Using Natural History Attributes of Stream Invertebrates to Measure Stream Health

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Abstract

The benthic index of biotic integrity (B-IBI) measures the biological health of wadeable streams in the Puget Sound watershed. The B-IBI evaluates 10 aspects of aquatic invertebrate communities related to taxonomic composition, trophic complexity, sensitivity to human disturbance, and other aspects of biological condition. For this study, taxonomic information for three of the 10 metrics was updated based on current scientific literature; these were long-lived taxa richness, percent predator individuals and clinger taxa richness. Correlation with percent urban area in the watershed improved slightly for long-lived taxa richness but did not change for clinger taxa richness or percent predator individuals, although the association with human disturbance remained significant for all three metrics.

Taxonomic information used to calculate metrics for intolerant taxa richness and percent tolerant individuals was updated with data collected by city, county, and state agencies available in a regional database (PSSB, 2011). Individual taxa were tested for their response to a regional gradient of watershed urbanization. The most intolerant and most tolerant taxa were selected by comparing the cumulative frequency distributions of the sites where a taxon was found to the distribution of all sites sampled. A development data set (784 site visits) was used to evaluate individual taxa and a validation data set (507 site visits) was used to test the response of metrics derived from the new taxonomic information. Metric correlation with watershed urbanization increased markedly for intolerant taxa richness and percent tolerant individuals when data from local streams were used to define the sensitivity of aquatic invertebrates to human land use.

Introduction

The benthic index of biotic integrity (B-IBI) is a multimetric index composed of 10 measures of aquatic invertebrate communities collected from stream sites. The B-IBI was developed as an integrative measure of the biological health of wadeable streams in the Pacific Northwest (Karr, 1998; Table 1). The index has been tested and applied by numerous authors in a variety of situations throughout the Puget Sound region (May et al., 1997). Morley and Karr (2002) used the B-IBI and its component metrics to evaluate the relative impact of human disturbance at different spatial scales. DeGasperi et al. (2009) used the B-IBI to evaluate hydrologic indicators for their ability to predict changes in biological condition and identify the best indicators for evaluating basin management scenarios. The B-IBI has been consistently correlated with independent measures of human disturbance because it measures biological characteristics of invertebrate communities that respond predictably to changes in site condition associated with human disturbance (Fore et al., 2001; Booth et al., 2004).

The B-IBI was originally developed and tested in the early 1990s. Since that time, interest in using the B-IBI as a regional indicator of stream condition has increased, new information about natural history has become available for individual taxa, and over 3,000 benthic invertebrate samples have been collected from Puget Sound streams. When originally developed in the early 1990's, the taxa attributes used to calculate the B-IBI were derived from information available at the time and the best professional judgment of regional experts (Fore et al., 1996). Since then, information for long-lived, predator, and clinger taxa has been updated in peer-reviewed and other published sources. Ideally, the designation of tolerant and intolerant taxa would be empirically based; however, when the B-IBI was developed in the early 1990's sufficient data were not available. The development of the Puget Sound Stream Benthos (PSSB) data management system provides a significant source of data from throughout the region to directly test the response of individual taxa to the types of human disturbance typically found in Puget Sound watersheds (PSSB, 2011).

Several approaches have been used to test the response of individual taxa to stressor gradients associated with human influence (see review in Yuan [2006]). Most studies use weighted averaging to define optimum values for taxa along a stressor gradient or cumulative percentiles to determine at what level of disturbance, or change, taxa are lost from the ecosystem (Black et al., 2004; Utz et al., 2009; Whittier et al., 2008; Whittier and Van Sickle, 2010). For this study, a simple graphical approach using cumulative percentiles was used to compare the set of sites where a taxon occurred to all the sites that were sampled relative to the amount of watershed urbanization (Utz et al., 2009). To calculate B-IBI metrics, identification of only the most tolerant and most intolerant taxa are needed; therefore, tolerant and intolerant taxa classification was not necessary for all taxa. Numerous authors have noted that the geographic scale of the data used can impact the results of taxa testing because natural processes interact with human influence across the landscape (Black et al., 2004; Munn et al., 2008). For this reason, taxa lists for tolerant and intolerant taxa were developed using data local to Puget Sound watersheds.

The goals of this effort were to 1) modify taxonomic lists for predators, long-lived and clinger individuals using published literature and knowledge of local taxa; 2) test individual taxa for their tolerance and intolerance of human disturbance; and 3) evaluate the correlation of metrics derived from the updated taxonomic information with an independent measure of human disturbance in the watershed.

Table 1. Component metrics of B-IBI, their response to human disturbance, and whether they were updated in this study.

Metric	Response to Disturbance	Updated in 2012?
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	Yes
Tolerance		
Number of intolerant taxa	Decrease	Yes
% of individuals in tolerant taxa	Increase	Yes
Feeding ecology		
% of predator individuals	Decrease	Yes
Number of clinger taxa	Decrease	Yes
Population attributes		
% dominance (3 taxa)	Increase	

Methods

Two different approaches were employed to update the taxa attribute lists. Long-lived, predator, and clinger attributes were updated from published literature relying on best available science. Tolerant and intolerant attributes were derived empirically by testing individual taxa for their association with watershed urbanization, selecting the 15% most tolerant and 15% most intolerant taxa. B-IBI metrics were calculated from the old and new lists of taxa attributes and both versions of the five metrics were tested for correlation with watershed urbanization.

Measuring human disturbance

Several measures of human influence and site condition were evaluated for their association with B-IBI. The goal was not to evaluate the responsiveness of the B-IBI to human disturbance, that relationship has already been demonstrated for Puget Sound streams (e.g., Morley and Karr, 2002; DeGasperi et al., 2009). Rather, the primary goal was to summarize human disturbance with a single measure, or a composite measure, in order to identify the most tolerant and intolerant taxa to use in calculation of metrics for the B-IBI.

Human impact on aquatic systems is complex and can be measured in a variety of ways. Variables were selected to represent different measures of human impact at multiple spatial scales (Bressler et al., 2009). Land use and land cover were evaluated at four spatial scales to determine which scale was the best predictor of biological condition: (1) within the upstream contributing watershed, (2) within a 1-km radius of the contributing watershed, (3) within a 90-m buffer in the contributing watershed, and (4) within a 90-m buffer in the 1-km contributing watershed (Figure 1). B-IBI was highly correlated with all measures of human disturbance at all four spatial scales. In addition, principal components analysis (PCA) was used to create a linear combination of population density, road crossings, percent forested area in the watershed, and percent urban area at all four spatial scales (Whittier and Van Sickle, 2010). The data set included the most recent visits to 815 sites for which both land use/cover and B-IBI information were available. Half the sites were used to develop the linear combination of seven measures (PCA) and the other half of the sits were used to validate the results.

Land use/land cover data was derived from the 2006 National Landcover Dataset; road information was obtained from NAVTEQ; the streams layer was derived from the flow accumulation grid of the National Hydrologic Dataset; and population estimates were from the 2008 U.S. Census.

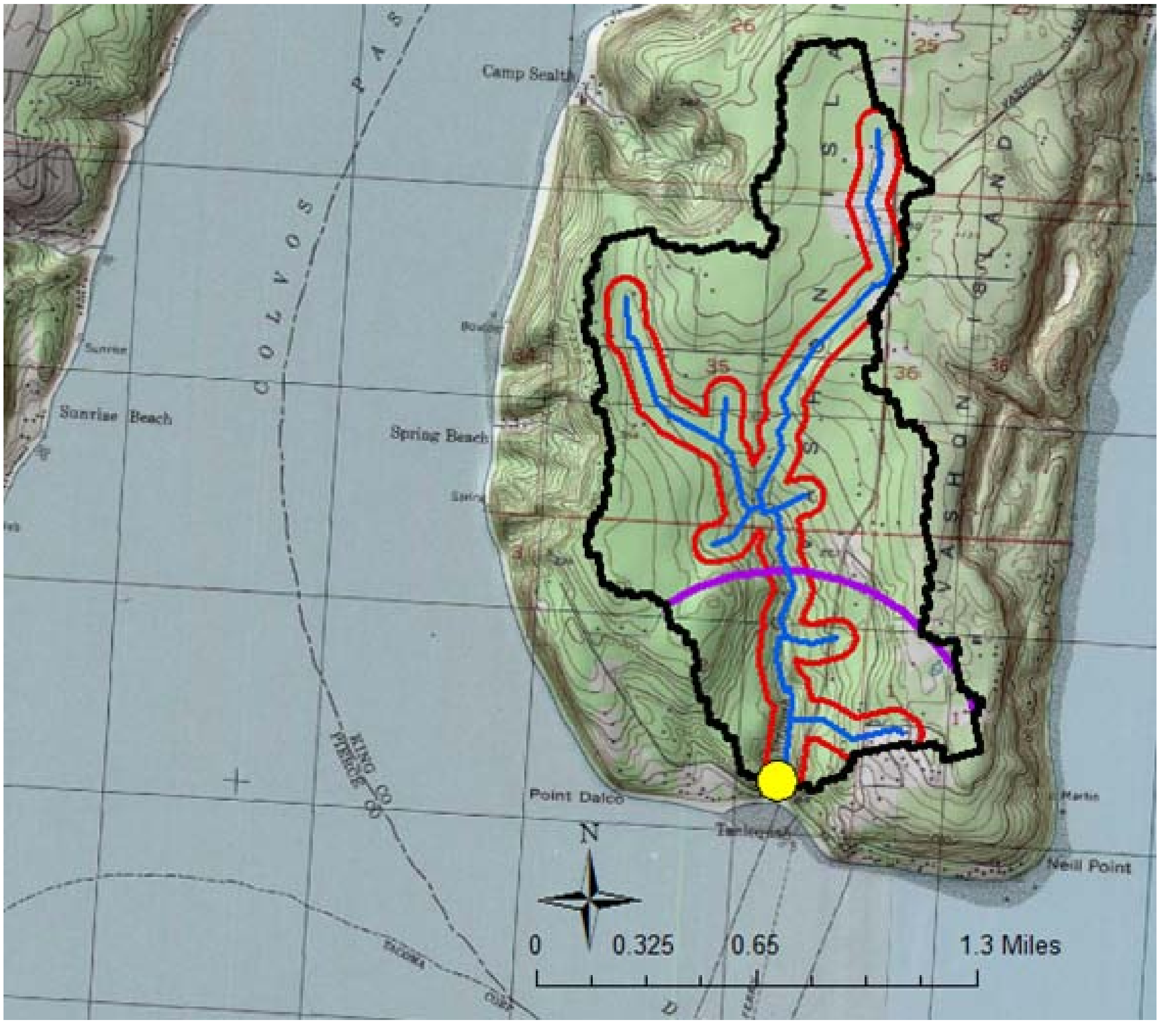

Figure 1. Example watershed showing entire upstream watershed (black line), 90-m buffer (red outline), and 1-km area upstream of the pour point (yellow dot) where invertebrate sample was collected.

Defining taxa attributes for long-lived, predator, and clinger taxa

The PSSB data system includes approximately 850 unique taxa names for aquatic invertebrates collected in the Puget Sound region. Approximately 500 of the most common taxa were selected for review and update of their status as long-lived, predator, and clinger taxa. The list of most common taxa was derived from three sources:

the PSSB, Washington Department of Ecology's data for western Washington State, and the US Geological Survey's data for the Puget Sound Lowlands. In general, there was broad agreement on which taxa were most common across the three data sources.

Long-lived benthic invertebrate taxa are those that require more than one year to complete their life cycle. To identify long-lived taxa for Puget Sound lowland streams, published references on life histories were used when available and supplemented with best professional judgment as needed. Poff et al. (2006), Vieira et al. (2006), and Huryn et al. (2008) summarize life history for a number of North American aquatic insects. Primary resources for stoneflies were Stewart and Stark (2002); for caddisflies, Wiggins (1996); for non-insects, Pennak (1989) and Thorp and Covich (2001); for clams, Mackie (2007); and for other mollusks, Dillon (2000).

Merritt et al. (2008) was the primary source of information used to designate insects as predators, which are defined as carnivores that attack and engulf animal prey or pierce prey tissue and suck fluids. Information from Pennak (1989) and Thorp and Covich (2001) was used for non-insect groups.

Cummins et al. (2008) define clingers as taxa that possess morphological adaptations that allow them to maintain position (cling) to surfaces while exposed to water current in erosional (riffle) habitats. Adaptations include flattened body forms, tarsal claws for grasping, suction discs, and use of silk. The original B-IBI only included insects in this metric and the same has been done here (Karr and Rossano, 2001). Merritt et al. (2008) define taxa as clingers at the genus level. When genus descriptions listed more than one habit, classification was based on the habit of the species that are most typically found in the Puget Sound region.

Testing the response of individual taxa to human disturbance

Over 20 local jurisdictions in the Puget Sound region have uploaded stream invertebrate data to the PSSB which included 3011 site visits when data were downloaded for this study (PSSB, 2011). Samples of stream invertebrates have been collected for a variety of reasons, e.g., status and trend monitoring, and evaluation of specific sites or management actions. Only data collected from sites at an elevation of less than 500m were included in the analysis. To select tolerant and intolerant taxa, data were used from the most recent sampling visit to 784 sites between 2000 and 2010. A second data set based on the next most recent site visit at 507 sites between 2000 and 2010 was used to calculate and test tolerant and intolerant metrics based on the new attribute lists. In this way, a development data set was used to select the tolerant and intolerant taxa and a second validation data set was used to test the updated versions of the metrics.

A total of 638 unique taxa names represented a mix of taxonomic levels, e.g., species, genus, family, etc. Species level taxa were "rolled up" to the genus level for testing which reduced the number of taxa to 492. In order to evaluate taxa individually, sufficient data were needed to define the distribution of sites with the taxon present (Utz et al., 2009). Consequently, only taxa with 25 or more occurrences from 784 site-visits were tested for their association with watershed urbanization. In other words, a taxon had to occur at >=3% of visits. A total of 205 taxa met the criterion, 42 of which were chironomid midges. An exception to genus level testing was made for *Rhyacophila*, a large genus that includes many taxa of free-living caddisflies. Sufficient data were available to test 8 species and species groups. For chironomid midges, genera were also combined and tested at the subfamily level because many of the genera had relatively few occurrences, and because the subfamilies often include genera that share similar characteristics.

The method developed by Utz et al. (2009) was applied to Puget Sound invertebrate data to test individual taxa for their sensitivity and tolerance to human disturbance measured as percent urbanization in the watershed. For each taxon, two populations of sites were compared: the population of all sites sampled (N = 784), this is the "null model," and the population of sites where the taxon was present. Both sets of sites were ordered according to percent watershed urbanization and then compared using their cumulative distribution functions (CDF). CDFs display the same information as a histogram, but rather than using categories for values (e.g., low, medium and high values for percent watershed urbanization), the percentage accumulates from 0-100% of all sites as a function of percent watershed urbanization.

Tolerant taxa were defined as taxa that were more likely to be found in sites with greater watershed urbanization. To quantify tolerance of disturbance, the maximum difference between the two CDF distributions was calculated for sites with the taxon present and for all sites sampled. The 15% of taxa that had the greatest maximum difference in CDF values were defined as tolerant; these taxa were the most likely to occur at disturbed sites.

Intolerant taxa were defined as taxa that were less likely to be found in sites with higher watershed urbanization. To quantify intolerance, the observed value of urbanization in the watershed was recorded for the 95th percentile of sites with the taxon present, that is, the value of urbanization at which the taxon began to disappear from samples. To define taxa as intolerant, 15% of taxa that were the most sensitive to urbanization were selected. These taxa were the first to disappear from samples as urbanization in the watershed increased.

If a genus or family was selected as tolerant (or intolerant), their taxonomic 'children,' e.g., species, inherited their designation as well. In the other direction, if all the children of a taxonomic group were identified as tolerant or intolerant, the designation was extended up to the next coarser taxonomic level. Lists were reviewed by the author (R. Wisseman) and a professional taxonomist (W. Bollman, personal communication) to ensure that designations at the species level were appropriate.

Many taxa that were previously identified as intolerant were too rare to test using the criteria developed for this project; i.e., they occurred at <3% of 784 sites. Therefore, rare taxa were evaluated separately, even though this is not a metric included in B-IBI. 'Rare' was defined as genera with <= 10 site occurrences in all the most recent visits (N = 784). To test the value of rare taxa as an indicator of biological condition, the number of rare taxa occurring at each site was tested for correlation with watershed urbanization.

Results

Measuring human disturbance

B-IBI was highly correlated with all measures of human disturbance at multiple spatial scales (Table 2). Two measures of disturbance showed the highest correlation with B-IBI; these were the factor scores from PCA and percent watershed urbanization (Table 2). Percent urbanization within the watershed was used to test individual taxa for two reasons. It was the most highly correlated with B-IBI compared to other spatial scales and it was easier to apply and interpret than the factor scores from PCA.

Table 2. Measures of human disturbance, correlation with B-IBI for both a development and validation data set (Pearson's r), and whether the measure was included in the PCA to create a single factor from multiple measures of disturbance.

Disturbance measure	Correlation (r)		Used in PCA?
	Development data set	Validation data set	
Population within 1km	-0.59	-0.60	
Road Density within 1km	-0.59	-0.61	
Road Crossings within 1km	-0.46	-0.46	
Watershed Population Density	-0.64	-0.63	Yes
Watershed Road Density	-0.66	-0.66	Yes
Watershed Road Crossings per km	-0.61	-0.59	
% Urban within 1km in the Watershed	-0.61	-0.64	Yes
% Forest area in the Watershed	0.65	0.67	Yes
% Urban area in the Watershed	-0.68	-0.68	Yes
% Urban within a 90m buffer 1km upstream	-0.57	-0.61	Yes
% Urban within a 90m buffer in the upstream watershed	-0.67	-0.67	Yes
First factor from PCA	0.68	0.69	

Taxa attributes for long-lived, predator, and clinger taxa

In general, changes to these attribute lists had a relatively minor impact at the level of the metrics because many of the taxa that changed their status were relatively uncommon in the database. New taxa added to the lists included new designations based on recent natural history information, updates to uncommon taxa new to the database, and corrections. Complete taxa lists are available from the Puget Sound Stream Benthos regional database (PSSB).

For long-lived taxa, a total of 97 taxa were identified as long-lived, of these, 34% were originally listed as long-lived taxa. Several taxa were added to the list of long-lived taxa including pea clams (Sphaeriidae,e.g. *Pisidium*); most leeches (Hirudinea) with the exception *Helobdella stagnalis;* the megalopteran, *Sialis*; several taxa of stoneflies (Plecoptera) including all the peltoperlids; a few species groups of rhyacophilid caddisflies (Trichoptera); and all the elmid beetles. Several taxa of beetles are no longer considered long-lived; these include taxa in the Haliplidae, Hydrophilidae and Dytiscidae.

For predator taxa, a total of 186 taxa were identified as predators including 51% of the taxa from the earlier list. The major change to the predator list was the addition of several taxa, mostly true flies (Dipterans) such as the higher flies and midges including Brachycera, Ceratopogoninae, Tanypodinae, *Chelifera/Metachela*, *Limnophila*, and *Pilaria*; a mayfly, *Drunella grandis/spinifera*; a stonefly, *Kogotus/Rickera*; and a caddisfly, *Oecetis*. One midge taxon, Forcipomyiinae, was removed from the predator list.

Changes to the list of clinger taxa were mostly due to additions of new taxa, many of which were relatively uncommon. Of the 220 taxa listed as clingers, 65% of the taxa names were from the earlier clinger list.

Long-lived taxa decreased as watershed urbanization increased. The correlation was slightly stronger (higher correlation coefficient) for the taxa richness metric derived from the updated attribute list (Table 3). Correlation for percent predators and clinger taxa richness changed very little, reflecting the relatively minor changes to the attributes for these taxa. In contrast, intolerant taxa richness and percent tolerant individuals showed a marked increase in correlation with disturbance based on the empirically-derived taxa lists.

Response of individual taxa to human disturbance

Overall, more taxa were present at sites with less urbanization in the watershed reflecting the general observation that taxa richness declines with human disturbance. When tested individually, some taxa, such as Erpobdellidae (leeches), were tolerant of disturbance and found more frequently in sites with greater watershed urbanization (Figure 2). In contrast, taxa such as *Epeorus* (a heptageniid mayfly) showed a strong preference for sites with less urbanization in the watershed (Figure 3). *Epeorus* was rarely found at sites with more than 40% urbanization. Often other genera within a family showed similar patterns of intolerance to disturbance, for example, *Drunella* was intolerant of increasing urbanization as were other genera in its family Ephemerellidae (Figure 4).

The taxa that were the most tolerant and the most intolerant of urbanization in the watershed were selected for calculating the percent of tolerant individuals and number of intolerant taxa as metrics in the B-IBI. Of the 205 taxa evaluated, 23 were identified as intolerant and 17 were identified as tolerant (Appendices 1 and 2). For intolerant taxa, 30% of the taxa were on the earlier list for intolerant taxa; for tolerant taxa 27% of the designated taxa were on the previous list. Individual species within a genus were not directly tested but inherited the designation as tolerant or intolerant from their parent genus. A few species were identified that should not inherit the genus level designation.

The total number of rare taxa ranged from 0-10 for the site-visits. Correlation of the number of rare taxa with percent urbanization in the watershed was low (-0.2, Spearman’s r, N = 741).

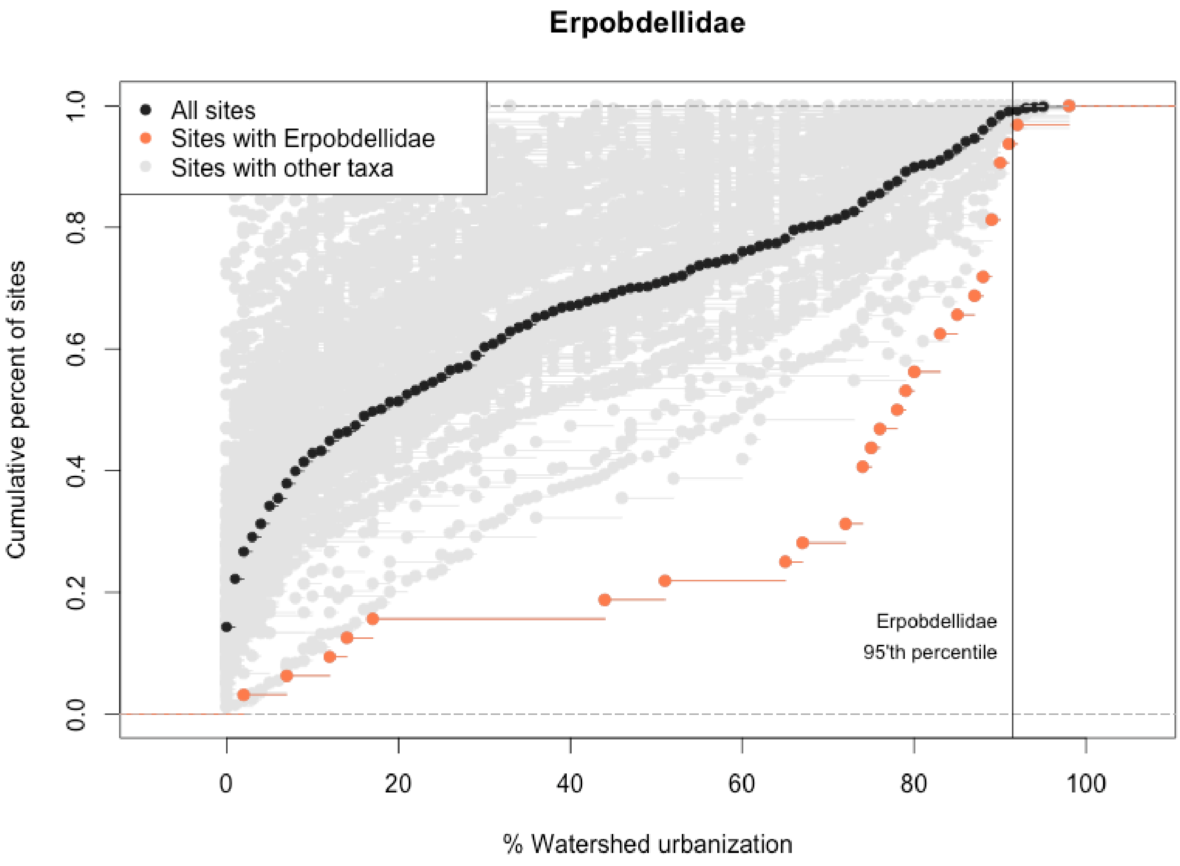

Figure 2. Example of a taxon tolerant of disturbance. The cumulative distribution of sites with Erpobdellidae (a family of leeches, orange points) differed markedly from the distribution of all possible sites (null model, black points) and illustrate that Erpobdellidae were typically found at sites with greater urbanization.

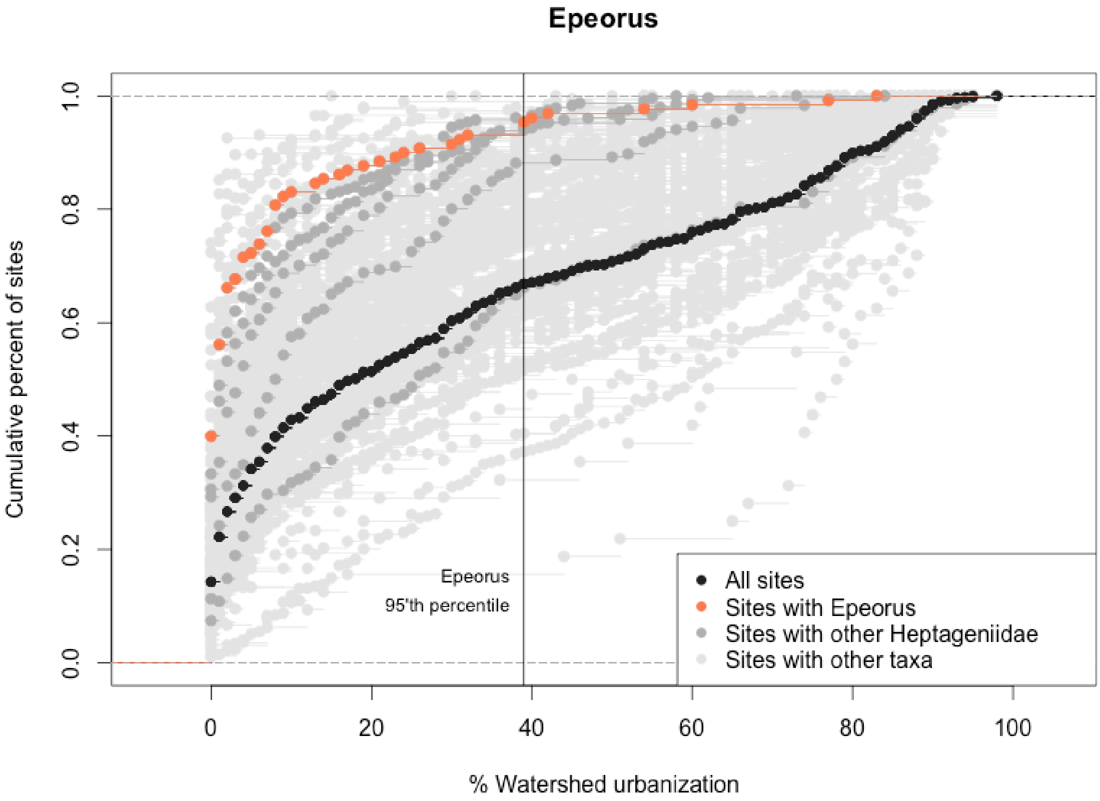

Figure 3. Example of a taxon intolerant of disturbance. The cumulative distribution of sites with *Epeorus* (orange points) differed markedly from the distribution of all possible sites (null model, black points). This taxon was much more likely to be found at sites with less urbanization; 95% of sites with *Epeorus* present occurred in watersheds with less than 40% urban area. Most of the genera in this family (Heptageniidae; grey points) were also found more frequently in less disturbed watersheds.

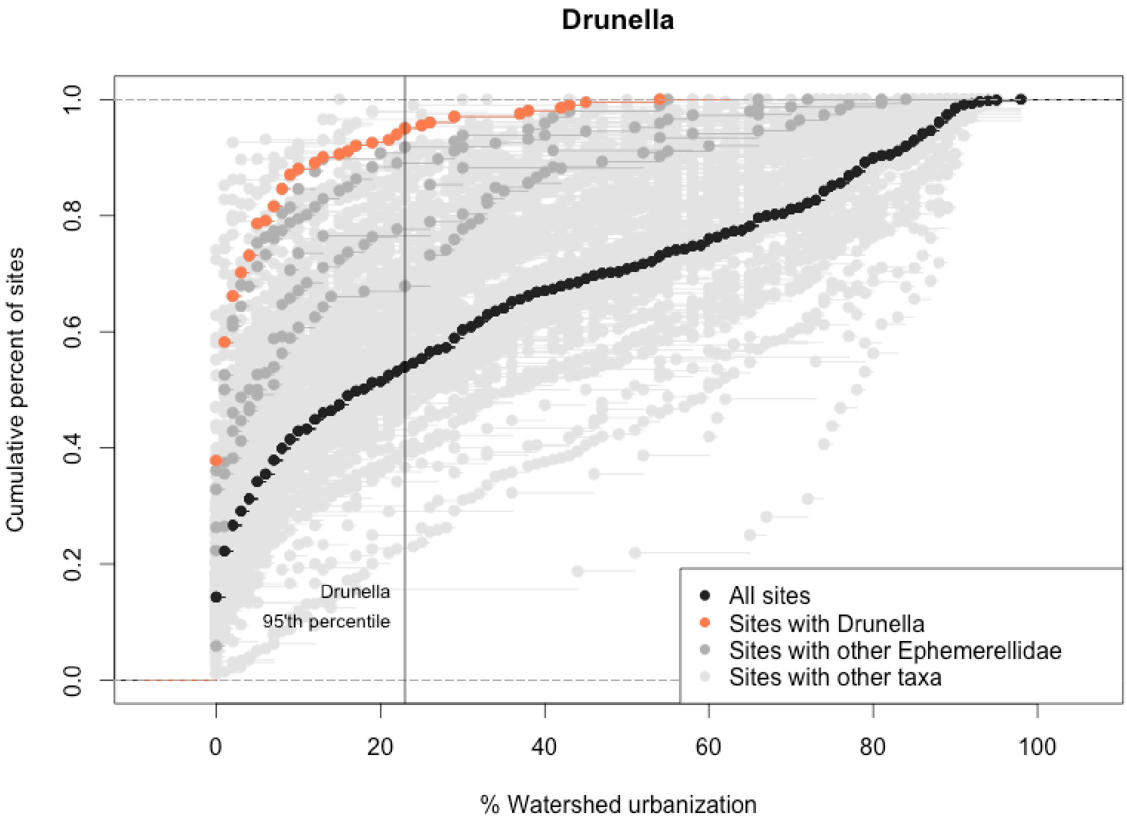

Figure 4. *Drunella* (orange points) was found more frequently at sites with less urbanization; 95% of all observations occurred at sites with <25% urbanization in the watershed. Other genera within Ephemerellidae showed similar patterns to disturbance (dark grey points).

Table 3. Correlation of metrics with percent watershed urbanization (Spearman's r, N = 507, p < 0.01). Shown are correlation values for metrics derived from the original taxa attribute lists for all five metrics and for metrics derived from the updated taxa lists for long-lived, predator, clinger, intolerant and tolerant taxa.

Metric name	**Original (1998)**	**Updated (2012)**
Long-lived taxa	-0.39	-0.43
% Predators	-0.43	-0.42
Clinger taxa	-0.61	-0.60
Intolerant taxa	-0.52	-0.75
% Tolerant	0.47	0.62

Conclusions

Regional monitoring and restoration targets for B-IBI

B-IBI was originally tested and developed using diverse data sets from a variety of short-term scientific studies and projects. Like similar multimetric indexes designed to assess and report biological condition, B-IBI was originally 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 their water quality standards (Davies and Jackson, 2006).

Since its original development, the B-IBI has been broadly applied in a variety of contexts in western Washington including status and trend monitoring by counties, tribes and local jurisdictions and effectiveness monitoring of restoration projects for salmonid habitat. The Washington State Department of Ecology will use B-IBI data submitted by local jurisdictions for their 2012 assessment of whether streams are meeting their water quality standards under the Clean Water Act. B-IBI has also been adopted as a regional indicator of freshwater condition by the Puget Sound Partnership, a state agency created in 2007 to lead the ecological recovery of Puget Sound. The PSP works with regional stakeholders to set specific, numeric targets for indicators such as B-IBI so that legislators, scientists, and citizens can track regional status and trends (Puget Sound Partnership, 2012).

Calibrating the B-IBI

Several factors support the idea to develop an index calibrated specifically for streams in the Puget Sound watershed. First, numerous local agencies and organizations are using B-IBI to make decisions in the Puget Sound region. Second, an increasing human population is driving the pressure on water resources in this region, creating a need for regionally specific indicators. Other regional studies have identified tolerant and intolerant taxa, e.g., Whittier and Van Sickle (2010) used data from 12 western states. Their lists could have been adopted for the Puget Sound B-IBI; however, a similar amount of data (more than 2,500 visits to more than 900 sites) was available for Puget Sound lowland streams. Thus, regional stakeholders were interested in results derived from their own local data.

For Puget Sound streams, percent urban area in the watershed was a simple and effective measure for summarizing site condition. Urbanization may be more accurately described as ‘developed area’ because the land cover measures human structures in rural areas as well as urban areas. B-IBI and its component metrics were consistently correlated with several measures of human disturbance, and most highly with percent urban area in the watershed. Morley and Karr (2002) also found a stronger association between B-IBI and measures of urbanization made at the watershed scale rather than within the riparian buffer. A more accurate measure of disturbance could perhaps be created from the data, but for the purpose of metric testing, the high correlation (Pearson’s $r = -0.89$) observed for B-IBI and percent watershed urbanization was sufficient. Agriculture is another important human activity in this region, but is more difficult to quantify because farming practices and their impacts differ according to the type of crops and livestock.

The updated taxa lists will improve the accuracy of B-IBI for measuring site condition and confidence in what the metrics are measuring. The five metrics were tested based on the new and updated information for taxonomic attributes. All metrics continued to be highly correlated with watershed urbanization supporting the idea of a consistent and measurable response for B-IBI and its component metrics. Correlation of percent tolerant individuals and intolerant taxa richness metrics with watershed urbanization increased markedly after the taxa were empirically selected based on data from Puget Sound streams. Correlation for only one of the other three metrics improved, and only slightly (long-lived taxa richness), indicating that the initial designations for predators, clingers and long-lived taxa were accurate and these updates represent refinements to the original lists.

The greatest change in this update to B-IBI was elimination of many taxa previously identified as intolerant because there were insufficient data to test their response to disturbance (i.e., they occurred at less than 25 sites). Rare taxa can be highly sensitive and early indicators of habitat loss. When the most rare taxa were selected and summarized, the measure had a low correlation with urbanization in the watershed. Rarity was not a strong indicator of site condition, and also not necessarily equal to intolerance. Recent studies of other taxonomic groups have shown that rarity is also a poor indicator of total taxa richness. Mazaris et al. (2013) concluded from comparisons of taxa richness measures of rare, common and randomly selected taxa, that rare taxa were biased measures of total richness and more indicative of the effect of sampling methods rather than underlying biological patterns of diversity.

Multimetric indexes such as B-IBI distill data derived from taxonomic lists of stream invertebrates into a neat summary of biological condition. Component metrics of B-IBI were originally selected for their responsiveness to independent measures of site condition. Metrics are designed to measure ecological concepts, e.g., the percent of predator individuals reflects the trophic complexity of the invertebrate community. Long-lived taxa richness measures whether condition at the stream site provided adequate habitat for invertebrates to complete their life cycles over multiple years. Taxa are defined as predators, long-lived or clingers according to their natural history.

In contrast, tolerant and intolerant taxa were selected for their response to urbanization in the watershed. The approach used here for selecting taxa was straightforward in that comparisons of individual taxa were based on simple graphs and summary statistics (percentiles and maximum differences of distributions) and did not require the assumptions of more complex statistical models. The analysis used local data from Puget Sound lowland streams to ensure that the metrics are as sensitive as possible to changes in stream condition typical for this region. Sensitive tools are needed to discern which restoration methods are most effective because restoration is expensive and its impact is hard to measure (Whiteway et al., 2010; Roni et al., 2011). Stream invertebrates are particularly sensitive to the types of habitat changes associated with stream restoration (Miller et al., 2010). B-IBI and its component metrics transform invertebrate sample data into sensitive indicators of stream health.

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Appendix 1. Intolerant taxa.

Taxonomic order, family, and taxon names for invertebrates identified as intolerant of watershed urbanization in Puget Sound lowland streams. T95 is the percentage of urbanization in the watershed below which 95% of occurrences were observed; lower values of T95 indicate greater intolerance.

Order	**Family**	**Taxon name**	**T95 (%)**
Diptera	Empididae	*Oreogeton*	38
Diptera	Tipulidae	*Hesperoconopa*	10
Ephemeroptera	Ameletidae	*Ameletus*	16
Ephemeroptera	Ephemerellidae	*Attenella margarita*	
Ephemeroptera	Ephemerellidae	*Attenella delantala*	
Ephemeroptera	Ephemerellidae	*Attenella*	38
Ephemeroptera	Ephemerellidae	*Drunella grandis/spinifera*	
Ephemeroptera	Ephemerellidae	*Drunella doddsii*	
Ephemeroptera	Ephemerellidae	*Drunella*	23
Ephemeroptera	Heptageniidae	*Cinygmula*	41
Ephemeroptera	Heptageniidae	*Epeorus*	39
Ephemeroptera	Heptageniidae	*Ironodes*	41
Ephemeroptera	Heptageniidae	*Rhithrogena*	31
Plecoptera	Capniidae	Capniidae	33
Plecoptera	Capniidae	*Capnia*	
Plecoptera	Chloroperlidae	*Kathroperla*	23
Plecoptera	Chloroperlidae	*Kathroperla perdita*	
Plecoptera	Chloroperlidae	*Paraperla*	46
Plecoptera	Leuctridae	*Moselia infuscata*	37
Plecoptera	Peltoperlidae	*Yoraperla*	41
Plecoptera	Perlidae	*Calineuria californica*	41
Plecoptera	Perlidae	*Doroneuria*	14
Plecoptera	Perlidae	*Hesperoperla pacifica*	45
Plecoptera	Perlidae	Perlidae	37
Trichoptera	Apataniidae	*Apatania*	16
Trichoptera	Hydropsychidae	*Arctopsyche*	42
Trichoptera	Limnephilidae	*Ecclisomyia*	22
Trichoptera	Polycentropodidae	*Polycentropus*	30
Trichoptera	Rhyacophilidae	*Rhyacophila arnaudi*	37
Trichoptera	Uenoidae	*Neophylax occidentis*	
Trichoptera	Uenoidae	*Neophylax splendens*	
Trichoptera	Uenoidae	*Neophylax rickeri*	
Trichoptera	Uenoidae	*Neophylax*	45

Appendix 2. Tolerant taxa.

Taxonomic order, family, and taxon names for invertebrates identified as tolerant of watershed urbanization in Puget Sound lowland streams.

Order	**Family**	**Taxon name**
Arhynchobdellida	Erpobdellidae	*Erpobdella*
Arhynchobdellida	Erpobdellidae	*Mooreobdella*
Arhynchobdellida	Erpobdellidae	*Erpobdellidae*
Diptera	Chironomidae	*Diplocladius*
Diptera	Chironomidae	*Pagastia*
Diptera	Chironomidae	*Parakiefferiella*
Diptera	Simuliidae	Simuliidae
Diptera	Simuliidae	*Simulium*
Diptera	Tipulidae	*Tipula*
Trichoptera	Hydropsychidae	*Parapsyche almota*
Trichoptera	Hydroptilidae	*Hydroptila*
Amphipoda	Crangonyctidae	*Crangonyx*
Amphipoda	Crangonyctidae	*Crangonyctidae*
Amphipoda		Amphipoda
Isopoda	Asellidae	*Caecidotea*
Isopoda	Asellidae	*Asellidae*
Isopoda		Isopoda
Basommatophora	Physidae	*Physa*
Basommatophora	Physidae	Physidae
Basommatophora	Physidae	*Physella*
Basommatophora	Planorbidae	*Promenetus*
Basommatophora	Planorbidae	*Menetus*

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