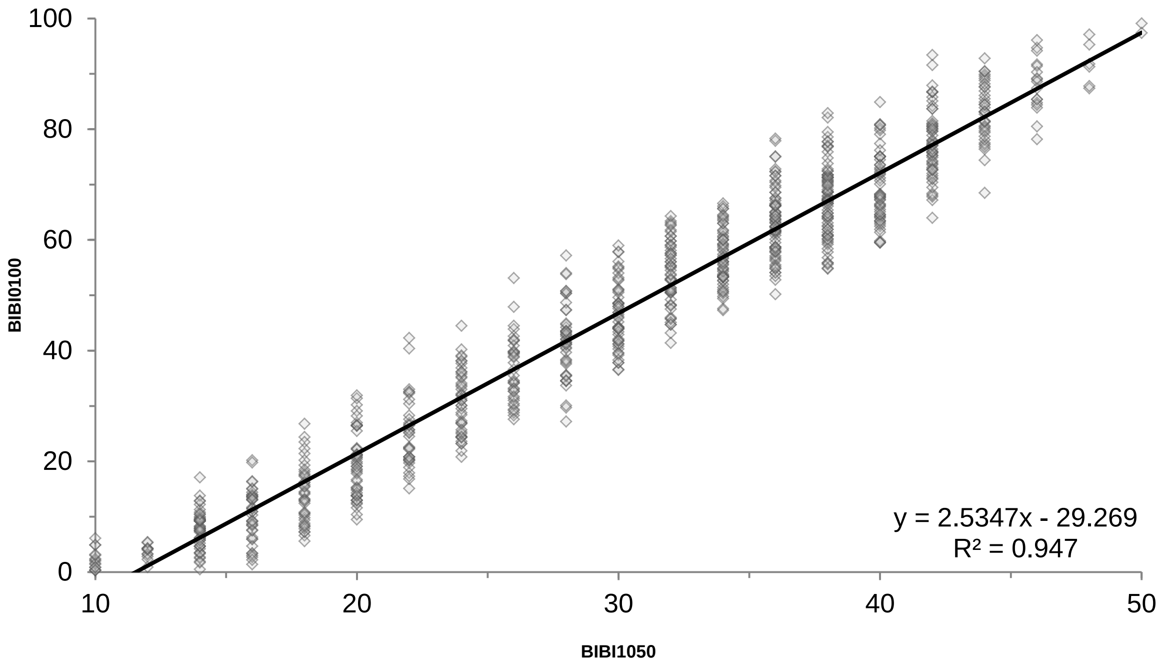

Figure 4. Least squares regression of the original B-IBI$_{10-50}$ and recalibrated B-IBI$_{0-100}$. n = 856.

3.1 Response to disturbance gradient

The ability to discriminate changes in biological communities resulting from human impacts is one of the most important qualities of a reliable biological index (Klemm et al. 2002; Karr and Chu 1999). Both B-IBI$_{10-50}$ and B-IBI$_{0-100}$ are highly correlated with human disturbance, decreasing with percent urbanization in the watershed, but B-IBI$_{0-100}$ is more correlated with disturbance than B-IBI$_{10-50}$ (Figure 5, Spearman's rho -0.66 for B-IBI$_{10-50}$ and -0.69 for B-IBI$_{0-100}$). The observed relationship of B-IBI with a human disturbance gradient indicates that macroinvertebrate communities continue to be excellent indicators of biological integrity for Puget Lowland streams.

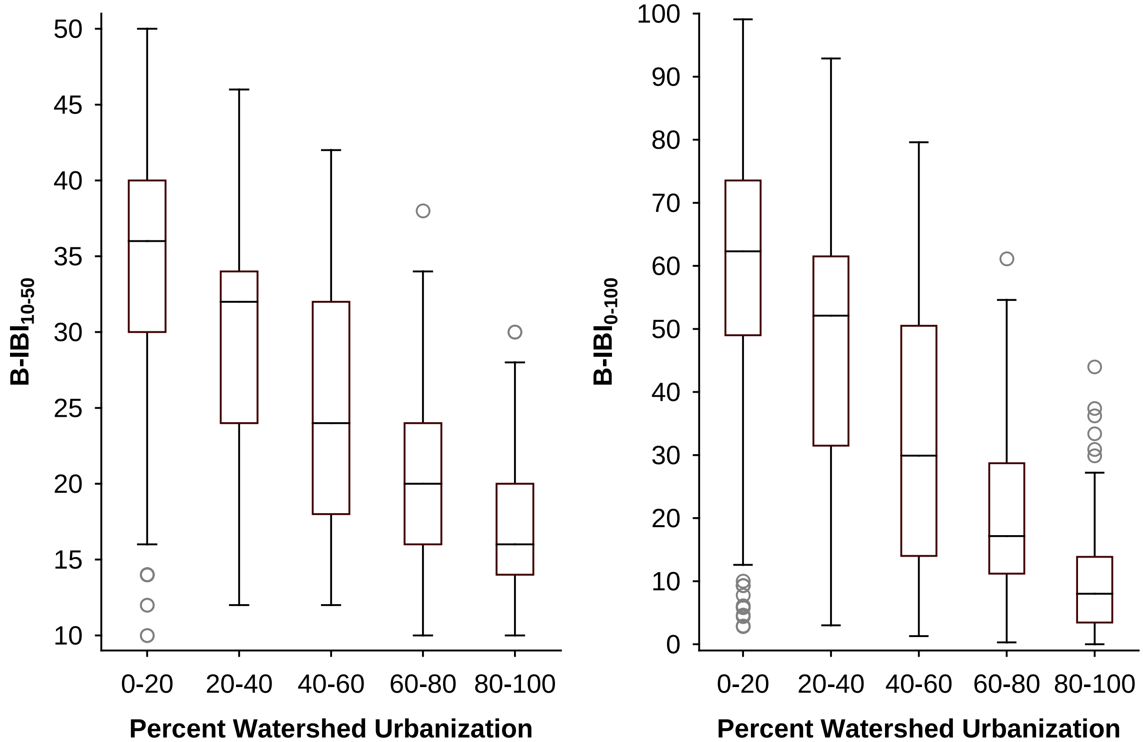

Figure 5. B-IBI$_{10\text{-}50}$ and B-IBI$_{0\text{-}100}$ response to watershed urbanization; n = 856.

3.2 Biological condition categories

When condition categories are linked to biological endpoints, the designations are helpful in evaluating management strategies designed to improve watershed health. Biological condition categories are commonly used by resource managers to diagnose stream condition, set restoration targets, or communicate management decisions (Davies and Jackson 2006; Kenney et al. 2009).

Results from B-IBI variance analysis above indicate that B-IBI$_{0\text{-}100}$ has the statistical precision to detect at least five narrative categories of biological condition based on a single site sample. To report B-IBI$_{0\text{-}100}$ values in a narrative format, the recalibrated B-IBI$_{0\text{-}100}$ scores were divided evenly across the existing five categories of biological condition also used for B-IBI$_{10\text{-}50}$: Excellent, Good, Fair, Poor and Very Poor (Table 1).

B-IBI$_{0\text{-}100}$ has more discernment across the range of conditions as seen by the more evenly distributed B-IBI$_{0\text{-}100}$ scores across the biological condition categories compared to B-IBI$_{10\text{-}50}$ (Figure 6). B-IBI$_{0\text{-}100}$ scores binned fewer sites into the poor and fair categories and more sites into the two extreme conditions (very poor and excellent). For the majority of sites (604 or 71%) there was no change in biological condition category for both B-IBI$_{10\text{-}50}$ and B-IBI$_{0\text{-}100}$. However, 252 sites (29%) shifted biological condition category, of which 146 shifted up one biological condition to a higher quality condition category (i.e., from fair to good) while 106 sites shifted down one category (i.e., from poor to very poor). There were no cases of condition category shifts of two or more categories. Managers should be aware of these minor binning shifts when communicating and evaluating stream condition, or prioritizing restoration projects based upon B-IBI biological condition categories.

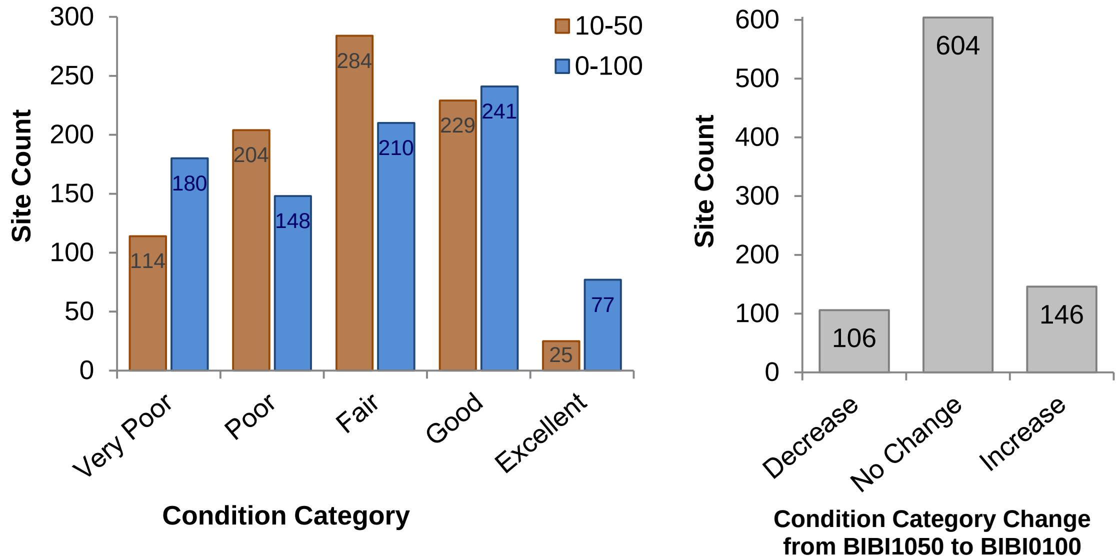

Figure 6. Condition category for both B-IBI$_{10\text{-}50}$ and B-IBI$_{0\text{-}100}$ and condition category change. n = 856. See Table 1 for condition category scoring ranges.

3.3 Transitioning from B-IBI$_{10\text{-}50}$ to B-IBI$_{0\text{-}100}$

The two versions of B-IBI (B-IBI$_{10\text{-}50}$ and B-IBI$_{0\text{-}100}$) are based on the same metrics; both B-IBIs measure the same aspects of the macroinvertebrate community. Both B-IBIs are highly correlated. The recalibration of B-IBI$_{10\text{-}50}$ to a 0-100 numeric scale brings some changes to interpretation. The difference in scale means that any reporting needs to be specific about which B-IBI is being used. The cumbersome subscript need not be used, but somewhere a note is needed about the range of B-IBI; e.g., from 0-100. A second change relates to the variance. Because B-IBI$_{0\text{-}100}$ has an expanded range of possible values, the observed variance in B-IBI over time will be greater. This is a simple consequence of the greater range of values and the larger possible scores for B-IBI$_{0\text{-}100}$. The values associated with different narrative categories will also change (e.g., poor shifted from 18-26 to 20-40). Narrative categories should not be compared for the two versions of B-IBI because the categories may have shifted slightly with B-IBI$_{0\text{-}100}$. Thus, comparisons through time should use a consistent version of B-IBI and the recommended approach is to calculate B-IBI$_{0\text{-}100}$ for earlier samples, which can easily be done in the PSSB.

4.0. Recommendations and Next Steps

B-IBI has been the primary analytical tool used to evaluate biological condition of Puget Lowland streams since the mid-1990s. The recalibration process summarized in this report improves the reliability of biological assessments of stream health within the Puget Sound region. B-IBI$_{0\text{-}100}$ can be used for management and restoration of water resources and provides an accurate tool for evaluating anthropogenic impacts on streams. The following sections provide an overview of regional applicability, recommendations, and next steps.

4.1 Regional applicability of B-IBI

The steps involved in the B-IBI recalibration process were based on available data stored in the PSSB; the characteristics of these data have an influence on the regional applicability of B-IBI$_{0\text{-}100}$. All data were collected from the Puget Sound drainage basin (WRIA 1-19) and over 80% of the data met the following conditions: (1) sites located within the Puget Lowland ecoregion; (2) site elevation less than 150 m; (3) samples collected in August or September; and (4) watershed area less than 4000 hectares (Appendix G). B-IBI$_{0\text{-}100}$ has been recalibrated specifically for these conditions. Application outside of these criteria may also be appropriate, but may require further exploration and testing to determine if scoring adjustments are necessary. The ten B-IBI component metrics have been shown to respond to disturbance gradients from Japan (Rossano 1995, 1996) to Tennessee (Kerans and Karr 1994) and are expected to be applicable in other locations as well. Exploration of the influence of natural factors across Puget Sound such as elevation, watershed size, and sampling date did not indicate that it was necessary to adjust metric scoring to account for these factors (King County 2014b). B-IBI$_{0\text{-}100}$ is likely to be indicative of human disturbance for all streams and small rivers within Western Washington with similar geology, elevation, watershed size and climate and precipitation patterns from the coast to the Cascade crest.

4.2 National B-IBI context

The conversion of B-IBI from a discrete scoring system ranging from 10-50 to a continuous scoring system ranging from 0-100 brings the Puget Sound region in line with several state and national efforts. Many states or regions in the United States are shifting to continuous scoring for multimetric indices and frequently report an overall index score ranging from 0-100. For example, the national wadeable streams assessment conducted by the EPA scores each metric on a 0-10 continuous scale (Stoddard et al. 2008, EPA 2013a). Similarly, indexes designed for urban areas, states or regions in the Pacific Northwest, and states scattered across the country have been updated or developed since approximately 2000 using continuous metric scoring rather than discrete scoring and frequently have index ranges from 0-100 (urban: Purcell et al. 2009; Oregon: Herlihy and Whittier 2010; Idaho: Tetra Tech 2011; Northern California: Rehn et al. 2005; Mid Atlantic: Klemm et al. 2003; Southern California: Ode et al. 2005; New Hampshire: Blocksom 2004; Virginia: Tetra Tech 2003; West Virginia, Tetra Tech 2000; Wyoming: Hargett and ZumBerge 2006; and Iowa: Iowa Department of Natural Resources 2004).

4.3 Summary and next steps

This report summarizes the work of King County to enhance and standardize benthic macroinvertebrate monitoring by recalibrating the primary analysis tool used in biomonitoring for the Puget Sound region (B-IBI). The recalibrated B-IBI$_{0\text{-}100}$ is a robust and sensitive tool that can be applied to assess the ecological condition of Puget Lowland streams, where urbanization is a major stressor on water resources. The major improvements to B-IBI include continuous scoring that eliminated scoring gaps, development of three STEs to reduce taxonomy-related variability, and scoring adjustments that account for taxonomic level differences. These improvements are readily available on the PSSB. Increased cross-jurisdictional cooperation, verification of method comparability (King County 2014a), development of more precise and accurate analysis tools, and improved ease of data access and manipulation evolved from the B-IBI recalibration process. These tools enable improved regional evaluation of biological health and increased confidence in the ability to evaluate changes in biotic integrity, especially due to urbanization.

The efforts described here and summarized in King County 2014c represent significant improvements and advancements in biomonitoring throughout Puget Sound. However, there is still room for improvement and possible next steps related to use of B-IBI in the Puget Sound region should seek to do the following:

1. **Define impairment thresholds and develop condition categories to communicate ecological conditions of watershed health.**
    - While the work presented in this report has enhanced the sensitivity of B-IBI, it is still necessary to define what B-IBI scores represent impaired conditions. This information is necessary for making regional assessments such as for the Washington State water quality assessment and subsequent 303(d) listing. Various options for determining impaired conditions have been proposed (e.g. Hughes et al. 1998; McCormick et al. 2001; Ode et al. 2005), but the process is inherently subjective and building regional consensus on the B-IBI$_{0\text{-}100}$ impairment threshold is necessary.
    - The five B-IBI condition categories (e.g., very poor to excellent) help communicate ecological conditions of watershed health. However, setting the dividing line between these condition categories is somewhat subjective. The five B-IBI condition categories could be evaluated by regional experts and standardized to compliment gradient categorization developed in other regions of the country.
    - 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 2013b). 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).

2. **Fill data gaps in order to better link B-IBI and specific stressors.**
    - Integrate sampling designs and address geographic data gaps. Determining how to integrate probabilistic and targeted sampling designs for regional assessments is a challenge identified by the PSP freshwater workgroup (PSEMP 2013). Currently, Ecology is the only agency with a probabilistic sampling program established specifically for the Puget Sound region with up to 50 sites sampled every fourth year (Merritt et al. 2009; 2010). These data are greatly augmented through monitoring by local jurisdictions, including cities and counties in addition to tribal and volunteer monitoring efforts. However, the ongoing monitoring programs usually involve targeted (not probabilistic) sampling designs and are not geographically balanced across the region with some areas (e.g., WRIAs 7, 8, 9, and 15) representing the majority of data available and other areas (e.g., Jefferson, Island, and Whatcom counties) largely unrepresented.
    - Collect additional habitat, hydrology, and water quality data to fill in supplementary data gaps. Unmeasured variables and incomplete or inconsistent data for stream sites limit the ability to test factors contributing to B-IBI response other than urbanization. Expanding and standardizing field data collection at stream sites where macroinvertebrates are collected and incorporating metrics of stream hydrology, in-stream water quality parameters, and habitat assessment variables at routinely visited sites may enhance future analyses. Establishing correlative relationships between taxa and particular habitat, water quality, or flow parameters could lead to a better understanding of the connection between B-IBI and specific stressors resulting in early actions to address identified stressors.

3. **Report and evaluate B-IBI data from existing and planned programs.**
    - The Regional Stormwater Monitoring Program (RSMP) is scheduled to conduct macroinvertebrate sampling in 2015. Sites were selected using a probabilistic sampling design from Ecology's master sample draw, with 50 sites within urban growth areas and 50 sites in rural areas (Ecology 2014). B-IBI results should be reported and uploaded to the PSSB when data are available.
    - B-IBI results for Ecology's probabilistic status and trends sampling in the Puget Sound region for 2009 (Merritt and Hartman 2012) and 2013 have been uploaded to the PSSB. These data should be evaluated to assess how stream condition has changed between 2009 and 2013.

4. **Continue to work with stakeholders to refine and improve the PSSB.** Some examples of potential improvements follow.
    - Expand analysis capabilities based on users' needs, but could include incorporation of the River Invertebrate Prediction and Classification System (RIVPACS)-type models if developed by Ecology, other indices (e.g., sediment tolerance index), and additional attribute lists.

- Develop a trend analysis tool to aid in identifying statistically and biologically significant trends.
- Incorporate the STE levels being developed by regional taxonomy experts in an effort coordinated by the Pacific Northwest Aquatic Monitoring Partnership (Pfeiffer et al. 2014). Minor adjustments to B-IBI$_{0\text{-}100}$ may be necessary if the lists differ substantially from those used for the recalibration process described in section 2.2 of this report.
- Replace the Google Map interface with a geographic information systems (GIS) user interface that enables spatially explicit searches and analysis and incorporation of landscape metrics.

5. Update PSP targets, share results and evaluate restoration and protection effectiveness.

- Two of the PSP's Ecosystem Recovery Targets are based on freshwater benthic macroinvertebrates and aim to: (1) protect all streams with excellent B-IBI scores and, (2) restore 30 streams with fair B-IBI scores to a classification of good B-IBI (PSP 2012). These PSP targets are currently based on B-IBI$_{10\text{-}50}$ (PSP 2012). The improvements incorporated in B-IBI$_{0\text{-}100}$ need to be communicated to the appropriate regional leaders at PSP and stakeholders to transition the PSP targets to the revised index.
- The PSP targets provide a mechanism to use biological data to prioritize stream and watershed restoration and preservation efforts and to evaluate the most effective strategies (based on biological results). Thanks to funding from EPA channeled through Ecology, King County is currently tasked with identifying sites for restoration and prioritization (King County 2014d) and developing planning level strategies and budgets. Funding is currently lacking for implementation of the proposed strategies, but as these and other restoration projects are implemented, follow up monitoring is essential to evaluate which actions are most effective to restore and preserve good biological integrity and inform future projects.

5.0. References

Adams, K. 2010. Quality Assurance Monitoring Plan: Ambient Biological Monitoring in Rivers and Streams: Benthic Macroinvertebrates and Periphyton. Publication No. 10-03-109. Prepared by Environmental Assessment Program, Washington Department of Ecology, Olympia, Washington.

Barbour, M. T., J. B. Stribling, and J. R. Karr. 1995. Multimetric approach for establishing biocriteria and measuring biological condition. Pages 63-77 (Chapter 66) in W. S. Davis and T. P. Simon, editors. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Blocksom, K. A. 2003. A performance comparison of metric scoring methods for a multimetric index for Mid-Atlantic Highland streams. Environmental Management 31: 670-682.

Blocksom, K. A., and J. E. Flotemersch. 2008. Field and laboratory performance characteristics of a new protocol for sampling riverine macroinvertebrate assemblages. River Research and Applications 24: 373-387.

Clements, W. H., D. S. Cherry, and J. Cairns Jr. 1988. Impact of heavy metals on insect communities in streams: a comparison of observational and experimental results. Canadian Journal of Fisheries and Aquatic Sciences 45:2017-2025.

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.

[Ecology] Washington State Department of Ecology. 2012. Water Quality Program Policy 1-11. Chapter 1: Assessment of Water Quality for the Clean Water Act Sections 303(d) and 305(b) Integrated Report. July 2012 revisions. Lacey, Washington.

[Ecology] Washington State Department of Ecology. 2014. Quality Assurance Project Plan for Status and Trends Monitoring of Small Streams in the Puget Lowlands Ecoregion for Monitoring Conducted by Permittee to Comply with NPDES Stormwater Permit Special Condition S8.B Requirements. Olympia, Washington.

[EPA] United States Environmental Protection Agency. 2013a. National Rivers and Streams Assessment 2008-2009: A Collaborative Survey. U.S. Environmental Protection Agency. Office of Wetlands, Oceans and Watersheds Office of Research and Development, Washington, D.C.

[EPA] United States Environmental Protection Agency. 2013b. 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. 2012. Healthy Bugs = Healthy Streams: Stream Bugs Tell an Important Story. Prepared for Kitsap County Surface and Stormwater Management. Port Orchard, Washington.

Fore, L. S., J. R. Karr, and L. L. Conquest. 1994. Statistical properties of an index of biotic integrity used to evaluate water resources. Canadian Journal of Fisheries and Aquatic Sciences 51: 1077-1087.

Fore, L. S., J. R. Karr, and R. W. Wisseman. 1996. Assessing invertebrate responses to human activities: evaluating alternative approaches. Journal of the North American Benthological Society 15: 212-231.

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

Hargett, E. G., and J. R. ZumBerge. 2006. Redevelopment of the Wyoming stream integrity index (WSII) for assessing the biological condition of wadeable streams in Wyoming. Wyoming Department of Environmental Quality Water Quality Division, Cheyenne, Wyoming.

Herlihy, A. T., and T. R. Whittier. 2010. Developing Numeric Biocriteria for Western Oregon Streams and Rivers. EPA-R10-09-OWW-WU. U.S. Environmental Protection Agency, Region 10, Water Quality Program Funding.

Hughes, R. M., P. R. Kaufmann, A. T. Herlihy, T. M. Kincaid, L. Reynolds, and D. P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. Journal of Fisheries and Aquatic Sciences 55: 1618-1631.

Iowa Department of Natural Resources. 2004. Biological Assessment of Iowa's Wadeable Streams. Prepared by Thomas F. Wilton TMDL and Water Quality Assessment Section Environmental Services Division Iowa Department of Natural Resources, Des Moines, Iowa.

Kaller, M. D. 2001. Effects of sediment upon benthic macroinvertebrates in forested northern Appalachian streams. West Virginia University.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21–27.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: A method and its rationale. Illinois Natural History Survey, Special Publication 5.

Karr, J. R. 1998. Rivers as sentinels: using the biology of rivers to guide landscape management. Pages 502-528. In Naiman, R. J. and R. E. Bilby (editors). River Ecology and Management: Lessons from the Pacific Coastal Ecosystem. Springer, New York, NY.

Karr, J. R. and E. W. Chu. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Washington, DC.

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.

Kenney, M. A., A. E. Sutton-Grier, R. F. Smith, and S. E. Gresens. 2009. Benthic macroinvertebrates as indicators of water quality: the intersection of science and policy. Terrestrial Arthropod Reviews 2:99-128.

Kerans, B.L. and J. R. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4:768-785.

Kiffney, P. M., and W. H. Clements. 1994. Effects of heavy metals on a macroinvertebrate assemblage from a Rocky Mountain stream in experimental microcosms. Journal of the North American Benthological Society 13:511-523.

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

King County. 2013a. 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. 2013b. Watershed Delineation and Land Cover Calculations for Puget Sound Stream Basins. Prepared by Jo Opdyke Wilhelm (King County Water and Land Resources Division (WLRD)), Peter Leinenbach (US Environmental Protection Agency (EPA)), Leska Fore (Statistical Design), Deb Lester (WLRD), Karen Adams (Washington State Department of Ecology), and Gretchen Hayslip (EPA). Seattle, Washington.

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

King County. 2014b. 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. 2014c. 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)), Jo Opdyke Wilhelm (WLRD), Leska Fore (Statistical Design), and Deb Lester (WLRD). Seattle, Washington.

King County. 2014d. B-IBI Restoration Decision Framework and Site Identification. Prepared by Jo Opdyke Wilhelm, Debra Bouchard, Chris Gregersen, Chris Knutson, and Kate Macneale. King County 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.

Klemm, D. J., K. A. Blocksom, W. T. Thoeny, F. A. Fulk, A. T. Herlihy, P. R. Kaufmann, and S. M. Cormier. 2002. Methods development and use of macroinvertebrates as indicators of ecological conditions for streams in the Mid-Atlantic Highlands Region. Environmental Monitoring and Assessment 78:169-212.

Klemm, D. J., K. A. Blocksom, F. A. Fulk, A. T. Herlihy, R. M. Hughes, P. R. Kaufmann, D. V. Peck, J. L. Stoddard, W. T. Thoeny, M. B. Griffith, and W. S. Davis. 2003. Development and evaluation of a Macroinvertebrate Biotic Integrity Index (MBII) for regionally assessing Mid-Atlantic highlands streams. Environmental Management 31:0656-0669.

McCormick, F. H., R. M. Hughes, P. R. Kaufmann, D. V. Peck, J. L. Stoddard, and A. T. Herlihy. 2001. Development of an index of biotic integrity for the Mid-Atlantic highlands region. Transactions of the American Fisheries Society 130:857-877.

McDonald, B. S., G. W. Mullins, and S. Lewis. 1991. Macroinvertebrates as indicators of stream health. The American Biology Teacher 53:462-466.

Merritt, G. 2009. Status and Trends Monitoring for Watershed Health and Salmon Recovery: Field Data Collection Protocol Wadeable Streams. Draft, May 14, 2009. Environmental Assessment Program. Washington State Department of Ecology, Olympia, WA.

Merritt, G., D. Monahan, and C. Hartman. 2010. Status and Trends Monitoring for Watershed Health and Salmon Recovery: Field Data Collection Protocol Wide Streams and Rivers. Draft, January 27, 2010. Environmental Assessment Program. Washington State Department of Ecology, Olympia, WA.

Merritt, G. and C. Hartman. 2012. Status of Puget Sound Tributaries 2009. Biology, Chemistry, and Physical Habitat. Publication No. 12-03-029. Environmental Assessment Program. Washington State Department of Ecology, Olympia, WA.

Minns, C. K., V. W. Cairns, R. G. Randall, and J. E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zones of Great Lakes' Areas of Concern. Canadian Journal of Fisheries and Aquatic Sciences 51: 1804-1822.

Morley, S. A. 2000. Effects of Urbanization on the Biological Integrity of Puget Sound Lowland Streams: Restoration with a Biological Focus. 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.

Ode, P. R., A. C. Rehn, and J. T. May. 2005. A quantitative tool for assessing the integrity of southern coastal California streams. Environmental Management 35:493-504.

Patterson, A. J. 1996. The Effect of Recreation on Biotic Integrity of Small Streams in Grand Teton National Park. M.S. thesis, University of Washington, Seattle, Washington.

Pfeiffer, J., A. Puls, S. Salter, S. Sullivan, and R. Wisseman. 2014. Improving freshwater macroinvertebrate data sharing in the Pacific Northwest through the development of a standard taxonomic effort (STE) agreement. Presentation at the May 18-23, 2014 Joint Aquatic Sciences Meeting prepared by EcoAnalysts, PNAMP, Cordillera Consulting, Rhithron Associates, Inc. and Aquatic Biology Associates, Inc. Portland, Oregon.

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.

[PSEMP] Puget Sound Ecosystem Monitoring Program Freshwater Work Group. 2013. Monitoring Inventory and Data Gap Analysis. January 31, 2013.

[PSP] Puget Sound Partnership. 2012. The 2012/2013 Action Agenda for Puget Sound. Tacoma, Washington.

Purcell, A. H., D. W. Bressler, M. J. Paul, M. T. Barbour, E. T. Rankin, J. L. Carter, and V. H. Resh. 2009. Assessment tools for urban catchments: Developing biological indicators based on benthic macroinvertebrates. JAWRA Journal of the American Water Resources Association 45:306-319.

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, State Water Resources Control Board, Sacramento, CA.

Rossano, E. M. 1995. Development of an Index of Biological Integrity for Japanese streams (IBI-J). MS Thesis, University of Washington, Seattle, Washington.

Rossano, E. M. 1996. Diagnosis of Stream Environments with Index of Biological Integrity. Museums of Streams and Lakes, Sankaido Publishers, Tokyo, Japan.

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. Lomnicky, 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 Stream and Rivers Statistical Summary. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC. EPA 620/R-05/006.

Stoddard, J. L., A. T. Herlihy, D. V. Peck, R. M. Hughes, R. R. Whittier, and E. Tarquinio. 2008. A process for creating multi-metric indices for large-scale aquatic surveys. Journal of the North American Benthological Society 27: 878-891.

Tetra Tech, Inc. 2000. A Stream Condition Index for West Virginia Wadeable Streams. Prepared by Tetra Tech, Inc. Owings Mills, Maryland for US EPA Region 3 Environmental Services Division and US EPA Office of Science and Technology, Office of Water.

Tetra Tech, Inc. 2003. A Stream Condition Index for Virginia Non-coastal Streams. Prepared by June Burton and Jeroen Gerritsen, Tetra Tech, Inc. Owings Mills, Maryland for USEPA Office of Science and Technology, Office of Water, Washington, DC, USEPA Region 3 Environmental Services Division, Wheeling, West Virginia, and Virginia Department of Environmental Quality, Richmond, Virginia.

Tetra Tech, Inc. 2011. Biological Assessment Frameworks and Index Development for Rivers and Streams in Idaho. Prepared by Tetra Tech, Inc. for Idaho Department of Environmental Quality, Boise, Idaho.

Wagenhoff, A., C. R. Townsend, and C. D. Matthaei. 2012. Macroinvertebrate responses along broad stressor gradients of deposited fine sediment and dissolved nutrients: a stream mesocosm experiment. Journal of Applied Ecology 49:892-902.

Walsh, C. J. 2006. Biological indicators of stream health using macroinvertebrate assemblage composition: a comparison of sensitivity to an urban gradient. Marine and Freshwater Research 57:37-47.

Wilhelm, J. O. 2012. A Look at the Influence of Taxonomic Resolution on B-IBI Scores and Metrics: Spotlight on Acari, Oligochaetes, and Chironomids. A June 5, 2012 memorandum prepared for EPA macroinvertebrate grant core team by Jo Opdyke Wilhelm, King County Water and Land Resources Division. Seattle, Washington.

Wiseman, C. D. 2003. Multi-metric Index Development for Biological Monitoring in Washington State Streams. Publication No. 03-03-035, Washington Department of Ecology, Olympia, Washington.

Appendices

Appendix A: B-IBI component metric descriptions

Both B-IBI$_{10\text{-}50}$ and B-IBI$_{0\text{-}100}$ are composed of the same ten component metrics (Table A-1) which are briefly described in this section (Fore 2012). Those denoted with an asterisk (*) are dependent on taxa attributes which were updated for B-IBI$_{0\text{-}100}$ as part of this project (King County 2013a)[5]. Citations after the metric title indicate that the metric varied systematically across a human disturbance gradient for that data set.

Table A-1. Ten B-IBI metrics and their expected response to disturbance. Table adapted from Karr and Chu (1999).

Metric	Response to Disturbance
Taxa richness and composition	
Total number of taxa	Decrease
Number of Ephemeroptera (mayfly) taxa	Decrease
Number of Plecoptera (stonefly) taxa	Decrease
Number of Trichoptera (caddisfly) taxa	Decrease
Number of long-lived taxa	Decrease
Tolerance	
Number of intolerant taxa	Decrease
Percent of individuals in tolerant taxa	Increase
Feeding ecology and other habits	
Percent of individuals that are predators	Decrease
Number of clinger taxa	Decrease
Population attributes	
Percent dominance (3 taxa)	Increase

Total Taxa Richness (Kerans and Karr 1994, Fore et al. 1996, Kleindl 1995, Rossano 1995, Patterson 1996, Morley 2000)

The biodiversity of a stream declines as flow regimes are altered, habitat is lost, pollutants are introduced, energy cycles are disrupted, and alien taxa invade. Total taxa richness includes a count of all the different macroinvertebrates collected from a stream site including but not limited to Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies), Diptera (true flies), Chironomidae (midges), Bivalvia (clams and mussels), Gastropoda (snails), and Oligochaeta (segmented worms).

Ephemeroptera (Mayfly) Taxa Richness (Kerans and Karr 1994, Fore et al. 1996, Kleindl 1995, Rossano 1995, Patterson 1996, Morley 2000)

Ephemeroptera taxa richness is a count of the number of different mayfly taxa in a sample. The diversity of Ephemeroptera declines in response to most types of human influence. Many Ephemeroptera graze on algae and are particularly sensitive to chemical pollution

[5] There are two attribute lists now available on the PSSB. It is recommended that the Wisseman 1998 attribute lists be used when calculating B-IBI$_{10\text{-}50}$ and the Fore, Wisseman 2012 attribute lists be used when calculating B-IBI$_{0\text{-}100}$. Each B-IBI was calibrated based on the attribute lists available at the time.

that interferes with their food source. Ephemeroptera may disappear when heavy metal concentrations are high (Clements et al. 1988, Kiffney and Clements 1994) while Trichoptera and Plecoptera are unaffected. In nutrient-poor streams, livestock feces and fertilizers from agriculture can increase the numbers and types of Ephemeroptera present. If many different taxa of Ephemeroptera are found while the variety of Plecoptera and Trichoptera is low, enrichment may be the cause (Kerans and Karr 1994, Fore et al. 1996, Kleindl 1995, Rossano 1995, Patterson 1996).

Plecoptera (Stonefly) Taxa Richness (Kerans and Karr 1994, Fore et al. 1996, Kleindl 1995, Patterson 1996, Morley 2000)

Plecoptera taxa richness is a count of the number of different stonefly taxa in a sample. Plecoptera are the first to disappear from a stream as human disturbance increases. Many Plecoptera are predators that stalk their prey and hide around and between rocks. Hiding places between rocks are lost as excess sediment is deposited in a stream. Many Plecoptera are shredders and feed on leaf litter that drops from an overhanging tree canopy. Most Plecoptera, like salmonids, require cool water temperatures and high oxygen to complete their life cycles.

Trichoptera (Caddisfly) Taxa Richness (Kerans and Karr 1994, Fore et al. 1996, Kleindl 1995, Rossano 1995, Patterson 1996, Morley 2000)

Trichoptera taxa richness is a count of the number of different caddisfly taxa in a sample. Different Trichoptera species (or taxa) feed in a variety of ways: some spin nets to trap food, others collect or scrape food on top of exposed rocks. Many Trichoptera build gravel or wood cases to protect them from predators; others are predators themselves. Even though they are very diverse in habit, taxa richness of Trichoptera declines steadily as humans eliminate the variety and complexity of their stream habitat.

***Long-Lived (Semi-Voltine) Taxa Richness** (Fore et al. 1996, Kleindl 1995, Morley 2000)

Long-lived taxa richness is a count of the number of different taxa in a sampled designated as long-lived. These macroinvertebrates require more than one year to complete their life cycle; thus, they are exposed to anthropogenic stressors that influence the stream throughout one or more years. If the stream is dry part of the year or subject to flooding, these animals may disappear. Loss of long-lived taxa may also indicate an on-going problem that repeatedly interrupts their life cycles.

***Intolerant Taxa Richness** (Kerans and Karr 1994, Fore et al. 1996, Kleindl 1995, Rossano 1995, Patterson 1996, Morley 2000)

Intolerant taxa richness is a count of the number of different taxa in a sample identified as intolerant. Animals identified as intolerant are the most sensitive taxa; they represent approximately 5-10% of the taxa present in the region. These animals are the first to disappear as human disturbance increases.

***Percent Tolerant** (Kerans and Karr 1994, Fore et al. 1996, Kleindl 1995, Rossano 1995, Patterson 1996, Morley 2000)

Percent tolerant is the total number of tolerant individuals counted in each sample divided by the total number of individuals in that sample, multiplied by 100. Tolerant animals are present at most stream sites, but as disturbance increases, they represent an increasingly large percentage of the assemblage. Invertebrates designated as tolerant represent the 5-10% most tolerant taxa in a region. In a sense, they occupy the opposite end of the spectrum from intolerant taxa.

***Percent Predator** (Kerans and Karr 1994, Kleindl 1995, Patterson 1996, Morley 2000)

Percent predator is the total number of predatory individuals counted in each sample divided by the total number of individuals in that sample, multiplied by 100. Predator taxa represent the peak of the food web and depend on a reliable source of other macroinvertebrates as a food source. Predators may have adaptations such as large eyes and long legs for hunting and catching other animals. The percentage of animals that are obligate predators provides a measure of the trophic complexity supported by a site. Less disturbed sites support a greater diversity of prey items and a variety of habitats in which to find them.

***Clinger Taxa Richness** (Kleindl 1995, Rossano 1995, Morley 2000)

Clinger taxa richness is a count of the number of different taxa in a sample identified as clingers. Taxa defined as clingers have physical adaptations that allow them to hold onto smooth substrates in fast water. These animals typically occupy the open area between gravel and cobble along the bottom of the stream. Thus they are particularly sensitive to fine sediments that fill these spaces and eliminate the variety and complexity of these small habitats (Kaller 2001, Wagenhoff et al. 2012). Clingers may use these areas to forage, escape from predators, or lay their eggs. Sediment also prevents clingers from moving down deeper into the stream bed, or hyporheos, of the channel. Ecology's Western Washington multimetric index uses Percent Clinger rather than Clinger taxa richness (Wiseman 2003).

Percent Dominance (Kerans and Karr 1994, Fore et al. 1996, Patterson 1996, Morley 2000)

Dominance is calculated by adding the number of individuals in the three most abundant taxa and dividing by the total number individuals in the sample. As diversity declines, a few taxa come to dominate the assemblage. Opportunistic species that are less particular about where they live replace species that require special foods or particular types of physical habitat.

Appendix B: Summary statistics for recalibration data set

Table B-1. Summary statistics for the data set used to recalibrate B-IBI; n = 856. Spatial scale abbreviations include WS = contributing watershed, 1km WS = 1-km contributing watershed, BF = 90-m buffer.

Variable	Mean	Minimum	Maximum	Standard Deviation
Elevation (m)	86.2	0.5	647.3	94.1
% Forest (WS)	52.6	0.0	100.0	31.6
% Wetland (WS)	1.8	0.0	21.5	2.4
% Urban (WS)	27.9	0.0	97.7	30.3
% Ag (WS)	13.3	0.0	62.4	11.1
% Forest (1km WS)	48.3	0.0	100.0	30.1
% Wetland (1km WS)	3.3	0.0	40.8	4.9
% Urban (1km WS)	28.1	0.0	99.0	28.1
% Ag (1km WS)	16.2	0.0	82.6	13.9
% Forest (BF WS)	53.8	0.0	100.0	30.5
% Wetland (BF WS)	3.3	0.0	58.7	4.5
% Urban (BF WS)	24.5	0.0	95.0	27.8
% Ag (BF WS)	14.4	0.0	87.1	12.0
% Forest (BF 1km)	49.9	0.0	100.0	30.2
% Wetland (BF 1km)	5.1	0.0	58.7	7.6
% Urban (BF 1km)	24.3	0.0	97.5	26.5
% Ag (BF 1km)	16.9	0.0	87.9	15.0
Total road length (m) (WS)	61,450	0	944,407	105,864
Road Density (km/km^2) (WS)	4.4	0.0	18.4	4.1
Road crossings (#/km) (WS)	2.2	0.0	14.2	2.3
Total road length (m) (1km WS)	4397	0	34317	4464
Road Density (km/km^2) (1km WS)	4.7	0.0	21.5	3.9
# road crossings (#/km) (1km WS)	2.1	0.0	17.8	2.2
Population density ($\#/km^2$) (WS)	538	0	3164	738
Population density ($\#/km^2$) (1km WS)	542	0	4117	752
Watershed area (hectares) (WS)	2,418	9	142,417	6,556
Watershed area (hectares) (1km WS)	93	3	214	40
Mean % slope (WS)	13.9	1.5	65.9	12.2
Mean precipitation (mm) (WS)	1,437	476	3,737	553
Total Stream length (m) (WS)	48,082	1	2,588,371	124,523
Stream Density (km/km^2) (WS)	2.0	0.0	6.7	0.4

Appendix C: B-IBI component metrics versus watershed urbanization

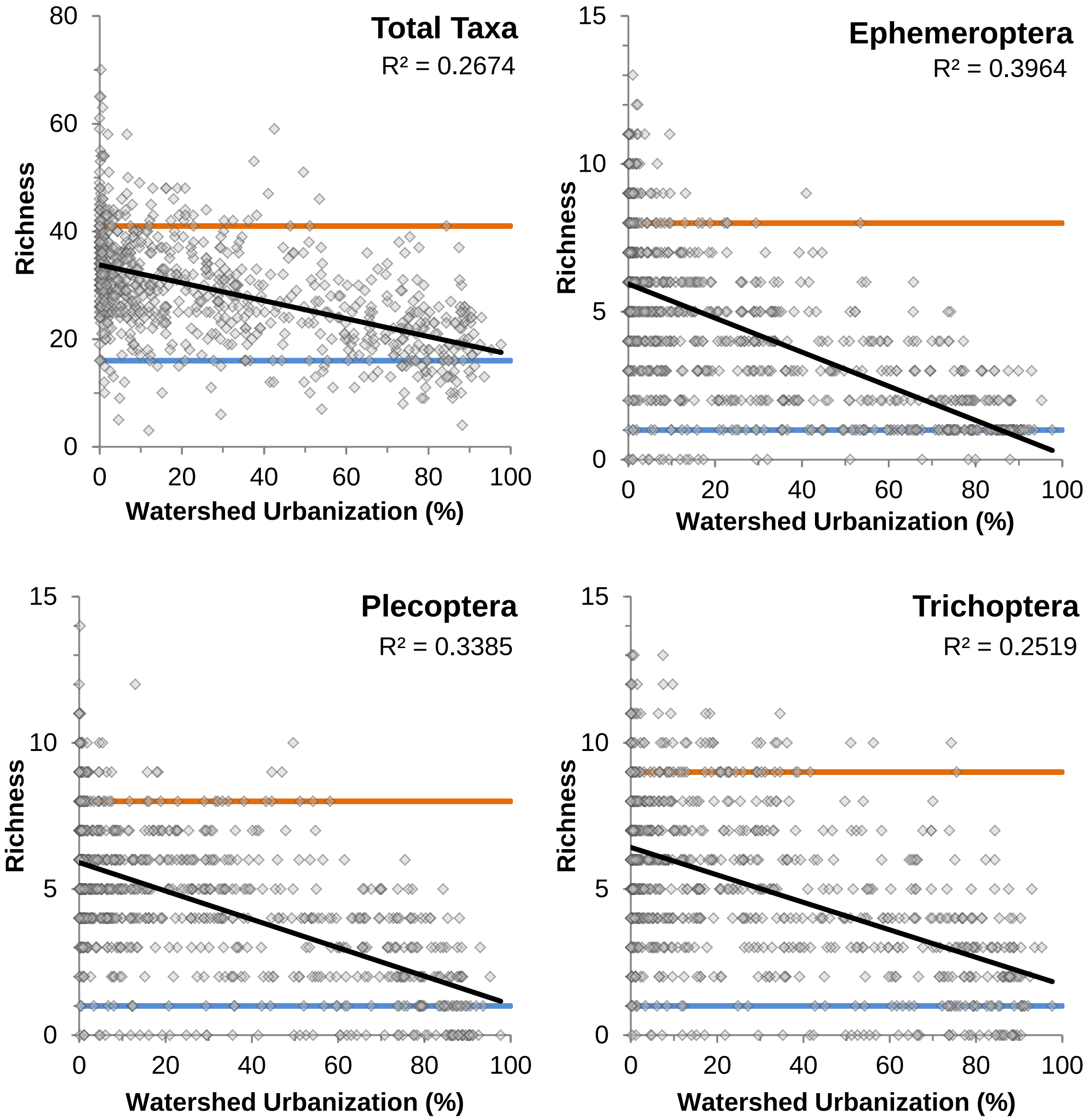

Figure C-1. Total, Ephemeroptera, Plecoptera, and Trichoptera taxa richness versus watershed urbanization. Black line is the best fit line; orange is the 90th percentile; blue is the 10th percentile.

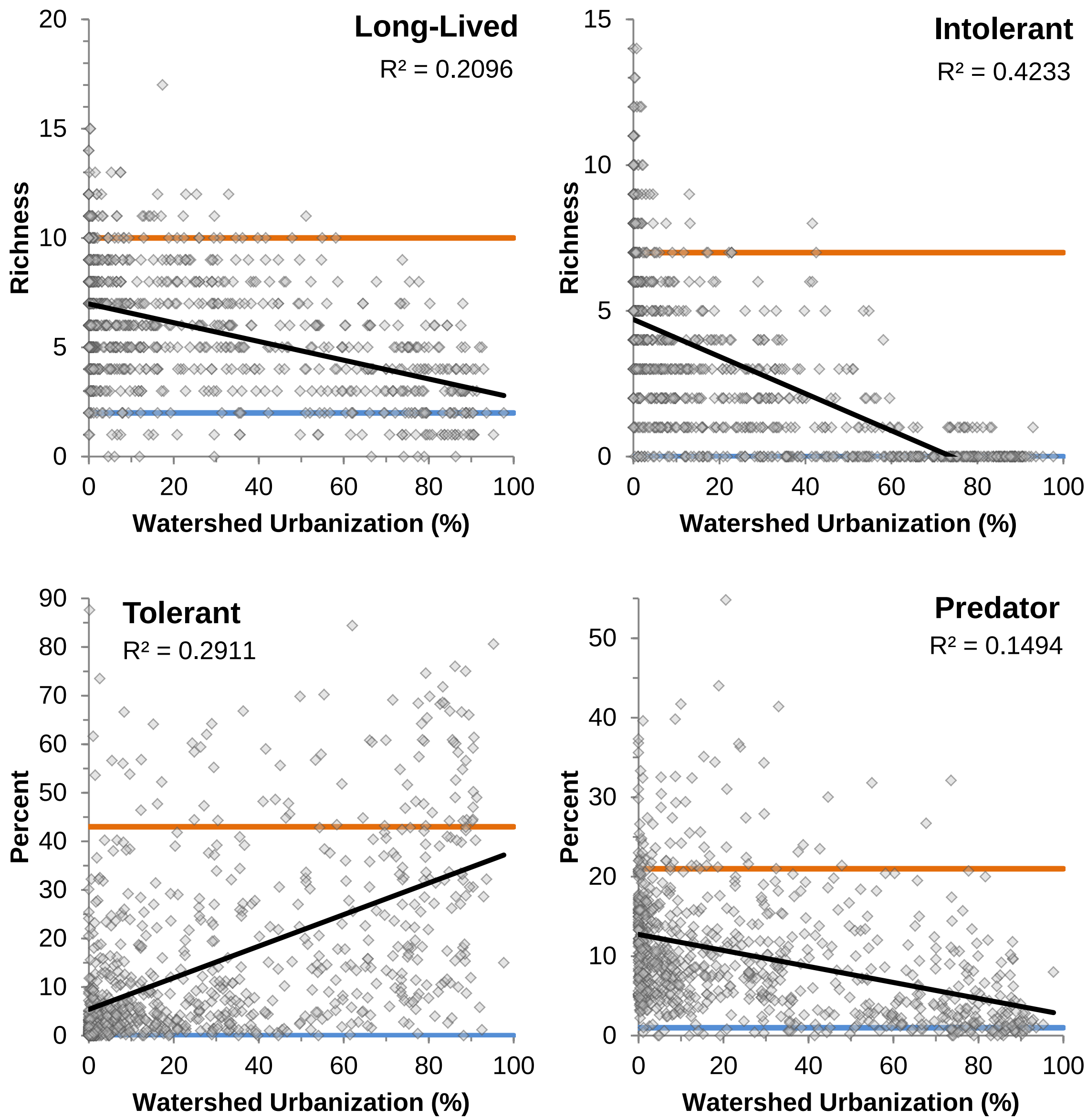

Figure C-2. Long-lived, intolerant taxa richness, percent tolerant and percent predator versus watershed urbanization. Black line is the best fit line; orange is the 90th percentile; blue is the 10th percentile. Where no blue line is visible the 10th percentile is zero.

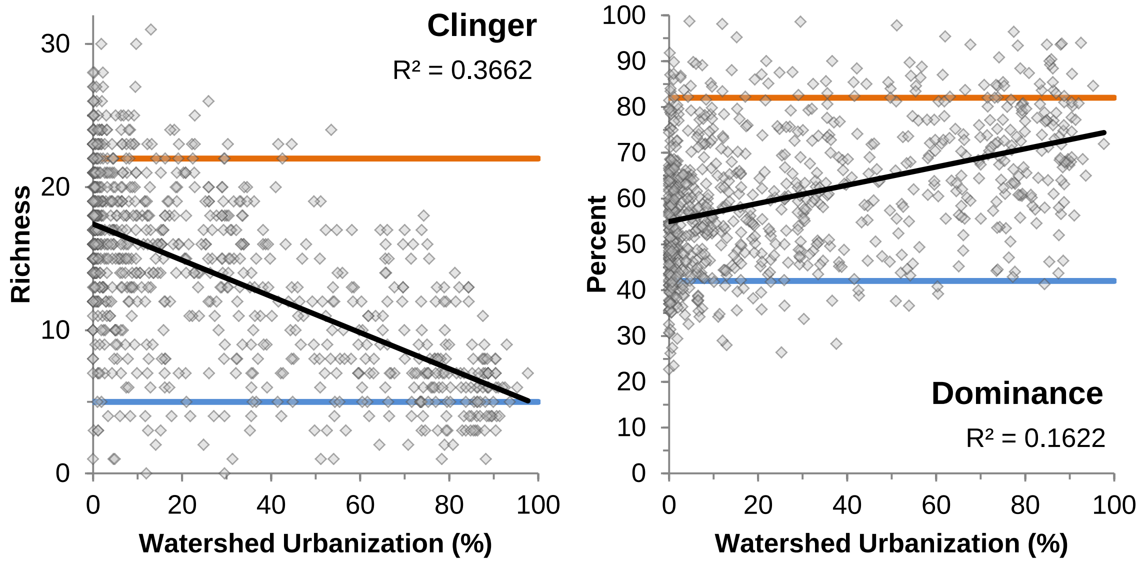

Figure C-3. Clinger richness and percent dominance versus watershed urbanization. Black line is the best fit line; orange is the 90th percentile; blue is the 10th percentile.

Appendix D: Examples of scoring B-IBI$_{0\text{-}100}$ metrics

Two examples for scoring metrics follow:

- Metric values *decrease* with disturbance: Ephemeroptera taxa richness
  6 unique Ephemeroptera observed at site
  10^{th} percentile is 1 and 90^{th} percentile is 8
  10 x (Observed value – 10^{th} percentile)/(90^{th} percentile – 10^{th} percentile)
  10 x (6 – 1)/(8 – 1) = 7.1
  Ephemeroptera richness metric score = 7.1

- Metric values *increase* with disturbance: % tolerant individuals
  20% of individuals at site are tolerant taxa
  10^{th} percentile is 0% and 90^{th} percentile is 43%
  10 – [10 x (Observed value – 10^{th} percentile)/(90^{th} percentile – 10^{th} percentile)]
  10 – [10 x (20 – 0)/(43-0)] = 5.3
  % tolerant metric score = 5.3

Appendix E: B-IBI$_{10\text{-}50}$ scoring table

Table E-1. B-IBI$_{10\text{-}50}$ scoring table. Scoring for three metrics (taxa richness, clinger richness, and percent dominant) is dependent on the taxonomic effort level for chironomids. Closed brackets [ ] include endpoints; open brackets ( ) exclude endpoints.

Metric	1	3	5
Taxa richness			
Chironomidae genus	[0, 20)	[20, 40]	(40, ∞]
Chironomidae family	[0, 15)	[15, 28]	(28, ∞]
Ephemeroptera richness	[0, 4]	(4, 8]	(8, ∞]
Plecoptera richness	[0, 3]	(3, 7]	(7, ∞]
Trichoptera richness	[0, 5)	[5, 10)	[10, ∞]
Long-lived richness	[0, 2]	(2, 4)	[4, ∞]
Intolerant richness	[0, 2]	(2, 3)	[3, ∞]
Percent tolerant	[50, 100]	(19, 50)	[19, 0]
Percent predator	[0, 10)	[10, 20)	[20, ∞]
Clinger richness			
Chironomidae genus	[0, 10]	(10, 20]	(20, ∞]
Chironomidae family	[0, 8]	(8, 18]	(18, ∞]
Percent dominant			
Chironomidae genus	[75, 100]	[50, 75)	[0, 50)
Chironomidae family	[80, 100]	[60, 80)	[0, 60)

Appendix F: Non-formula B-IBI$_{0\text{-}100}$ scoring table

Table F-1. Non-formula B-IBI$_{0\text{-}100}$ scoring table showing the approximate observed values for each metric score for all ten metrics including taxonomic effort adjustments. Use of the full formulas (Table 6) is preferred to avoid rounding errors and scoring gaps, but this table enables estimating B-IBI$_{0\text{-}100}$ without requiring extensive calculations. R is richness, % is percent.

Metric/Score	0	1	2	3	4	5	6	7	8	9	10
Total Taxa R											
Coarse	≤17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	≥36
Medium	≤21	22-23	24-25	26-28	29-30	31-32	33-34	35-37	38-39	40-41	≥42
Fine	≤28	29-31	32-34	35-37	38-40	41-42	43-45	46-48	49-51	52-54	≥55
Ephemeroptera R	≤1	2		3	4		5	6		7	≥8
Plecoptera R	≤1	2		3	4		5	6		7	≥8
Trichoptera R	≤1	2		3	4	5	6		7	8	≥9
Long-lived R	≤2	3		4	5	6	7		8	9	≥10
Intolerant R	0	1		2	3		4	5		6	≥7
Tolerant %	≥40.9	36.6-40.8	32.3-36.5	28-32.2	23.7-27.9	19.4-23.6	15.1-19.3	10.8-15	6.5-10.7	2.2-6.4	≤2.1
Predator %	≤1.9	2-3.9	4-5.9	6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18-19.9	≥20
Clinger R											
Coarse	≤5	6-7	8-9	10	11-12	13-14	15-16	17	18-19	20-21	≥22
Medium	≤7	8-9	10	11-12	13-14	15	16-17	18	19-20	21-22	≥23
Fine	≤7	8-9	10-11	12	13-14	15-16	17-18	19	20-21	22-23	≥24
Dominant %											
Coarse	≥80.2	76.4-80.1	72.6-76.3	68.8-72.5	65-68.7	61.2-64.9	57.4-61.1	53.6-57.3	49.8-53.5	45.9-49.7	≤45.9
Medium	≥73.3	69.7-73.2	66.1-69.6	62.5-66	58.9-62.4	55.3-58.8	51.7-55.2	48.1-51.6	44.5-48	40.9-44.4	≤40.8
Fine	≥67.2	63.5-67.1	59.8-63.4	56.1-59.7	52.4-56	48.7-52.3	45-48.6	41.4-44.9	37.6-41.3	33.9-37.5	≤33.8

Appendix G: Recalibration data set characteristics

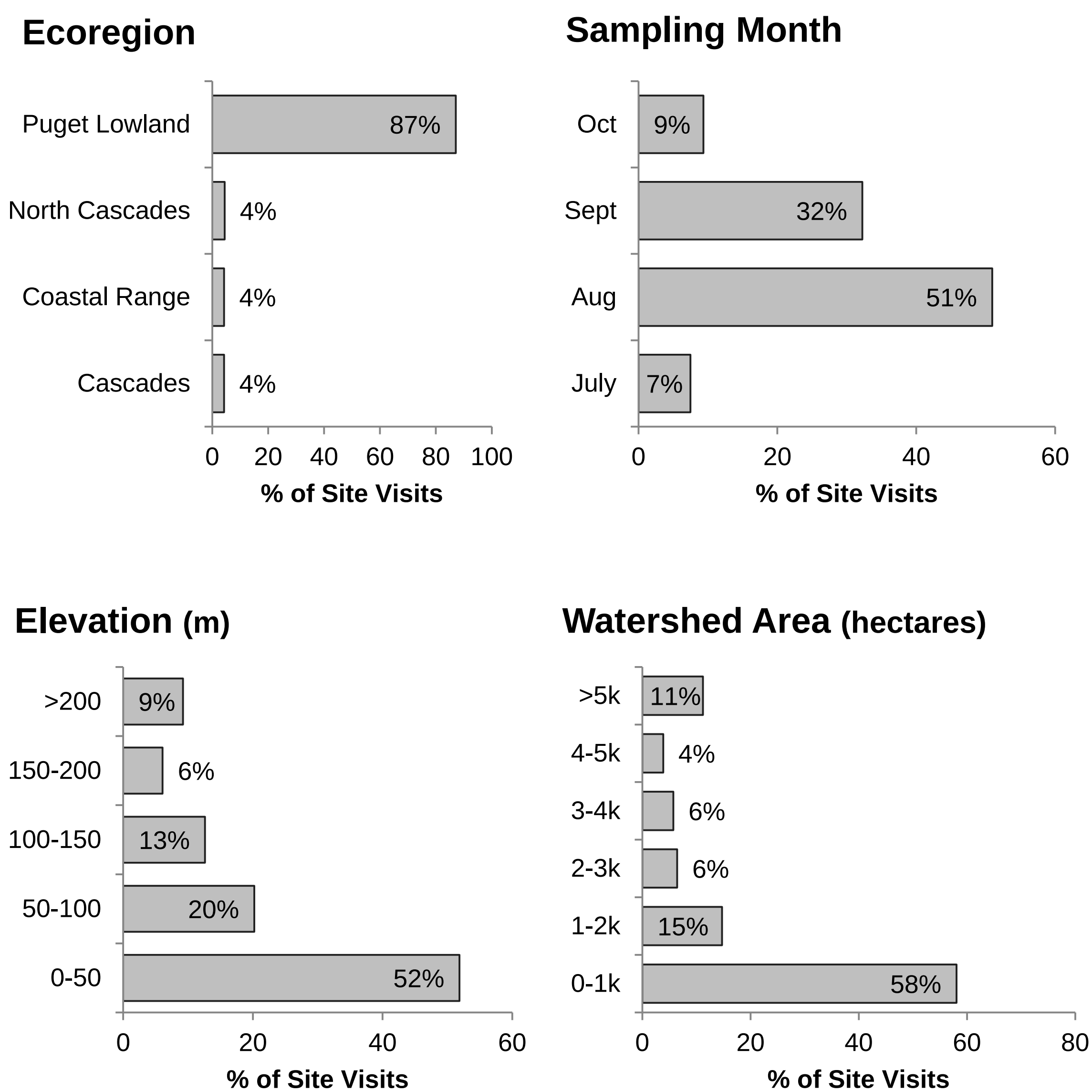

Figure G-1. Percent of site visits (out of 856) falling into different classes for ecoregion, sampling month, site elevation, and watershed area for data used for the B-IBI recalibration. Totals may not sum to 100 percent due to rounding error.