Puget Lowland River Benthic Macroinvertebrate Sampling: Pilot Study

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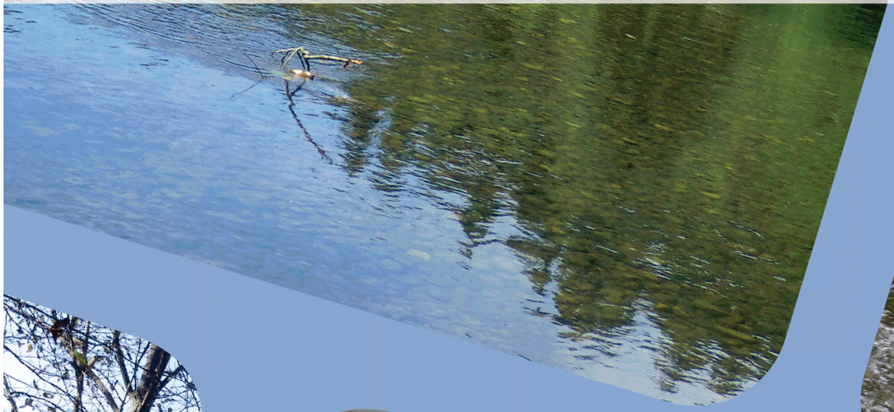

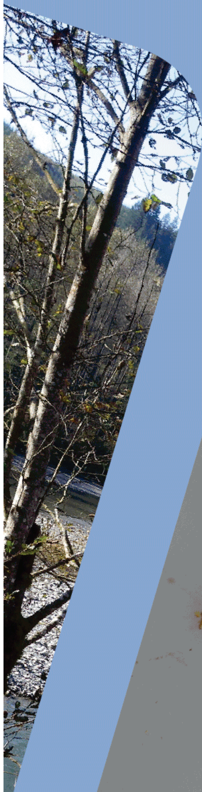

Cover photos by Jo Wilhelm:

Top left: Cedar River

Bottom left: Predatory stonefly (Cedar River)

Top right: Pink salmon carcass (North Fork Stillaguamish River)

Middle right: Nicole Casper (Cedar River)

Bottom right: Mary Lear (Snoqualmie River)

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Prepared for:

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Submitted by:

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Department of Natural Resources and Parks

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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

Benthic macroinvertebrates have been successfully used to assess stream health and biological integrity across the world, predominantly in wadeable streams. The lack of sampling and data analysis tools to evaluate rivers in the Puget Sound region has been identified as a gap by the Puget Sound Partnership Freshwater Workgroup. However, due to expected changes in macroinvertebrate community composition from headwaters to rivers, regional stakeholders have also questioned the applicability of the Puget Lowland benthic index of biotic integrity (B-IBI) to large streams and rivers.

In fall of 2013, a pilot benthic macroinvertebrate sampling effort was conducted at 20 reaches on four rivers in the Puget Sound basin. The purpose of this sampling effort was to collect data to begin to assess the feasibility of sampling fluvial systems larger than those typically targeted in local agency, state, and Tribal bioassessment programs (e.g., watersheds >80 square miles, "non-wadeable" streams and rivers). An additional goal was to begin to evaluate which biologic metrics (e.g., taxonomic richness, percent predators, tolerant richness, etc.) might be the most effective to determine impairment in these waterbodies in order to move towards a benthic index of biotic integrity (B-IBI) for Puget Sound rivers and large streams.

Results of the 2013 pilot sampling efforts were combined with additional macroinvertebrate data from Puget Sound rivers available from the Puget Sound Stream Benthos (PSSB) data management system. An additional 49 site visits were identified that were (1) located within the Puget Sound basin, (2) were the most recent visit for a particular site with more than 300 organisms in the composited sample, (3) had accurate basin delineations and landcover readily available from previous work, and (4) had contributing watershed areas greater than 80 mi^2.

Percent watershed urbanization was selected as the human disturbance gradient to calibrate metric response in recent B-IBI recalibration efforts because it was highly correlated with B-IBI and it is a simple and effective measure for summarizing site condition that is easy to apply and interpret. Disturbance was assessed at both the watershed and local (1-km) watershed scales.

The ten metrics that comprise the Puget Lowland B-IBI were assessed, in addition to a select set of 63 additional metrics to determine which, if any, effectively distinguish impairment in larger Puget Sound water bodies. The multistep screening process used to evaluate metrics followed the methods of similar metric and index evaluation studies. These steps include assessing (1) range and distribution, (2) responsiveness to disturbance variables, and if any metrics pass the range and responsiveness tests, then (3) correlation with other responsive metrics.

All ten B-IBI metrics passed the range and distribution screening, however only four (taxa, Trichoptera, clinger, and long-lived richness) had statistically significant correlations with disturbance in the expected direction (i.e., values decreased as disturbance increased). Of

the 63 additional metrics tested, 26 were eliminated because they were either too skewed towards zero values or had an insufficient range of values. Of the 37 remaining, 22 had statistically significant correlations with at least one scale of disturbance. These 22 metrics were plotted against disturbance to visually evaluate whether a linear or wedge-shaped relationship existed. None of these correlations were especially strong, however, seven metrics may warrant further consideration based on their wedge shaped relationship with local urbanization including Ephemerellidae richness and Baetidae, Ephemeroptera, Baetis, Plecoptera, Rhyacophilidae, and non-Baetis Ephemeroptera percent individuals.

The 2013 pilot sampling effort and subsequent analysis is a first step towards increasing the scope of B-IBI beyond wadeable lowland streams. However, additional work is necessary before any decisive conclusions can be reached. Recommended next steps include a literature review of rivers bioassessment analysis methods, adding existing river data not currently in the PSSB, identifying and supplementing gaps in the existing data set, testing and evaluating collection methods, and developing a multi-scale, multimetric human disturbance index.

With millions of dollars spent annually on salmon recovery in the Puget Sound region on projects frequently targeting river restoration it is imperative that appropriate bioassessment techniques exist to evaluate impairment and the response to future disturbance or restoration efforts in Puget Sound river systems.

1.0 INTRODUCTION

Benthic macroinvertebrates have been successfully used to assess stream health and biological integrity across the world, predominantly in wadeable streams. The lack of sampling and data analysis tools to evaluate rivers in the Puget Sound region has been identified as a gap by the Puget Sound Partnership Freshwater Workgroup (PSEMP 2013). However, due to expected changes in macroinvertebrate community composition from headwaters to rivers (e.g., Minshall et al. 1992, Vannote et al. 1980), regional stakeholders have also questioned the applicability of the Puget Lowland benthic index of biotic integrity (B-IBI) to large streams and rivers. In fall of 2013, a pilot benthic macroinvertebrate sampling effort was conducted at 20 reaches on four rivers in the Puget Sound basin. This work was funded by an U.S. Environmental Protection Agency (EPA) Puget Sound Science and Technical Assistance Grant awarded to the King County Department of Natural Resources and Parks (DNRP), Water and Land Resources Division (WLRD) under the 2010 Puget Sound Initiative titled: "Enhancement and Standardization of Benthic Macroinvertebrate Monitoring and Analysis Tools for the Puget Sound Region."

The purpose of this sampling effort was to collect data to begin to assess the feasibility of sampling fluvial systems larger than those typically targeted in local agency, state, and Tribal bioassessment programs (e.g., watersheds >80 square miles, "non-wadeable" streams and rivers). An additional goal was to begin to evaluate which biologic metrics (e.g., taxonomic richness, percent predators, tolerant richness, etc.) might be the most effective to determine impairment in these waterbodies in order to move towards a benthic index of biotic integrity (B-IBI) for Puget Sound rivers and large streams. This document describes the sampling methodologies used for the 2013 sampling pilot project, in addition to results of this pilot assessment. Also included in the analysis were additional macroinvertebrate data from Puget Sound rivers available from the Puget Sound Stream Benthos (PSSB) data management system. In addition, recommendations to more fully develop a biotic index suitable for evaluating rivers in the Puget Sound Basin are presented.

2.0 METHODS

Collection methods are described for the 2013 sampling efforts and for existing data. The additional data obtained from the PSSB were limited to locations that met certain size criteria (e.g., watershed area greater than 80 square miles). The 2013 study sites are referred to as "pilot" sites and those assembled from existing PSSB records are referred to as "non-pilot" sites throughout this report.

2.1 2013 Pilot Sampling and Taxonomic Analysis Methods

Collection methods are described in more detail in the project quality assurance project plan (QAPP) (King County 2011) and the QAPP addendum for river sampling (King County 2013a). Methods are briefly summarized here.

2.1.1 Pilot Sampling Site Selection

Puget Sound is home to over a dozen rivers, which represent the sampling universe for this project (Table 1).

Table 1. Watershed area and discharge for major Puget Sound rivers. From Czuba et al. 2011.

River Basin	Watershed Area (mi^2)	Mean Annual Discharge (ft^3/s)
Skagit	3,200	18,000
Snohomish/Skykomish/Snoqualmie/Tolt	1,800	10,000
Puyallup/White/Carbon/Greenwater	980	3,600
Nooksack	840	3,200
Nisqually	770	2,100
Stillaguamish	700	2,700
Lake Washington Ship Canal (Cedar/Sammamish/Lake Washington)	600	1,400
Duwamish/Green	500	1,400
Elwha	320	2,000
Skokomish	250	1,300
Dungeness	200	460
Deschutes	170	400
Samish	120	190
Dosewallips	120	670
Hamma Hamma	80	500
Duckabush	80	570
Big Quilcene	70	180

Macroinvertebrate samples were collected at 20 sites from 4 river basins in September and October 2013 (Appendix A, Figure 1). Sites were selected from rivers draining to Puget Sound based on GIS analysis, field reconnaissance, and recommendations from regional aquatic science practitioners. Rivers chosen for this study had watershed areas greater than typical stream sites in the PSSB database (>80 mi^2). All sampling locations were located upstream of saltwater and or tidal influence.

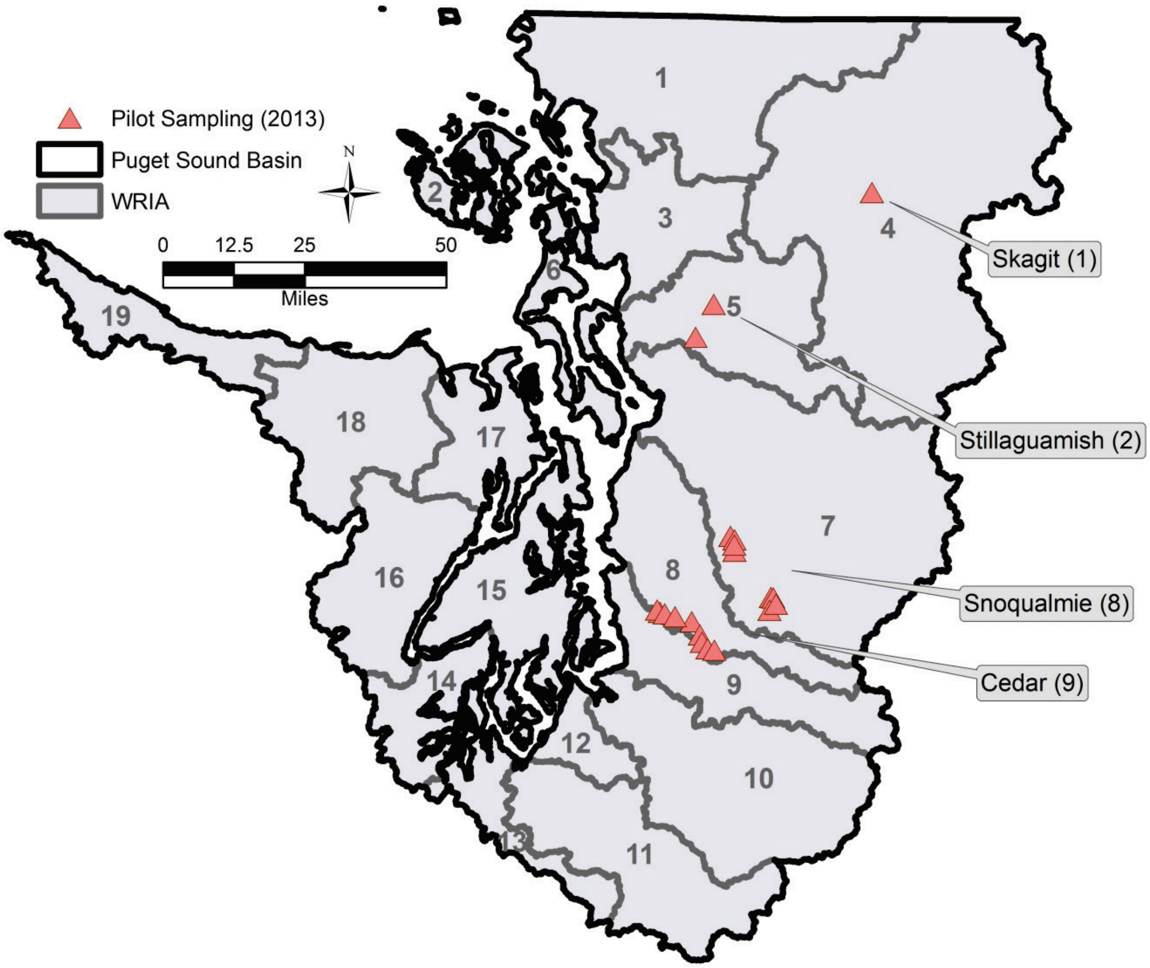

Figure 1. 2013 Puget Sound river sampling locations.

2.1.2 Pilot Field Collection Methods

Field operations to collect macroinvertebrate samples and record basic site information were completed by a minimum of two people. All collections were done using a D-frame kick net with a 500 µm mesh net from a 1 ft^2 area. A 500 µm mesh size is consistently used across all state and federal biological assessment programs in the Pacific Northwest and is recommended for use in stream bioassessment (Hayslip 2007). At each site eight 1-ft^2 collections were composited for a total of 8 ft^2 sampled area. Compositing combines multiple macroinvertebrate collections from the study reach into a single sample which is then sent to a taxonomic laboratory for enumeration and identification. Composite samples are routinely collected by state bioassessment programs across the United States (Carter and Resh 2001) and have the advantage of being less expensive to process than multiple samples per location.

Initial field collection was conducted using the Washington Department of Ecology's (Ecology) methods for wide streams and rivers (Merritt et al. 2010) which evolved from methods presented in Hayslip 2007, Peck et al 2006, Lazorchak et al. 2000. This methodology was implemented at four sites, but proved to be extremely time consuming (e.g., it could take up to 10 hours to sample one site). However, in the interest of collecting samples from as many sites as possible, the collection method was altered for the remaining 16 sites. At these locations riffles were targeted (instead of reach-wide transects) and samples were collected from a much shorter sampling reach.

The Ecology method, included establishing 11 transects within a reach. 1 ft^2 samples are collected from the littoral area of one river bank from 8 of the 11 transects, for a total sampled surface area of 8 ft^2. Transects were established at intervals twice the bankfull width or a maximum of 200-m apart for a maximum reach length of 2 km. Ecology's methods describe a procedure to randomly select which bank to sample, however during the 2013 sampling effort, one bank was often too deep or swift to sample. Therefore, logistical feasibility took precedence to determine where along each transect to sample; the distance from the nearest bank was measured using a laser rangefinder. The transect method can result in sampling both flowing and slack water habitats; however, in this pilot effort all samples were collected from areas with flowing water and hard substrate (e.g., cobble or gravel).

The non-Ecology method targeted relatively shallow, fast flowing habitat (e.g., generally less than < 0.6 m depth, riffle or run/glide). When possible, samples were collected from at least two riffles separated by pool or glide habitat. However, net placement was largely opportunistic based on balancing safe access with sufficient depth and distance from the river margins to assure samples were collected in permanently wet and flowing locations.

In all cases (Ecology and non-Ecology sampling method), eight 1-ft^2 collections were composited for a total of 8 ft^2 sampled area. Sampling was conducted while wading upstream if conditions permitted, or floating downstream if a boat was required for sampling. The sample contents were preserved in the field with 95% denatured ethanol.

2.1.3 Additional Field Data Collection

The focus of this effort was to collect macroinvertebrate samples; however, minimal habitat data that could be collected relatively efficiently were also collected. Field data sheets used to record this information are in Appendix B.

For each 1 ft^2 sample, substrate characteristics, distance from nearest bank, channel habitat type (pool, glide, riffle, rapid, or other), sample depth, and flow (fast or slack) were recorded. Substrate characteristics included measures of size and embeddedness.

Substrate size was assessed visually for the dominant and secondary size class for each 1 ft^2 sample area. Categories followed those used by Ecology (Merritt et al. 2010) including the following categories: smooth bedrock (>4 m), rough bedrock (> 4 m), large boulder (1 to 4 m), small boulder (250 mm to 1 m), cobble (64 to 250 mm), coarse gravel (16-64 mm), fine gravel (2 to 16 mm), sand (0.06 to 2 mm), or fines (< 0.06 mm, silt/clay/muck). Substrate embeddedness, defined as the fraction of a particle's surface that is surrounded by sand or finer sediments (< 2 mm) was estimated to the nearest 10 percent.
From the nearest bank to each sample, wetted width, bankfull width, and bankfull depth were measured using a laser rangefinder to the nearest tenth of a meter. Thalweg depth was initially collected in order to calculate a width to depth ratio, however at many transects or sites it was not possible to safely measure thalweg depth and this variable was dropped. Air and water temperature were recorded in degrees Celsius using a thermometer. Reach length was estimated to the nearest meter at most sites. A site sketch was drawn on the back of each data sheet highlighting direction of flow, collection locations, notable riparian disturbances, tributary confluences, access points, etc.

2.1.4 Pilot Taxonomic Laboratory Methods

Once all project samples were collected, they were transferred to Rhithron Biological Associates, Incorporated for sample processing and taxonomic identification. Rhithron's benthic macroinvertebrate sample processing includes taxonomic identification of macroinvertebrates, QA/QC procedures, and data upload to the PSSB. Upon arrival at the taxonomy laboratory, the samples were checked against the sample inventory sheet and COC information.

Standard sorting protocols (Plotnikoff and Wiseman 2001) using Caton subsampling devices (Caton 1991) were applied to each sample to achieve representative fixed-count 500 minimum subsamples. Subsampling is used to reduce the cost and time associated with processing benthic samples (Barbour et al. 1999) with the goal of providing an unbiased representation of a larger sample (Barbour and Gerritsen 1996). After the target number of organisms (500) was obtained in the subsample, the remainder of the sample material was scanned in the Caton tray for a maximum of 15 minutes to find any large or rare taxa that may have been missed during the subsampling procedures. These large and rare taxa were included in PSSB uploads and were used to calculate macroinvertebrate metrics.

Organisms were individually examined by certified taxonomists, using 10x – 80x stereoscopic dissecting scopes (Leica S8E and S6E) and identified to the lowest practical taxonomic level using appropriate published taxonomic references and keys. Identification, counts, life stages, and information about the condition of specimens were recorded and uploaded into the PSSB. The PSSB calculates the B-IBI and individual metrics for each site and also enables download of the raw taxonomic data which enables additional metric calculations.

2.2 Non-Pilot River Sampling Methods

As of fall 2014, the PSSB contained benthic macroinvertebrate data for nearly 5,500 site visits from over 1,500 sites throughout Washington State including 214 site visits from 156 sites designated as "rivers"[2]. Some additional data are available in projects designated as "private" and not widely available to the public. Permission was given to use mainstem river data from two private projects in this analysis including (1) King County's Chinook Bend monitoring on the Snoqualmie River, and (2) NOAA's monitoring on the Elwha River.

2.2.1 Identifying Non-Pilot River Data

Stream and river data for all public projects and the two private projects were downloaded on October 20, 2014. The following PSSB user-defined options were selected to download stream data: (1) replicates combined, (2) taxonomic resolution as defined by project metadata, and (3) 500 organism maximum count (i.e., subsampled when organism count is greater than 500).

Site visits were removed from consideration if they (1) were located outside the Puget Sound basin, (2) had fewer than 300 organisms in the composited visit sample, (3) were not the most recent visit for a particular site, and (4) did not have accurate basin delineations and landcover readily available. This culling process reduced the available site visits from 5,659 to 1,171 and of these, 49 were from sites with contributing watershed areas greater than 80 mi^2 (Figure 2).

[2] No standard has been established for what designates a river versus a stream in the PSSB and the distinction is left up to each project steward. Presumably rivers are larger, non-wadeable, higher order, and have larger watersheds however there does not seem to be a consistent threshold that distinguishes the current separation of streams and rivers in the PSSB.

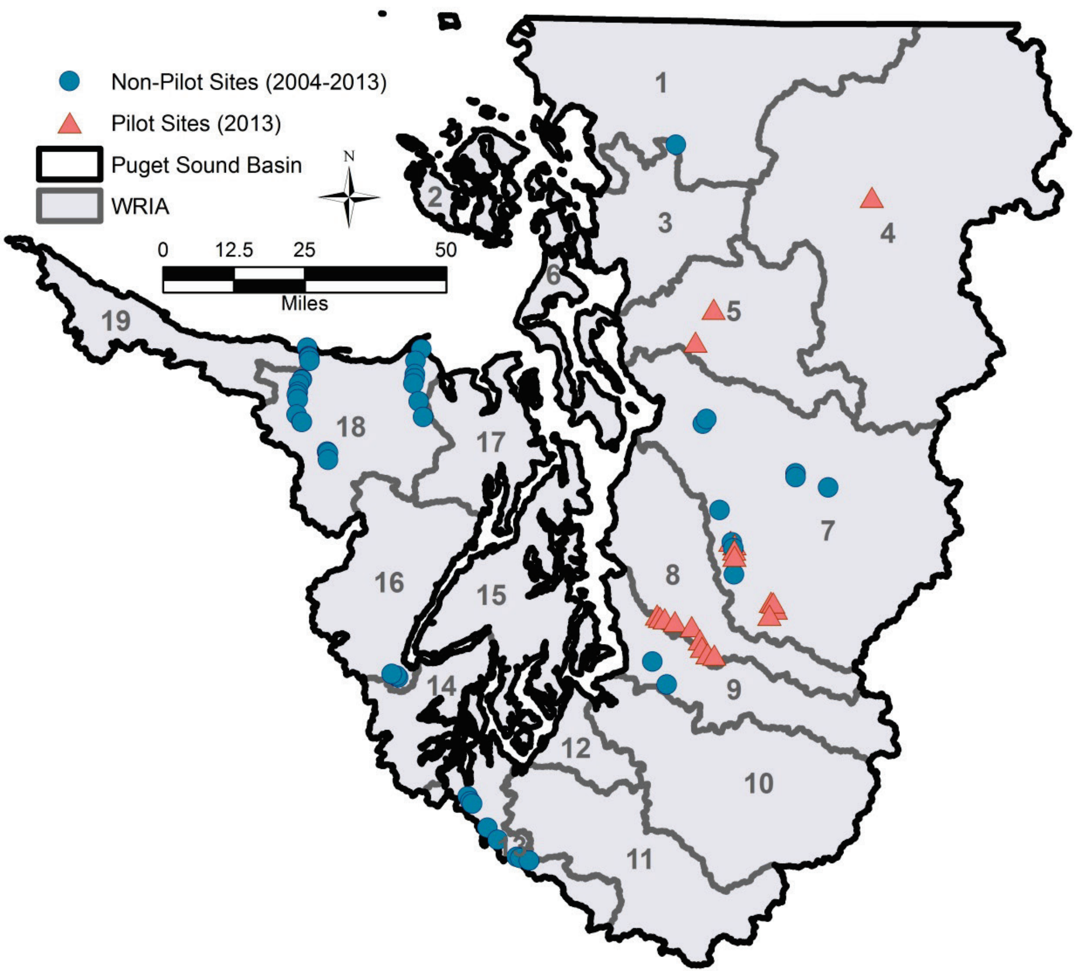

Figure 2. 2013 pilot and 2004-2013 non-pilot river sampling locations throughout Puget Sound.

2.2.2 Collection Methods Non-Pilot River Data

Collection methods varied for the 49 non-pilot river sites selected for further analysis and are summarized in Table 2. In most cases, collection methods were similar to the methods each agency uses on smaller streams where sample collection is focused in wadeable margins or riffles between late June and mid-October. Ecology's ambient and watershed health projects sampled reach-wide transects instead of riffles. Several studies have confirmed results from riffle targeted and reach wide methods are comparable (Gerth and Herlihy 2006, Rehn et al. 2007). Nets used included Surber samplers, d-frame kick nets, and slack samplers, but in all cases mesh size was 500 µm. The total surface area sampled was variable and included collection from 3, 6, 8, 9, or 13.5 ft^2. Taxonomic lab handling typically involved fine taxonomic effort (e.g., most organisms to lowest practical level typically genus or species, the standard taxonomic effort level specified by Ecology, see Appendices G and H in Adams 2010) and a targeted 500 count. However, data derived from two projects (Clallam County Streamkeepers and King County Chinook Bend) were based on coarse taxonomic effort (e.g., Chironomidae to family) and NOAA's Elwha sampling had a targeted 600 organism count. The counts were standardized to 500 organisms from PSSB downloads for subsequent analysis. For more sample collection details see the Puget Sound collection methods matrix table (Wilhelm 2013).

Table 2. Summary of macroinvertebrate collection methods for pilot (top 2 rows) and non-pilot river data.

# Sites	Agency/Project	Timing	Habit at	Net Type	Area (Ft^2)	Taxa Effort	Target Count	Reference
4	King County – DNRP/ Puget Sound Rivers	Sept 4- Sept 20	Reach wide	D-net	8	Fine	800	Merritt et al. 2010, Section 2.1.2
16	King County – DNRP/ Puget Sound Rivers	Sept 24- Oct 15	Riffles	D-net	8	Fine	500	Section 2.1.2
7	Clallam County/ Streamkeepers	Sept 1 - Oct 15	Riffles	Surber	9	coarse	500	Chadd 2011
1	King County - DNRP/ Ambient Monitoring	Aug 1 - Sept 15	Riffles	Surber	8	fine	500	King County 2002
2	King County - DNRP/ Chinook Bend	early Sept	Riffles	Surber	6	coarse	500	
19	NOAA/ Elwha Benthic Invertebrates	July - Sept	Riffles	Slack	13.5	fine	600	Morley et al. 2008
2	Skokomish Tribal Nation/ Benthic Invertebrates	late Aug - mid Oct	Riffles	Surber	8	fine	500	
4	Snohomish County/ Ambient	Aug - Sept	Riffles	Surber	3 or 8	fine	500	
1	Thurston County/ Macroinvertebrate Monitoring	late June - mid Aug	Riffles	Surber	9	fine	500	
1	Ecology/ Ambient	July 1- Oct 15	Reach wide	D-net	8	fine	500	
6	Ecology/ TMDL Effectiveness	July 1- Oct 15	Riffles	D-net	8	fine	500	Collyard and Von Prause 2009
6	Ecology/ Watershed Health	July 1- Oct 15	Reach wide	D-net	8	fine	500	Merritt et al. 2010

2.3 Data Analysis Methods

2.3.1 Landcover and Disturbance Gradients

Landuse/landcover data were calculated and sites were categorized based on watershed disturbance at two spatial scales. Landcover was calculated following the methods outlined in King County 2013b for multiple spatial scales including the entire contributing watershed (watershed or WS) and a local watershed derived by intersecting a 1km radius circle with the contributing watershed (local). Two disturbance gradients were used: percent watershed urbanization and local urbanization. Percent watershed urbanization was selected as the human disturbance gradient to calibrate metric response in recent B-IBI recalibration efforts because it was highly correlated with B-IBI and it is a simple and effective measure for summarizing site condition that is easy to apply and interpret (see

King County 2013c, King County 2014a). Percent local urbanization was also highly correlated with B-IBI scores for sites used in the recalibration effort and covers a larger range of disturbance for the rivers targeted in this report.

2.3.2 Candidate Metric Evaluation

The ten metrics that comprise the Puget Lowland B-IBI were assessed, in addition to a select set of 63 additional metrics (Table 3) to determine which, if any, effectively distinguish impairment in larger Puget Sound water bodies (i.e., streams or rivers with drainage areas greater than 80 square miles). B-IBI metrics were evaluated using both values and scores. 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 can be influenced by taxonomic effort; however they remain constant regardless of the scoring criteria applied. The metric score is the standardized interpretation of that count or percent (e.g., 0–10). Non-B-IBI metrics were evaluated only based on metric values.

Table 3. Additional non B-IBI metrics evaluated for suitability to detect disturbance in Puget Sound rivers.

Metric Category	# of Metrics	Metrics
Percent individuals	35	Amphipoda, Cheumatopsyche, Crustacea, Gastropoda, Hemiptera, Hirudinea, Hydropsyche + Cheumatopsyche, Hydropsyche, Hydroptilidae, Mollusca, Non-Hydropsyche Hydropsychidae, Pteronarcys, Baetidae, Baetis, Chironomidae, Coleoptera, Diptera, Elmidae, Ephemeroptera, EPT, Glossosomatidae, Hirudinea + Oligochaeta, Hydropsychidae, Insecta, Non Insect, Non-Baetis Ephemeroptera, Non-Hydropsyche + Cheumatopsyche Trichoptera, Oligochaeta, Perlodidae, Plecoptera, Rhyacophilidae, Simuliidae, Top 1 dominance, Top 5 dominance, Trichoptera
Abundance	12	Antocha, Attenella delantala, Dicranota, Drunella doddsii, Drunella spinifera, Ecclisomyia, Epeorus sp., Pteronarcys sp., Chironominae, EPT, Oligochaeta, Zapada sp.
Richness	12	Crustacea, Hemiptera, Hydropsychidae, Mollusca + Crustacea, Mollusca, Odonata taxa, Chironomidae, Coleoptera, Diptera, Elmidae, Ephemerellidae, EPT
Other	4	EPT/Chironomidae ratio, Number Individuals per taxon, Taxa in Chironomidae (%), Taxa in EPT (%)

The multistep screening process used to evaluate metrics followed the methods of Ode et al. (2005) and is similar to other metric and index evaluation studies (e.g., Stoddard et al. 2008, Royer et al. 2001). These steps include assessing (1) range and distribution, (2) responsiveness to disturbance variables, and if any metrics pass the range and responsiveness tests then (3) correlation with other responsive metrics.

Metrics were evaluated for range and distribution using the criteria established by Stoddard et al. 2008. That is, a metric was eliminated if its range was less than four or if more than 33% of the sample had values equaling zero.

The ability to discriminate changes in biological communities resulting from human impacts is one of the most important qualities of a reliable biological index and its component metrics (Klemm et al. 2002; Karr and Chu 1999). Responsiveness to disturbance was evaluated by correlating metrics (Spearman's rho) with disturbance and by plotting each candidate metric against the two disturbance gradients. Following the criteria established by Ode et al. (2005), only metrics with a linear or wedge shaped relationship with disturbance gradients were considered responsive to disturbance.

The final step in evaluating candidate metrics is reducing redundancy and maintaining independence in the final selected metrics. This was done by correlating metrics with each other. No strict cutoff is proposed here; however, other studies have used different criteria to determine if metrics are redundant: Stoddard et al. 2008 used a cutoff of $|r|>0.71$, but only from reference data; Ode et al. 2005 used $|r|>0.70$ from all data; and Royer et al. 2001 used $|r|\geq 0.90$.

3.0 RESULTS

Sample collection was conducted at 20 sites on 4 Puget Sound rivers in September and October 2013 (Figure 2 above). Ecology's reach-wide transect method (Merritt et al. 2010) was used for sample collection at 4 sites before shifting to riffle-based sampling for the remaining 16 sites (see Appendix C). Two sites had very low organism counts (13 at NF_Stilly_Cicero and 131 at SF_Stilly) both on the Stillaguamish River. These two sites were excluded from further analysis due to the low abundances. 67 sites were retained for further analysis (18 pilot and 49 non-pilot river sites). The following sections describe the site and watershed characteristics for these 67 sites. Also described is a metric evaluation of both B-IBI component metrics and 63 additional metrics.

3.1 Site and Watershed Characteristics

Of the 67 sites identified for use in this study, 62 are designated as "rivers" and 5 as "streams" in the PSSB. The sites cover 8 (out of 19) Puget Sound water resource inventory areas (WRIAs: 1, 4, 7, 8, 9, 13, 16, and 18), 8 counties (Whatcom, Skagit, Snohomish, King, Thurston, Mason, Jefferson, and Clallam), and 4 ecoregions (Puget Lowland, Cascades, North Cascades, and Coastal). Sites ranged from 4 to 1,443 feet in elevation and from 81 to 962 square miles in size (Table 4). See Appendix D for watershed characteristics and B-IBI scores for all 67 sites.

Table 4. Summary statistics for site and watershed characteristics (n=67)

				Watershed			Local (1 km)		
Statistic	**Watershed Area (sq mi)**	**Elevation (ft)**	**Mean Precip (in)**	**Urban (%)**	**Ag (%)**	**Natural (%)**	**Urban (%)**	**Ag (%)**	**Natural (%)**
Min	81.0	4.2	50.8	0.0	0.0	52.6	0.0	0.0	1.1
Max	961.5	1442.7	131.3	28.8	6.2	95.8	95.3	65.1	100.0
Median	178.0	187.9	99.9	1.0	0.3	90.1	5.3	1.9	73.7
Average	252.4	267.1	93.6	2.5	1.1	88.7	13.5	9.7	68.5
Std Dev	176.9	314.2	23.6	4.2	1.7	6.1	18.4	15.1	26.5

Watershed urbanization ranged from between 0 and 28.8%; however, at all but one of the 67 sites watershed urbanization less than 10% (Figure 3). Because of the large size of sampled watersheds (> 80 mi^2) localized human impacts such as urbanization or agriculture can be overshadowed by large expanses of forests, wetlands, shrubs, and grasslands ("natural" landcover). Local watershed urbanization was more evenly dispersed and ranged between 0 and 95.3%.

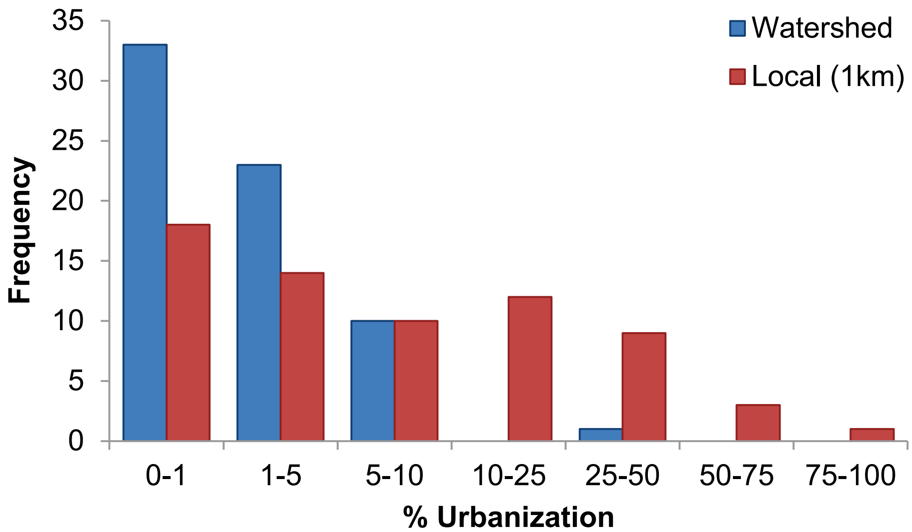

Figure 3. Histogram of watershed or local percent urbanization for 67 Puget Sound rivers sites.

85% of the samples were collected from riffle habitat, while the remaining samples were collected from glide habitat. All samples were collected in water averaging 1 foot deep (range 0.7 to 2.0 ft). Swift flow conditions precluded sampling in any deeper waters. The average wetted width of sampled rivers was 160.5 feet (range 53.8 to 767.7 ft). Substrate characteristics such as embeddedness or dominant and subdominant substrate were estimated using best professional judgment for each 1 ft^2 collection. Embeddedness was typically low with an average of 12.5% across all 1 ft^2 collections. 52% of the sample collections were dominated by cobble substrate (54-250 mm diameter, tennis ball to basketball sized), while 48% were dominated by coarse gravel substrate (16 – 64 mm, marble to tennis ball). One collection (<1%) was dominated by fine gravel (2 – 16 mm, ladybug to marble). The subdominant substrate was only slightly more diverse with 27% cobble, 46% coarse gravel, 21% fine gravel, 4% sand (0.06 – 2 mm, gritty to ladybug), and almost 2% small boulders (250 mm – 1 m, larger than a basketball).

3.2 Existing B-IBI and Component Metrics

The range in metric values and scores for the ten B-IBI component metrics at these locations was sufficient (>4 or < 33% of values = 0) (Table 5). Long-lived richness and Trichoptera richness metrics had the smallest range in values (8 and 9), whereas taxa richness values ranged from 15 to 63 (range 48) and percent dominant ranged from 20.7 to 94.8% (range 74.1%). Nine of the ten B-IBI component metrics had scores across the entire potential range of 0 to 10. Long-lived richness had a maximum score of 8.8 at river sites. B-IBI scores ranged from a low of 12.3 to a high of 90.6, spanning condition categories from very poor to excellent.

Table 5. Summary statistics for B-IBI metric values and scores for 67 Puget Sound river sites.

Metric	Values					Scores				
	Range	Min	Max	Avg	Std Dev	**Range**	Min	Max	Avg	Std Dev
Taxa Richness	48	15	63	40.2	11.1	10	0	10	5.3	3.1
Ephemeroptera Richness	14	0	14	7.6	2.7	10	0	10	8.4	2.5
Plecoptera Richness	10	0	10	5.2	2.1	10	0	10	5.9	2.8
Trichoptera Richness	9	1	10	5.2	2.1	10	0	10	5.2	2.6
Clinger Richness	30	6	36	20.7	6.0	10	0	10	7.6	2.7
Long-Lived Richness	8	1	9	4.5	1.9	8.8	0	8.8	3.2	2.3
Intolerant Richness	11	0	11	4.9	2.4	10	0	10	6.7	3.1
Percent Dominant	74.1%	20.7%	94.8%	53.2%	14.9%	10	0	10	4.9	3.3
Percent Predator	34.0%	0.4%	34.4%	9.6%	7.3%	10	0	10	4.1	3.1
Percent Tolerant	53.8%	0.0%	53.8%	4.3%	8.3%	10	0	10	9.0	1.7
B-IBI	N/A	N/A	N/A	N/A	N/A	78.3	12.3	90.6	60.3	17.2

The ten metrics and overall B-IBI have large scoring ranges; however, the distribution of the scores is variable across metrics. Four metrics including Ephemeroptera richness, clinger richness, intolerant richness, and percent tolerant are skewed towards high metric scores between 9 and 10. One metric (long-lived richness) is skewed towards low metric scores of between 0 and 3 (Figure 5). Cumulatively this results in over half the sites (36) having scores in the range of 60-80 (condition category of very good).

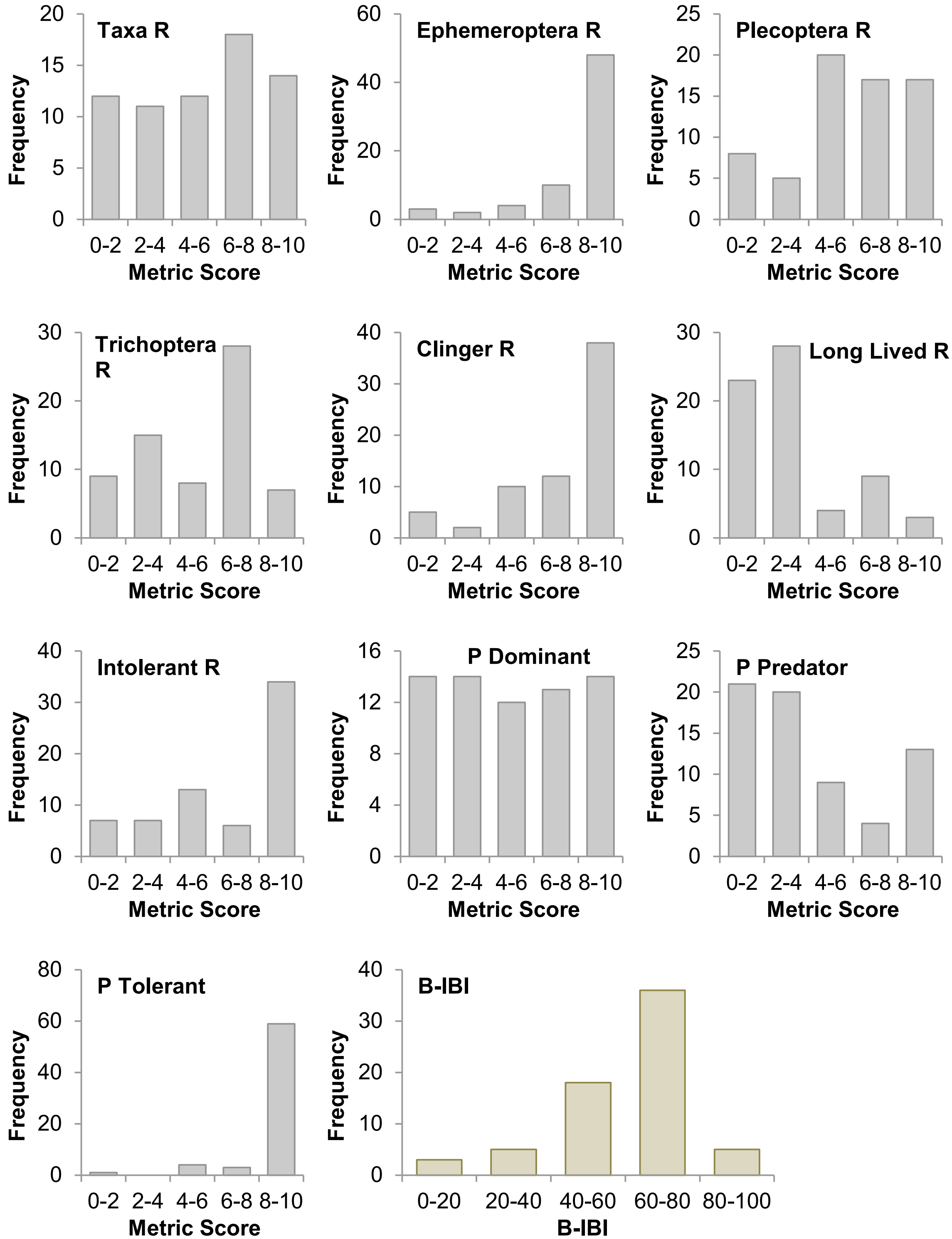

Figure 4. Frequency distributions of component metric scores and B-IBI (n=67).

Metric scoring adjustments may be appropriate for metrics where the range and distribution of metric values has shifted relative to the smaller stream data used to calibrate the existing B-IBI (King County 2014a). The data set used to calibrate the B-IBI was based primarily on small streams (watershed area 0.04 to 550 square miles), although 7 of the calibration watersheds were larger than the 80 square miles drainage area threshold used to identify rivers for this effort. The mean, median, and range of each of the ten B-IBI metrics were compared for the calibration (n = 856) and river (n = 67) data sets (Table 6). Seven of the ten metrics had significantly different means (see Appendix E for metric box plots). Taxa, Ephemeroptera, and clinger richness displayed some of the greatest increases in mean metric values for the river data set relative to the calibration data set (taxa +11.1, Ephemeroptera +3.2, clinger +6.8); percent tolerant had a large decrease (-10.1). If the range of data in the river data set is representative of the population of Puget Sound rivers, then scoring adjustments are recommended.

Table 6. Summary statistics of the B-IBI calibration data set and the river data set explored in this effort.
Based on metric values. 1-sided test: * significant at p< 0.05, ** significant at p<0.01.

Metric	Calibration Data (n = 856)			River Data (n = 67)		
	Mean	Median	Range	Mean	Median	Range
Taxa Richness**	29.1	29	3 - 70	40.2	39	15 - 63
Ephemeroptera Richness**	4.3	4	0 - 13	7.6	8	0 - 14
Plecoptera Richness	4.6	5	0 - 14	5.2	6	0 - 10
Trichoptera Richness	5.1	5	0 - 13	5.2	6	1 - 10
Clinger Richness**	13.9	14	0 - 31	20.7	21	6 - 36
Long-Lived Richness**	5.8	6	0 - 17	4.5	4	1 - 9
Intolerant Richness**	2.9	2	0 - 14	4.9	6	0 - 11
Percent Dominant	60.5	59.6	22.7 - 98.7	53.2	54	20.7 - 94.8
Predator Percent	9.9	8.2	0 - 54.8	9.6	7	0.4 - 34.4
Tolerant Percent**	14.5	5.8	0 - 87.6	4.3	1.2	0 - 53.8

There was no significant relationship between B-IBI and either watershed or local urbanization (Figure 6, p>0.05, Spearman's rho 0.068 for watershed and 0.111 for local). Similarly, none of the component metrics showed a strong correlation with watershed or local urbanization (Table 7; see Appendices F and G for plots). The two percent-based metrics (dominant and predator) were not significantly correlated to disturbance. The remaining eight metrics were significantly correlated to at least one of the disturbance scales. However, four richness metrics (taxa, Trichoptera, clinger, and long lived richness) had responses that were opposite of what was expected. For example, taxa richness increases as watershed disturbance increases whereas taxa richness is expected to decrease in these circumstances. The remaining four metrics (Ephemeroptera, Plecoptera, and intolerant richness and percent predator) had significant correlations with disturbance in the expected direction. These same four metrics also exhibited weak wedge shaped relationships of B-IBI with human disturbance gradients and warrant further exploration for use in a river B-IBI.

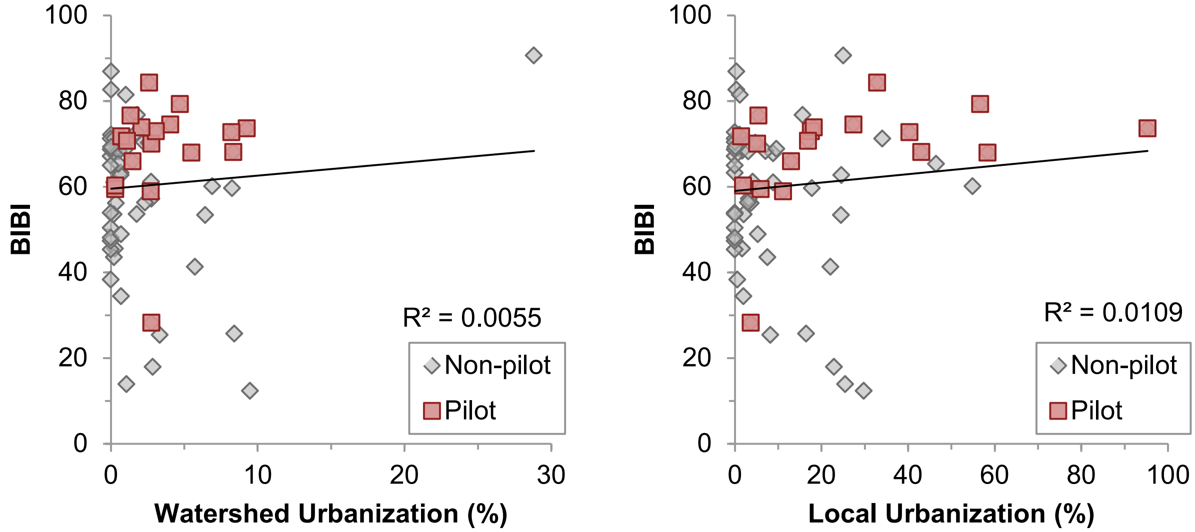

Figure 5. B-IBI response to watershed or local urbanization in Puget Sound rivers (n=67).

Table 7. Spearman's Rho correlation coefficient for B-IBI metrics and disturbance. Based on metric values. 1-sided test: * significant at p< 0.05, ** significant at p<0.01.

Metric	Expected Response to Disturbance	WS Urban (%)	Local Urban (%)
Taxa Richness	Decrease	.283*	.194
Ephemeroptera Richness	Decrease	-.247*	-.314**
Plecoptera Richness	Decrease	-.265*	-.111
Trichoptera Richness	Decrease	.328**	.263*
Clinger Richness	Decrease	.232*	.160
Long-Lived Richness	Decrease	.400**	.306**
Intolerant Richness	Decrease	-.387**	-.287**
Percent Dominant	Increase	-.039	-.106
Predator Percent	Decrease	-.527**	-.375**
Tolerant Percent	Increase	.027	.040
B-IBI Score	Decrease	.068	.111

3.3 Additional Candidate Metric Testing

63 additional metrics mostly derived using taxonomy or taxonomic hierarchy information were calculated (Table 8; references consulted for potential metrics include: Black and MacCoy 1999, Cole 2013, Royer et al. 2001, Flotemersch et al. 2006a, Ode et al. 2005, Cover et al. 2008 and Stoddard et al. 2008). Based on the range criteria, 26 metrics were eliminated because they were either too skewed towards zero values (greater than 33% zero values) or had an insufficient range of values (less than 4).

Table 8. Range and zero values for 63 candidate metrics. Metrics were eliminated from further consideration if 0 values were more than 33% or range was less than 4 and are noted as "omit".

Metric	N	0 values (%)	Range	Range		Note
				Min	Max	
Percent individuals						
Amphipoda	67	88.1	1.4	0.0	1.4	omit
Cheumatopsyche	67	97.0	2.0	0.0	2.0	omit
Crustacea	67	76.1	1.8	0.0	1.8	omit
Gastropoda	67	68.7	22.0	0.0	22.0	omit
Hemiptera	67	95.5	4.4	0.0	4.4	omit
Hirudinea	67	95.5	1.0	0.0	1.0	omit
Hydropsyche + Cheumatopsyche	67	38.8	36.2	0.0	36.2	omit
Hydropsyche	67	38.8	36.2	0.0	36.2	omit
Hydroptilidae	67	68.7	21.0	0.0	21.0	omit
Mollusca	67	64.2	22.0	0.0	22.0	omit
Non-Hydropsyche Hydropsychidae	67	65.7	2.0	0.0	2.0	omit
Pteronarcys	67	92.5	0.2	0.0	0.2	omit
Baetidae	67	1.5	44.4	0.0	44.4	
Baetis	67	6.0	36.6	0.0	36.6	
Chironomidae	67	0.0	75.0	0.4	75.4	
Coleoptera	67	9.0	38.0	0.0	38.0	
Diptera	67	0.0	78.6	1.6	80.2	
Elmidae	67	10.4	38.0	0.0	38.0	
Ephemeroptera	67	1.5	86.6	0.0	86.6	
EPT	67	0.0	96.2	0.8	97.0	
Glossosomatidae	67	32.8	44.9	0.0	44.9	
Hirudinea + Oligochaeta	67	11.9	69.2	0.0	69.2	
Hydropsychidae	67	31.3	36.2	0.0	36.2	
Insecta	67	0.0	73.6	25.4	99.0	
Non Insect	67	0.0	73.6	1.0	74.6	
Non-Baetis Ephemeroptera	67	3.0	77.4	0.0	77.4	
Non-Hydropsyche + Cheumatopsyche Trichoptera	67	0.0	74.0	0.2	74.2	
Oligochaeta	67	13.4	69.2	0.0	69.2	
Perlodidae	67	19.4	9.2	0.0	9.2	
Plecoptera	67	3.0	31.2	0.0	31.2	
Rhyacophilidae	67	17.9	6.4	0.0	6.4	
Simuliidae	67	28.4	53.8	0.0	53.8	
Top 1 dominance	67	0.0	61.8	7.4	69.2	
Top 5 dominance	67	0.0	67.5	30.1	97.6	
Trichoptera	67	0.0	74.0	0.2	74.2	
Abundance						
Antocha	67	73.1	20	0	20	omit
Attenella delantala	67	86.6	11	0	11	omit
Dicranota	67	77.6	11	0	11	omit
Drunella doddsii	67	61.2	54	0	54	omit

Metric	N	0 values (%)	Range	Range		Note
				Min	Max	
Drunella spinifera	67	98.5	11	0	11	omit
Ecclisomyia	67	95.5	3	0	3	omit
Epeorus sp.	67	62.7	228	0	228	omit
Pteronarcys sp.	67	92.5	1	0	1	omit
Chironominae	58	0.0	303	1	304	
EPT	67	0.0	481	4	485	
Oligochaeta	67	13.4	346	0	346	
Zapada sp.	67	29.9	63	0	63	
Richness						
Crustacea	67	76.1	2	0	2	omit
Hemiptera	67	95.5	1	0	1	omit
Hydropsychidae	67	31.3	2	0	2	omit
Mollusca + Crustacea	58	55.2	6	0	6	omit
Mollusca	58	60.3	5	0	5	omit
Odonata taxa	67	100.0	0	0	0	omit
Chironomidae	58	0.0	21	2	23	
Coleoptera	67	9.0	6	0	6	
Diptera	58	0.0	23	5	28	
Elmidae	67	10.4	6	0	6	
Ephemerellidae	67	9.0	6	0	6	
EPT	67	0.0	26	3	29	
Other (ratio, calculations)						
EPT/Chironomidae ratio	67	0.0	227.0	0.0	227.0	
Number Individuals per taxon	67	0.0	28.7	4.7	33.3	
Taxa in Chironomidae (%)	67	0.0	47.0	3.0	50.0	
Taxa in EPT (%)	67	0.0	61.4	8.6	70.0	

The 37 remaining metrics were evaluated for their correlation with watershed or local urbanization (Table 9). Twenty candidate metrics had significant Spearman's Rho correlations with either watershed or local urbanization (14 individual metrics that represent percent [Baetidae, Baetis, Coleoptera, Elmidae, Ephemeroptera, Glossosomatidae, Hydropsychidae, Insecta, Non-Insect, Non-Baetis Ephemeroptera, Non-Hydropsyche and Cheumatopsyche Trichoptera, Plecoptera, Rhyacophilidae, and Trichoptera]; 2 abundance metrics [Chironominae and Zapada sp.], 3 richness metrics: [Coleoptera, Elmidae, and Ephemerellidae], and one additional metric [percent taxa in EPT]).

Table 9. Spearman Rho's correlation coefficient for non B-IBI candidate metrics and disturbance.
Metrics with significant correlations based on 1-sided tests were considered further (* significant at p< 0.05, ** significant at p<0.01).

Metric	WS Urban	Local Urban
Percent Individual		
Baetidae	-.258*	-.332**
Baetis	-.321**	-.438**
Chironomidae	.017	.147
Coleoptera	.469**	.313**
Diptera	-.011	.114
Elmidae	.466**	.333**
Ephemeroptera	-.290**	-.489**
EPT	-.034	-.196
Glossosomatidae	.580**	.376**
Hirudinea + Oligochaeta	-.025	.194
Hydropsychidae	.485**	.349**
Insecta	-.094	-.290**
Non-Insect	.094	.290**
Non-Baetis Ephemeroptera	-.262*	-.401**
Non-Hydropsyche + Cheumatopsyche Trichoptera	.475**	.487**
Oligochaeta	-.041	.198
Perlodidae	-.065	.068
Plecoptera	-.407**	-.304*
Rhyacophilidae	-.384**	-.262*
Simuliidae	.030	-.053
Top 1 dominance	-.020	-.068
Top 5 dominance	-.026	-.073
Trichoptera	.535**	.454**
Abundance		
Chironominae	.201	.268*
EPT	-.039	-.171
Oligochaeta	-.038	.211*
Zapada sp.	-.289*	-.146
Richness		
Chironomidae	.172	.190
Coleoptera	.613**	.442**
Diptera	.119	.168
Elmidae	.578**	.480**
Ephemerellidae	-.387**	-.404**
EPT	-.078	-.124
Other		
EPT/Chironomidae ratio	-.039	-.190
Number Individuals per taxon	-.225*	-.126
Taxa in Chironomidae (%)	.086	.021
Taxa in EPT (%)	-.482**	-.380**

The twenty two metrics with significant correlations were plotted against watershed and/or local urbanization to evaluate their responsiveness to disturbance gradients

(Appendices H and I). None of these correlations were especially strong, however, seven metrics may warrant further consideration based on their wedge shaped relationship with local urbanization including Ephemerellidae richness and Baetidae, Ephemeroptera, Baetis, Plecoptera, Rhyacophilidae, and non-Baetis Ephemeroptera percent individuals.

3.4 Redundancy Testing

Redundancy of the eleven metrics (4 B-IBI, 7 non B-IBI) that may respond to disturbance gradients was evaluated based on correlation coefficients (Table 10). Three pairs of metrics were redundant: (1) percent Ephemeroptera and percent non-Baetis Ephemeroptera individuals (Spearman's Rho 0.902), (2) percent Baetis and percent Baetidae individuals (Spearman's Rho 0.876), and (3) percent Plecoptera individuals and percent predators (Spearman's Rho 0.751).

Table 10. Spearman's Rho correlation coefficients for pairs of metrics to assess redundancy. Based on metric values. 1-sided test: * significant at p< 0.05, ** significant at p<0.01.

Metric	Ephemeroptera Richness	Plecoptera Richness	Intolerant Richness	% Predator	% Ephemeroptera Individuals	% Baetidae percent Individuals	% Baetis Individuals	% Non-Baetis Ephemeroptera Individuals	Ephemerellidae Richness	% Plecoptera Individuals
Plecoptera Richness	.116									
Intolerant Richness	.567**	.392**								
% Predator	.170	.290**	.425**							
% Ephemeroptera Individuals	.497**	.155	.421**	.238*						
% Baetidae percent Individuals	.291**	.142	.056	.164	.642**					
% Baetis Individuals	.305**	.234*	.188	.190	.655**	.876**				
% Non-Baetis Ephemeroptera Individuals	.532**	.169	.459**	.239*	.902**	.387**	.323**			
Ephemerellidae Richness	.682**	.211*	.671**	.392**	.483**	.114	.188	.549**		
% Plecoptera Individuals	.130	.432**	.430**	.751**	.329**	.303**	.335**	.295**	.181	
% Rhyacophilidae Individuals	.320**	.409**	.477**	.423**	.318**	.360**	.318**	.257*	.424**	.347**

4.0 DISCUSSION

4.1 Logistical Considerations and Limitations

River sampling in general presents different considerations and challenges than stream sampling. For example, additional gear is frequently required including boats (raft or motorized), dry suits or wet suits, personal flotation devices. When a boat is necessary, a float plan must be created and approved, launch and take out locations need to be identified ahead of sampling and additional time must be allowed for shuttling vehicles. Safety is one of the most prominent considerations. Deep water, cold temperatures, fast flows, and strainers all represent potential dangers if not properly prepared and trained for. The lower reaches of many Puget Sound Rivers are influenced by saltwater intrusion and low gradients often create habitat conditions dominated by fine substrate and slack water rather than the coarse gravel and flowing water more commonly targeted for macroinvertebrate sampling.

The fall 2013 pilot sampling presented its own challenges. Pink salmon (*Oncorhynchus gorbuscha*) return to Washington State in odd years. 2013 was predicted to be a record year with 6.2 million pink salmon forecast to return to Puget Sound, up 1.1 million from the 2011 predictions (WDFW 2013a). This included big returns in three of the rivers included in this effort: 1.2 million in the Skagit, 409,700 in the Stillaguamish, and 988,621 in the Snohomish (WDFW 2013b, Spokesman-Review 2013). As a result, field staff avoided sample collection in areas with salmon redds from any species, but with the large number of spawning pink salmon, this presence of redds sometimes greatly restricted where sampling could be conducted.

In addition to spawning salmon, September rain necessitated adjustments to planned sample timing or locations (Appendices J, K, and L). The rainiest September day on record (1.71" on 9/28/13) contributed to making September 2013 the rainiest September month on record in both Olympia (9.14" for Sept 2013 breaking the old record of 7.59" in 1978; normal is 1.71") and Seattle (6.16" for 2013 breaking the record of 5.95" from 1978; normal is 1.5") (Sistek 2013, King 5 News 2013). Excess precipitation caused safety concerns associated with working during fast water velocities and powerful high flows. In addition, challenges were also experienced when gravel bars that had been above the water surface just days before and for much of the summer were now the only areas that could feasibly be sampled based on water depth and velocity constraints. For example, the Skagit River at Marblemount was 1.1 feet higher on October 7th than it was in mid-September, while the Middle Skagit River at Concrete was over 3 feet higher. These above-normal flows eliminated a significant amount of habitat that could have previously been sampled because it necessitated sampling at depths greater than 2 feet deep to access substrates that were wet throughout the summer low flows. Sampling in these conditions would not likely be representative of the true macroinvertebrate community condition. Sampling was canceled or postponed when flows were elevated. The duration of elevated flows were extended in dam-operated basins because dam-operators maximized flood control capacity by emptying out reservoirs following the rain events to make room for anticipated late fall and winter rains. These conditions prevented additional previously scheduled sampling on the Skagit River and restricted sampling on other Puget Sound rivers that otherwise may have been considered as alternative sites.

4.2 Suitability of B-IBI for Puget Sound Rivers and Recommendations for Additional Investigation

The results presented in this report are not a resounding endorsement to utilize the Puget Lowland B-IBI on Puget Sound rivers to evaluate river health or condition, however more work needs to be done. While the range of metric values and scores were appropriately broad, there were only weak wedge-shaped relationships with four of the metrics (taxa, Trichoptera, clinger, and long-lived richness) and urbanization at the watershed or local scale. Additional candidate metrics did not perform much better. Only five mayfly metrics (percent individuals: Baetis, Baetidae, Ephemeroptera, and non-Baetis Ephemeroptera and Ephemerellidae richness) and percent Plecoptera individuals and percent Rhyacophilidae individuals showed the potential to respond to disturbance based on this set of data.

This effort relied heavily on existing data. Collection methods associated with these data were variable which may have influenced data comparisons. Blocksom and Flotemersch (2005) compared six nonwadeable collection methods and concluded that sampling methods were not interchangeable and influence the ability to detect certain stressors. The collection area evaluated was particularly inconsistent (Table 2) ranging from 3 to 13.5 ft^2. A 2011 study of Puget Sound streams verified the comparability of 3 and 8 ft^2 collection areas (King County 2014b); however, the maximum watershed size in that study was 76 mi^2 (average of 13.3 mi^2). Collection area could have a more significant impact on river samples because rivers are expected to be more heterogeneous (Flotemersch 2006a). Therefore, it may be necessary to sample larger surface areas to capture this heterogeneity or sample many sites on a single river to characterize macroinvertebrate richness (Hughes et al. 2012, Hughes et al. 2013). This hypothesis could be tested with additional sample collection and by keeping 1 ft^2 samples separate to increase the potential combinations of post-sampling compositing. These data would provide a mechanism to better understand within site variability (see Flotemersch et al. 2006b or Blocksom and Flotemersch 2005 for potential approaches).

The assembled data set may not be representative of the true population of Puget Sound rivers. Over 85% (54 out of 63) of the site visits assembled represent only 5 Puget Sound Rivers (Elwha, Dungeness, Cedar, Snoqualmie, and Deschutes all had seven more sites; see Figure 2). This skewed sampling distribution could have biased results compared to a more evenly distributed or randomized sampling design across all Puget Sound rivers. On the other hand, the assembled data set consisting of site visits from 8 WRIAs, 8 counties, 4 ecoregions, elevations ranging from 4-1,443 feet and watershed areas from 81-962 mi^2 (Table 4) may encompass too much natural variability that masks any signal from disturbance. It may be necessary to further parse the data set and look for signals from streams with less diverse characteristics. Additional culling criteria may be appropriate such as excluding sites less than a certain distance downstream of large impoundments or major tributary junctions because these features may mask disturbance signals.

Stressors and drivers operate at multiple spatial scales to influence the ecological condition of rivers. This effort focused on watershed and local (1-km) watershed urbanization because these data were already calculated and readily available. However, whole watershed landcover metrics don't exhibit a wide range in values (Figure 3) and local metrics may over emphasize neighboring landcover without taking into account upstream drivers. Additional evaluation of candidate metrics may be appropriate for disturbance gradients at intermediate spatial scales such as 5-, 10-, and 25-km watersheds or in an index that combines impacts from multiple spatial scales.

All streams and rivers are exposed to cumulative impacts from all upstream disturbances. Percent watershed urbanization was selected as the human disturbance gradient to calibrate metric response in recent B-IBI recalibration efforts because it was highly correlated with B-IBI at stream sites and it is a simple and effective measure for summarizing site condition that is easy to apply and interpret (see King County 2013c, King County 2014a). However a disturbance gradient based on one variable (urbanization) may be too simplistic to capture the complexities of stressors on macroinvertebrate communities and ecological condition. It may be necessary to re-evaluate how to summarize human disturbance and a composite measure of disturbance that incorporates measures may be more appropriate for Puget Sound rivers (see King County 2013c for derivation of watershed urbanization as a single measure of disturbance).

4.3 Recommendations and Next Steps

The 2013 pilot sampling effort and subsequent analysis is a first step towards increasing the scope of B-IBI beyond wadeable lowland streams. However, additional work is necessary before any decisive conclusions can be reached. Recommended next steps include the following (with relevant questions or considerations in italics):

- Conduct a literature review of river sampling and analysis methods for biomonitoring to understand what is done elsewhere, how, and why.

  Are other entities using multimetric, predictive modeling, or other analysis methods? Where are river invertebrate multimetric indices already in use? Are the same metrics and scoring criteria typically applied for wadeable and non-wadeable streams and rivers?
- Identify additional Puget Sound river data and incorporate into the PSSB and re-run metric evaluation.

  Potential data sources include EPA's National Rivers and Streams data (EPA 2013), USGS's National Water Quality Assessment Program (USGS 2015a, 2015b), and previous studies on Puget Sound Rivers (Celedonia 2004, Black and MacCoy 1999, Hughes et al. 2013, etc.).
- Identify and supplement gaps in the existing population of river data.

Is the full range of human disturbance represented including least disturbed? Are the largest watersheds (Skagit, Snohomish, Puyallup, etc. see Table 1) represented? Should additional culling criteria be considered such as excluding sites within a certain distance downstream of large impoundments or major tributary junctions? Or separating watersheds dominated by glacial melt versus watersheds with no glacial influence.

- Test and evaluate collection methods including total collection area, habitat targeted, depth, and within river variability assessed via processing multiple replicates.

  Most data used in this effort were from samples collected in wadeable margins and focused on riffle habitat and were made comparable by compositing any replicates. Would methods that target deeper thalweg areas or sample all available habitats (e.g. Wessell et al. 2008) be better for river bioassessment purposes? Or perhaps it is more important to standardize field collection more with a narrower range of sample depths, velocities, or relative location within a riffle.

- Incorporate additional scales and metrics of human disturbance into a composite disturbance index appropriate for Puget Sound rivers and re-evaluate candidate metrics.

  Such a composite index might incorporate measures of road density, upstream floodplain modification, and forest stand age in addition to percent urbanization or impervious area and should consider intermediate spatial scales such as 5-. 10-, and 25-km contributing watersheds as opposed to only full watershed and local (1-km) conditions.

- Evaluate and adjust existing B-IBI component metric scoring and tolerant/intolerant attribute lists.

  Some existing B-IBI metrics may be appropriate for use in river systems, but the scoring criteria may need to be modified especially if the range of metric values for rivers is substantially different than for the streams used to calibrate the existing B-IBI (see Figure 4, King County 2014a). Tolerant and intolerant attributes were empirically derived from existing data for Puget Sound streams (see King County 2013c). This process may need to be repeated for Puget Sound rivers to evaluate if a different set of taxa are good indicators of disturbance in larger waterbodies.

- Evaluate additional biological metrics and/or add a functional feeding group analysis.

  Calculate functional feeding group or attribute-based metrics. The river continuum concept (Vannote et al. 1980) expects that collectors will dominate the composition or larger river systems. Puget Sound rivers may or may not conform to these expectations.

- Once appropriate metrics are identified, score the metrics and develop a river B-IBI.

  With development of a river B-IBI provide recommendations for what constitutes a river versus a stream and provide feedback to PSSB project stewards to encourage appropriate classification of data.

4.4 Summary

Bioassessment approaches for Puget Sound streams may not be directly applicable to larger rivers based on a 2013 pilot sample collection effort combined with other available non-pilot data collected between 2004 and 2013. However, further testing of existing data is warranted against a refined disturbance gradient. Additional sample collection may also be necessary using a well-designed sampling plan and standardized sampling protocol across all sites to increase sample size and eliminate differences resulting from collection methods. With millions of dollars spent annually on salmon recovery in the Puget Sound region on projects frequently targeting river restoration it is imperative that appropriate bioassessment techniques exist to evaluate impairment and the response to future disturbance or restoration efforts in Puget Sound river systems.

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APPENDIX A: SITE INFORMATION FOR 2013 RIVER PILOT SAMPLING

Table A-1. Site information for 2013 river sampling.

WRIA #	River	Site Code	Method	Access	Date	Latitude	Longitude	River Mile	Description
8	Cedar	CED_149	Riffles	Wading	9/24/13	47.469556	-122.1423	5.5	149th Nr Ron Regis Pk
8	Cedar	CED_BEL	Transect	Wading	9/4/13	47.458107	-122.0784	9.5	Belmondo Nat'l Area
8	Cedar	CED_DSLandsburg	Riffles	Wading	9/26/13	47.386033	-121.9922	20.3	Big Bend Nat'l Area
8	Cedar	CED_LOGANRD	Transect	Wading	9/16/13	47.486077	-122.2094	1.1	Logan Rd-SR900
8	Cedar	CED_RIVERSIDE	Riffles	Wading	9/24/13	47.47697	-122.1811	2.7	Riverside Pk
8	Cedar	CED_RM1.7	Transect	Wading	9/16/13	47.480411	-122.198	1.7	Cedar R Pk; E of 405
8	Cedar	CED_RM13.6	Riffles	Wading	9/24/13	47.424443	-122.0463	13.6	Access via 218th Pl
8	Cedar	CED_ROTARYPK	Riffles	Wading	9/26/13	47.405657	-122.0388	15.25	Habenicht Rotary Pk
8	Cedar	CED_USDorreDon	Riffles	Wading	9/26/13	47.389534	-122.0172	17.7	E of Cedar River Trail
4	Skagit	SKAG_DIABSOD	Transect	Jet Boat	9/20/13	48.558375	-121.4125	N/A	d/s end @ Diabsud Ck
7	Snoqualmie	MF_SNOQ_DSConf	Riffles	Wading	10/7/13	47.522512	-121.7809	42.1	3 forks; Reinig Rd
7	Snoqualmie	MF_SNOQ_Kaplan	Riffles	Wading	10/10/13	47.505844	-121.7623	1.3	Kaplan Property
7	Snoqualmie	NF_SNOQ	Riffles	Wading	10/7/13	47.521023	-121.7726	0.1	3 forks; W of 428
7	Snoqualmie	SF_SNOQ	Riffles	Wading	10/10/13	47.489739	-121.7859	3.2	Si View Park, N Bend
7	Snoqualmie	SNOQ_20.1	Riffles	Raft	10/15/13	47.677604	-121.9371	20.1	u/s Harris Ck
7	Snoqualmie	SNOQ_21.7	Riffles	Raft	10/15/13	47.668769	-121.9216	21.7	Chinook Bend
7	Snoqualmie	SNOQ_22.7	Riffles	Raft	10/15/13	47.654927	-121.9228	22.7	u/s McElhoe Pearson
7	Tolt	TOLT_Mouth	Riffles	Wading	10/10/13	47.638892	-121.9212	0.4	Tolt MacDonald Pk
5	Stillaguamish	NF_STILLY_Cicero	Riffles	Wading	10/14/13	48.268055	-122.0143	N/A	Cicero Bridge on 530
5	Stillaguamish	SF_STILLY	Riffles	Wading	10/14/13	48.183636	-122.0821	N/A	River Meadows Co Pk

APPENDIX B: FIELD DATA COLLECTION SHEETS – TRANSECT & RIFFLE METHODS

Two versions (one for transect methods, and one for riffle methods) of page one of a two-page field data sheet are shown on the following pages. The second page of the data sheet was blank and was used to hand draw the approximate location of sampled collected and the location of riffles and is not shown here.

2013 Puget Sound Non-wadeable River Sampling: Transect Sample Collection

Site:	Sample Name:	River:	Date:
Samplers:	Reach length (m):	Width used to determine length (m):	Wade or raft? W R
Location description:			
Time start:	Time end:	Air temp:	Water temp:

Reach length = Avg bankfull width x 20 but between 150-2000m

# of samples: _____ Name of samples:

	Sample #/ name	Tran sect	Bank (Left/ Right)	Flow (Fast/ Slack)	Distance to bank (m)	Dominant Substrate Circle one substrate code for each collection	Secondary Substrate Circle one substrate code for each collection	Channel Habitat Circle one habitat code for each collection	Sample Depth (m)	Embeddedness (%) To the nearest 10%	Wet Width (m)	BF Width (m)	Bankfull depth (m)	Thalweg depth (m)
1			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						
2			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						
3			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						
4			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						
5			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						
6			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						
7			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						
8			L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___						

Substrate Codes		Channel Habitat	Notes:
RS = Bedrock (smooth) > 4 m, > car	GF = Fine gravel, 2-16 mm, ladybug to marble	PO = Pool	
RR = Bedrock (rough) > 4 m, > car	SA = Sand, 0.06 to 2 mm, gritty to ladybug	GL = Glide	
RC = Concrete/Asphalt > 4 m, > car	FN = Fines (silt/clay/muck), < 0.06 mm, non gritty	RI = Riffle	
XB = Large Boulder 1 to 4 m, < car	HP = Hardpan - hardened fines any size	RA = Rapid	
SB = Small boulder, 250 mm to 1 m, > bball	WD = Wood any size	CA = Cascade	
CB = Cobble, 64 to 250 mm tennis to bball	OT = Other (doesn't fit choices above) any size	FA = Falls	
GC = Coarse gravel, 16-64 mm marble to tennis ball		DR = Dry Channel	

2013 Puget Sound Non-wadeable River Sampling: Targeted Riffle Sample Collection

Site:	River:	Date:
Samplers:	~ Reach length (m):	Wade or raft? W R
Location description:		

Time start:	Time end:	Air temp:	Water temp:

# of samples: _____ Name of samples:

	Sample #/ name	Bank (Left/ Right)	Flow (Fast/ Slack)	Distance to bank (m)	Dominant Substrate Circle one substrate code for each collection	Secondary Substrate Circle one substrate code for each collection	Channel Habitat Circle one habitat code for each collection	Sample Depth (m)	Embeddedness (%) To the nearest 10%	Wet Width (m)	BF Width (m)	Bankfull depth (m)
1		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					
2		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					
3		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					
4		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					
5		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					
6		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					
7		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					
8		L R	F S		CB GC GF SA ___	CB GC GF SA ___	PO GL RI RA ___					

Substrate Codes		Channel Habitat	Notes:
RS = Bedrock (smooth) > 4 m, > car	GF = Fine gravel, 2-16 mm, ladybug to marble	PO = Pool	
RR = Bedrock (rough) > 4 m, > car	SA = Sand, 0.06 to 2 mm, gritty to ladybug	GL = Glide	
RC = Concrete/Asphalt > 4 m, > car	FN = Fines (silt/clay/muck), < 0.06 mm, non gritty	RI = Riffle	
XB = Large Boulder 1 to 4 m, < car	HP = Hardpan - hardened fines any size	RA = Rapid	
SB = Small boulder, 250 mm to 1 m, > bball	WD = Wood any size	CA = Cascade	
CB = Cobble, 64 to 250 mm tennis to bball	OT = Other (doesn't fit choices above) any size	FA = Falls	
GC = Coarse gravel, 16-64 mm marble to tennis ball		DR = Dry Channel	

APPENDIX C: NON-PILOT SITE INFORMATION

Table C-1. Site information for historical river sampling locations.

WRIA#	River	Site Code	Agency/Project	Latitude	Longitude	Event Date
1	Nooksack	WAM06600-001660	Ecology/ Watershed Health	48.685211	-122.169344	8/15/2013
7	Snoqualmie	Chinook Bend Wetland	King Co. DNRP/ Chinook Bend	47.673541	-121.931896	9/9/2008
7	Snoqualmie	McElhoe Levee	King Co. DNRP/ Chinook Bend	47.658888	-121.926363	9/9/2008
7	Skykomish	skygb	Snohomish Co./ Ambient	47.851559	-121.694172	9/7/2006
7	Skykomish	skychan	Snohomish Co./ Ambient	47.816539	-121.570251	9/17/2006
7	Pilchuck	pilmach	Snohomish Co./ Ambient	47.975458	-122.049022	9/6/2006
7	Pilchuck	pilok	Snohomish Co./ Ambient	47.987189	-122.03606	8/30/2013
7	Snoqualmie	WAM06600-005067	Ecology/ Watershed Health	47.755544	-121.980336	10/8/2009
7	Skykomish	WAM06600-001899	Ecology/ Watershed Health	47.842257	-121.693362	8/1/2013
7	Snoqualmie	WAM06600-001047	Ecology/ Watershed Health	47.59189	-121.922613	8/4/2009
9	Big Soos Creek	09SOO0943	King Co. DNRP/ Ambient Monitoring	47.30855	-122.16904	8/14/2013
9	Green	WAM06600-006467	Ecology/ Watershed Health	47.366137	-122.224027	10/7/2009
13	Deschutes	DeschuThCoPionPk	Thurston Co./ Macroinvertebrate Monitoring	46.999143	-122.893539	8/16/2008
13	Deschutes	DREM0.5	Ecology/ TMDL Effectiveness	47.01167	-122.9035	10/2/2012
13	Deschutes	DREM1.76	Ecology/ TMDL Effectiveness	46.99325	-122.88676	10/4/2012
13	Deschutes	DREM12.1	Ecology/ TMDL Effectiveness	46.93267	-122.82734	10/4/2012
13	Deschutes	DREM16.5	Ecology/ TMDL Effectiveness	46.90327	-122.78805	10/6/2011
13	Deschutes	DREM24.9	Ecology/ TMDL Effectiveness	46.85206	-122.66947	9/28/2012
13	Deschutes	DREM22.7	Ecology/ TMDL Effectiveness	46.85798	-122.7026	10/8/2012
13	Deschutes	WAM06600-000566	Ecology/ Watershed Health	46.860537	-122.716045	7/19/2013
16	Skokomish	SkokSkokTrb101	Skokomish Tribal Nation/ Benthic Invertebrates	47.30998	-123.176394	8/11/2006
16	Skokomish	SkokSkokTrbRB	Skokomish Tribal Nation/ Benthic Invertebrates	47.318112	-123.202057	8/18/2006
16	Skokomish	Skokomish_ECY_549	Ecology/ Ambient	47.3142	-123.1822	7/8/2004
18	Dungeness	DungClalCty0.7	Clallam Co./ Streamkeepers	48.148809	-123.126787	9/27/2006

WRIA#	River	Site Code	Agency/Project	Latitude	Longitude	Event Date
18	Dungeness	DungClalCty3.0	Clallam Co./ Streamkeepers	48.118652	-123.147717	9/26/2007
18	Dungeness	DungClalCty5.9	Clallam Co./ Streamkeepers	48.084865	-123.148128	9/27/2007
18	Dungeness	DungClalCty6.6a	Clallam Co./ Streamkeepers	48.073698	-123.149134	9/27/2007
18	Dungeness	DungClalCty7.8	Clallam Co./ Streamkeepers	48.060821	-123.152787	9/27/2005
18	Dungeness	DungClalCty11.6	Clallam Co./ Streamkeepers	48.015536	-123.130475	10/14/2004
18	Dungeness	DungClalCty15.7	Clallam Co./ Streamkeepers	47.975852	-123.111991	9/30/2005
18	Elwha	ElwhaNMFSNmSc1	NOAA/ Elwha Benthic Invertebrates	48.14315	-123.56217	7/24/2006
18	Elwha	ElwhaNMFSNmSc2	NOAA/ Elwha Benthic Invertebrates	48.14315	-123.56217	7/25/2006
18	Elwha	ElwhaNMFSEjMs	NOAA/ Elwha Benthic Invertebrates	48.121867	-123.55439	8/1/2006
18	Elwha	ElwhaNMFSEjSc	NOAA/ Elwha Benthic Invertebrates	48.121867	-123.55439	8/1/2006
18	Elwha	ElwhaNMFSFhMs	NOAA/ Elwha Benthic Invertebrates	48.11924	-123.55408	7/25/2006
18	Elwha	ElwhaNMFSFhSc	NOAA/ Elwha Benthic Invertebrates	48.11853	-123.55282	7/25/2006
18	Elwha	ElwhaNMFSBrMs	NOAA/ Elwha Benthic Invertebrates	48.109873	-123.550794	7/25/2006
18	Elwha	ElwhaNMFSHwMs	NOAA/ Elwha Benthic Invertebrates	48.062102	-123.577908	7/27/2006
18	Elwha	ElwhaNMFSTfSc1	NOAA/ Elwha Benthic Invertebrates	48.060177	-123.579249	8/2/2006
18	Elwha	ElwhaNMFSPbMs	NOAA/ Elwha Benthic Invertebrates	48.04853	-123.58795	7/27/2006
18	Elwha	ElwhaNMFSCgMs	NOAA/ Elwha Benthic Invertebrates	48.02925	-123.59159	7/26/2006
18	Elwha	HughesNMFSHcSc	NOAA/ Elwha Benthic Invertebrates	48.02232	-123.59516	8/3/2006
18	Elwha	ElwhaNMFSAlMs	NOAA/ Elwha Benthic Invertebrates	48.01067	-123.590856	7/26/2006
18	Elwha	ElwhaNMFSWbSc	NOAA/ Elwha Benthic Invertebrates	47.971899	-123.592892	7/18/2006
18	Elwha	ElwhaNMFSKbMs	NOAA/ Elwha Benthic Invertebrates	47.953222	-123.573	8/1/2006
18	Elwha	ElwhaNMFSKbSc	NOAA/ Elwha Benthic Invertebrates	47.953056	-123.572222	8/1/2006
18	Elwha	ElwhaNMFSEhMs3b	NOAA/ Elwha Benthic Invertebrates	47.88006	-123.47249	8/3/2006
18	Elwha	ElwhaNMFSEhSc3b	NOAA/ Elwha Benthic Invertebrates	47.87704	-123.46881	8/3/2006
18	Elwha	ElwhaNMFSEhMs3	NOAA/ Elwha Benthic Invertebrates	47.859211	-123.467418	8/2/2005

APPENDIX D: SITE SPECIFIC WATERSHED DATA AND B-IBI SCORES

Table D-1. Watershed data and B-IBI scores for 67 Puget Sound river locations.

Site Code (River, WRIA)	County	Ecoregion	WS Area (sq mi)	Site Elevation (ft)	Mean Precip (in)	WS Urban (%)	WS Ag (%)	WS Natural (%)	Local Urban (%)	Local Ag (%)	Local Natural (%)	B-IBI
WAM06600-001660 (Nooksack, 1)	Whatcom	North Cascades	128.5	352.3	129.8	0.5	0.0	95.1	3.1	6.3	79.5	68.2
SKAG_DIABSOD (Skagit, 4)	Skagit	North Cascades	961.5	350.3	83.1	0.3	0.0	85.0	6.0	1.9	86.8	59.4
Chinook Bend Wetland (Snoqualmie, 7)	King	Puget Lowland	605.4	40.8	103.8	2.8	1.2	91.0	3.3	30.6	56.3	57.2
McElhoe Levee (Snoqualmie, 7)	King	Puget Lowland	602.7	51.5	104.1	2.7	1.1	91.1	4.1	31.3	58.3	61.1
SNOQ_20.1 (Snoqualmie, 7)	King	Puget Lowland	605.6	39.9	103.8	2.8	1.2	91.0	3.7	23.0	67.3	28.2
SNOQ_21.7 (Snoqualmie, 7)	King	Puget Lowland	605.0	46.4	103.8	2.8	1.2	91.0	5.2	46.1	43.4	70.0
SNOQ_22.7 (Snoqualmie, 7)	King	Puget Lowland	602.0	48.7	104.1	2.7	1.0	91.2	11.2	36.4	46.1	58.9
MF_SNOQ_DSConf (Snoqualmie, 7)	King	Puget Lowland	275.0	407.3	122.8	0.7	0.1	93.0	1.4	8.6	78.1	71.7
MF_SNOQ_Kaplan (Snoqualmie, 7)	King	North Cascades	169.8	435.2	120.4	0.3	0.0	92.4	1.9	0.4	87.4	60.2
NF_SNOQ (Snoqualmie, 7)	King	Puget Lowland	103.7	414.6	127.5	1.4	0.1	94.2	5.4	11.3	73.7	76.6
TOLT_Mouth (Snoqualmie, 7)	King	Puget Lowland	101.3	63.6	103.2	1.1	0.3	94.9	16.9	26.2	47.3	70.7
SF_SNOQ (Snoqualmie, 7)	King	Puget Lowland	81.0	439.3	105.3	4.7	0.1	92.1	56.6	0.7	16.2	79.3
skygb (Skykomish, 7)	Snohomish	Puget Lowland	549.9	184.1	111.7	1.1	0.0	93.5	25.5	0.0	52.3	13.9
skychan (Skykomish, 7)	Snohomish	North Cascades	146.5	501.0	124.8	0.4	0.0	94.6	3.7	0.0	91.6	56.1
WAM06600-001899 (Skykomish, 7)	Snohomish	Puget Lowland	539.1	187.9	111.4	1.0	0.0	93.6	1.2	0.0	72.0	81.4
pilmach (Pilchuck, 7)	Snohomish	Puget Lowland	119.5	98.4	77.9	8.4	3.2	82.1	16.5	7.4	65.6	25.7
pilok (Pilchuck, 7)	Snohomish	Puget Lowland	105.2	123.1	81.0	8.3	3.5	82.1	17.8	23.6	40.1	59.6
WAM06600-005067 (Snoqualmie, 7)	King	Puget Lowland	647.3	24.9	100.3	3.3	2.0	89.6	8.2	65.1	18.6	25.4
WAM06600-001047 (Snoqualmie, 7)	King	Puget Lowland	452.8	68.5	109.4	2.6	0.4	91.5	4.7	58.5	21.2	70.2
CED_LOGANRD (Cedar, 8)	King	Puget Lowland	174.6	25.8	87.7	9.3	0.9	85.4	95.3	1.4	1.1	73.6
CED_RM1.7 (Cedar, 8)	King	Puget Lowland	172.6	20.9	88.2	8.3	0.9	86.3	43.1	0.3	47.6	68.1
CED_RIVERSIDE (Cedar, 8)	King	Puget Lowland	172.0	39.1	88.4	8.2	0.9	86.5	40.3	0.0	48.0	72.7

Site Code (River, WRIA)	County	Ecoregion	WS Area (sq mi)	Site Elevation (ft)	Mean Precip (in)	WS Urban (%)	WS Ag (%)	WS Natural (%)	Local Urban (%)	Local Ag (%)	Local Natural (%)	B-IBI
CED_149 (Cedar, 8)	King	Puget Lowland	163.4	93.2	90.6	5.5	0.9	89.5	58.4	0.3	31.7	67.9
CED_BEL (Cedar, 8)	King	Puget Lowland	157.0	184.4	92.4	4.1	0.8	91.4	27.4	4.5	62.1	74.5
CED_RM13.6 (Cedar, 8)	King	Puget Lowland	148.5	251.8	94.7	3.1	0.5	93.3	17.6	1.8	65.1	72.9
CED_ROTARYPK (Cedar, 8)	King	Puget Lowland	143.4	319.4	96.3	2.6	0.4	94.2	32.9	1.5	44.7	84.3
CED_USDorreDon (Cedar, 8)	King	Puget Lowland	140.6	366.5	97.2	2.1	0.3	95.0	18.2	0.9	72.3	73.8
CED_DSLandsburg (Cedar, 8)	King	Puget Lowland	136.2	466.2	98.6	1.5	0.2	95.8	13.0	2.1	84.4	65.9
09SOO0943 (Big Soos Creek, 9)	King	Puget Lowland	85.4	73.1	52.0	28.8	3.8	52.6	25.1	0.0	60.8	90.6
WAM06600-006467 (Green, 9)	King	Puget Lowland	418.9	28.2	72.3	9.5	4.8	80.6	29.8	18.9	42.8	12.3
DeschuThCoPionPk (Deschutes, 13)	Thurston	Puget Lowland	153.6	101.5	50.8	6.4	6.1	81.7	24.6	1.9	48.3	53.4
DREM0.5 (Deschutes, 13)	Thurston	Puget Lowland	155.1	86.8	50.8	6.9	6.1	81.1	54.9	0.9	12.3	60.1
DREM1.76 (Deschutes, 13)	Thurston	Puget Lowland	151.0	106.8	50.8	5.7	6.2	82.8	22.1	8.6	51.3	41.3
DREM12.1 (Deschutes, 13)	Thurston	Puget Lowland	120.0	213.3	51.2	2.3	4.5	89.1	3.0	0.0	96.7	56.3
DREM16.5 (Deschutes, 13)	Thurston	Puget Lowland	112.6	262.9	51.3	2.2	4.7	89.2	0.0	0.0	100.0	70.4
DREM24.9 (Deschutes, 13)	Thurston	Puget Lowland	86.5	367.5	52.2	1.8	2.3	91.8	15.7	16.5	51.6	76.7
DREM22.7 (Deschutes, 13)	Thurston	Cascades	89.8	324.7	52.1	1.8	2.7	91.5	0.0	0.3	88.0	72.7
WAM06600-000566 (Deschutes, 13)	Thurston	Cascades	90.2	320.4	52.1	1.8	2.6	91.5	0.0	1.8	98.1	53.6
SkokSkokTrb101 (Skokomish, 16)	Mason	Puget Lowland	228.8	20.5	120.6	0.7	0.6	92.7	5.3	22.1	70.0	48.9
SkokSkokTrbRB (Skokomish, 16)	Mason	Puget Lowland	225.0	34.4	121.3	0.7	0.4	92.8	0.0	4.4	90.6	63.2
Skokomish_ECY_549 (Skokomish, 16)	Mason	Puget Lowland	228.2	25.5	120.7	0.7	0.6	92.7	2.0	11.2	81.3	34.4
DungClalCty0.7 (Dungeness, 18)	Clallam	Puget Lowland	197.8	8.8	61.2	2.9	4.2	79.4	22.9	42.3	24.8	17.9
DungClalCty3.0 (Dungeness, 18)	Clallam	Puget Lowland	181.1	64.4	65.0	1.0	1.0	83.5	9.6	35.0	49.8	68.8
DungClalCty5.9 (Dungeness, 18)	Clallam	Puget Lowland	178.0	196.3	65.7	0.7	0.6	84.0	24.6	31.0	38.3	62.7
DungClalCty6.6a (Dungeness, 18)	Clallam	Puget Lowland	177.4	242.1	65.9	0.5	0.5	84.2	46.5	4.0	45.1	65.3
DungClalCty7.8 (Dungeness, 18)	Clallam	Puget Lowland	173.8	319.9	66.7	0.2	0.3	84.4	34.1	21.5	31.3	71.2
DungClalCty11.6 (Dungeness, 18)	Clallam	Puget Lowland	156.6	553.6	69.4	0.0	0.0	83.4	0.1	0.0	99.7	69.3
DungClalCty15.7 (Dungeness, 18)	Clallam	Puget Lowland	147.6	825.6	71.3	0.0	0.0	81.5	0.0	0.0	100.0	64.9
ElwhaNMFSNmSc1 (Elwha, 18)	Clallam	Puget Lowland	321.8	4.2	99.3	0.3	0.3	90.8	1.7	2.2	89.6	45.5

Site Code (River, WRIA)	County	Ecoregion	WS Area (sq mi)	Site Elevation (ft)	Mean Precip (in)	WS Urban (%)	WS Ag (%)	WS Natural (%)	Local Urban (%)	Local Ag (%)	Local Natural (%)	B-IBI
ElwhaNMFSNmSc2 (Elwha, 18)	Clallam	Puget Lowland	321.8	4.2	99.3	0.3	0.3	90.8	1.7	2.2	89.6	68.4
ElwhaNMFSEjMs (Elwha, 18)	Clallam	Puget Lowland	319.6	33.3	99.8	0.2	0.2	90.8	8.9	1.2	85.4	61.0
ElwhaNMFSEjSc (Elwha, 18)	Clallam	Puget Lowland	319.6	33.3	99.8	0.2	0.2	90.8	8.9	1.2	85.4	67.8
ElwhaNMFSFhMs (Elwha, 18)	Clallam	Puget Lowland	319.2	34.3	99.9	0.2	0.2	90.8	7.5	0.8	86.6	43.5
ElwhaNMFSFhSc (Elwha, 18)	Clallam	Puget Lowland	319.2	33.5	99.9	0.2	0.2	90.8	7.1	2.3	86.2	68.3
ElwhaNMFSBrMs (Elwha, 18)	Clallam	Puget Lowland	317.9	64.9	100.2	0.2	0.1	90.9	2.0	17.9	77.2	53.5
ElwhaNMFSHwMs (Elwha, 18)	Clallam	Coastal Range	269.2	219.4	105.8	0.0	0.0	90.1	0.4	4.5	92.7	82.6
ElwhaNMFSTfSc1 (Elwha, 18)	Clallam	Coastal Range	268.8	219.9	105.9	0.0	0.0	90.1	0.3	3.4	93.4	86.9
ElwhaNMFSPbMs (Elwha, 18)	Clallam	Coastal Range	267.5	239.1	106.2	0.0	0.0	90.1	1.1	0.0	96.2	72.1
ElwhaNMFSCgMs (Elwha, 18)	Clallam	Coastal Range	262.2	315.1	106.9	0.0	0.0	89.9	0.0	0.6	94.3	53.9
HughesNMFSHcSc (Elwha, 18)	Clallam	Coastal Range	248.1	329.7	107.7	0.0	0.0	89.4	0.0	0.0	97.9	67.1
ElwhaNMFSAlMs (Elwha, 18)	Clallam	Coastal Range	246.8	379.7	107.9	0.0	0.0	89.4	0.6	0.0	96.3	38.3
ElwhaNMFSWbSc (Elwha, 18)	Clallam	Coastal Range	198.3	579.1	108.7	0.0	0.0	88.4	0.0	0.0	96.4	71.2
ElwhaNMFSKbMs (Elwha, 18)	Clallam	Coastal Range	193.7	678.9	109.4	0.0	0.0	88.2	0.0	0.0	94.6	45.3
ElwhaNMFSKbSc (Elwha, 18)	Clallam	Coastal Range	193.6	688.6	109.4	0.0	0.0	88.2	0.0	0.0	94.9	47.3
ElwhaNMFSEhMs3b (Elwha, 18)	Clallam	Coastal Range	125.0	1386.0	125.2	0.0	0.0	87.9	0.0	0.0	97.7	50.4
ElwhaNMFSEhSc3b (Elwha, 18)	Clallam	Coastal Range	124.0	1387.9	125.6	0.0	0.0	87.8	0.0	0.0	96.3	68.7
ElwhaNMFSEhMs3 (Elwha, 18)	Jefferson	Coastal Range	108.6	1442.7	131.3	0.0	0.0	87.7	0.0	0.0	98.6	48.1

APPENDIX E: B-IBI METRIC BOX PLOTS

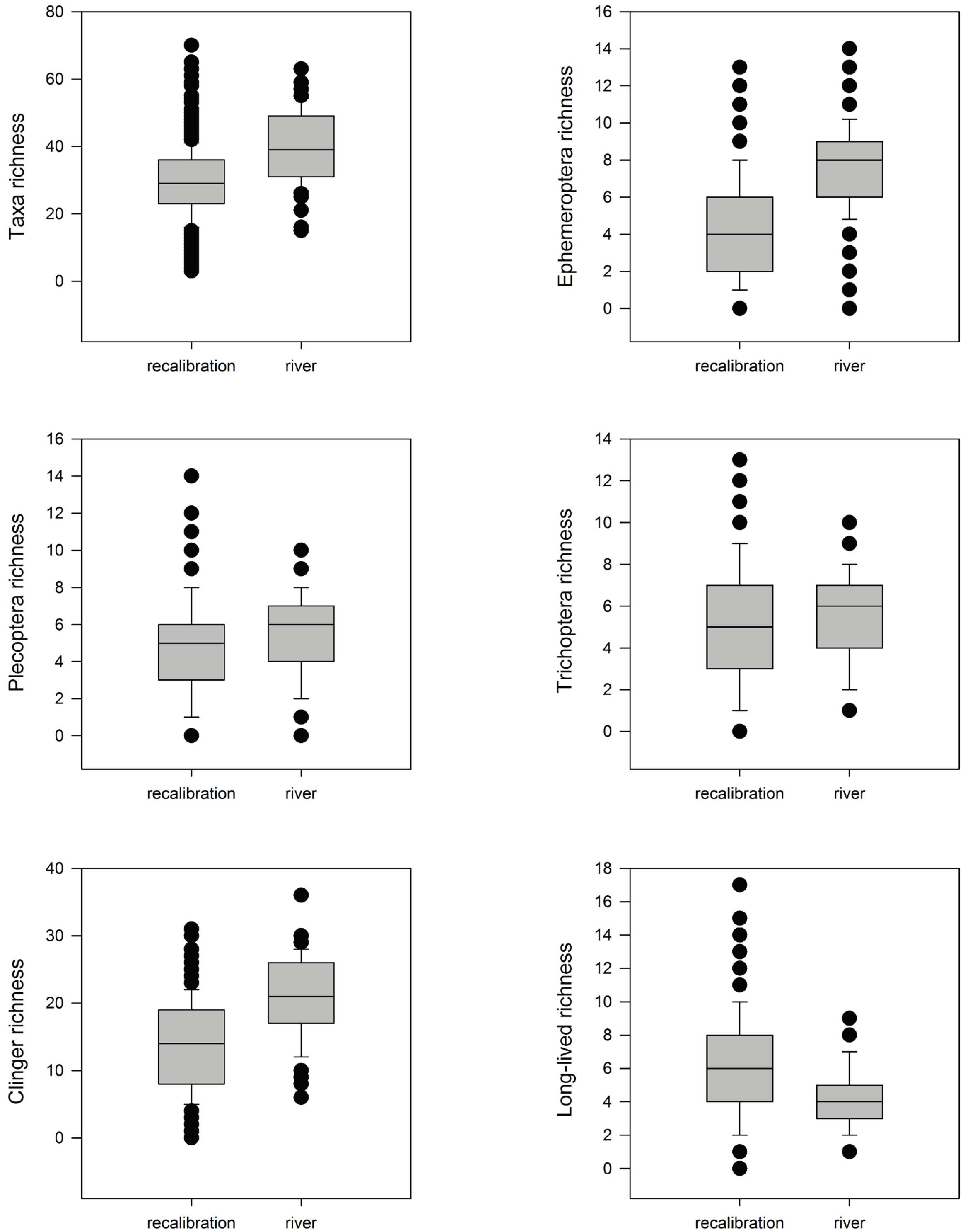


Figure E-1. Box plot for six B-IBI metrics for two data sets: Puget Lowland B-IBI recalibration (n=857, King County 2014a) and river (n = 67, this effort). Error bars extend to the 10^{th} and 90^{th} percentile.

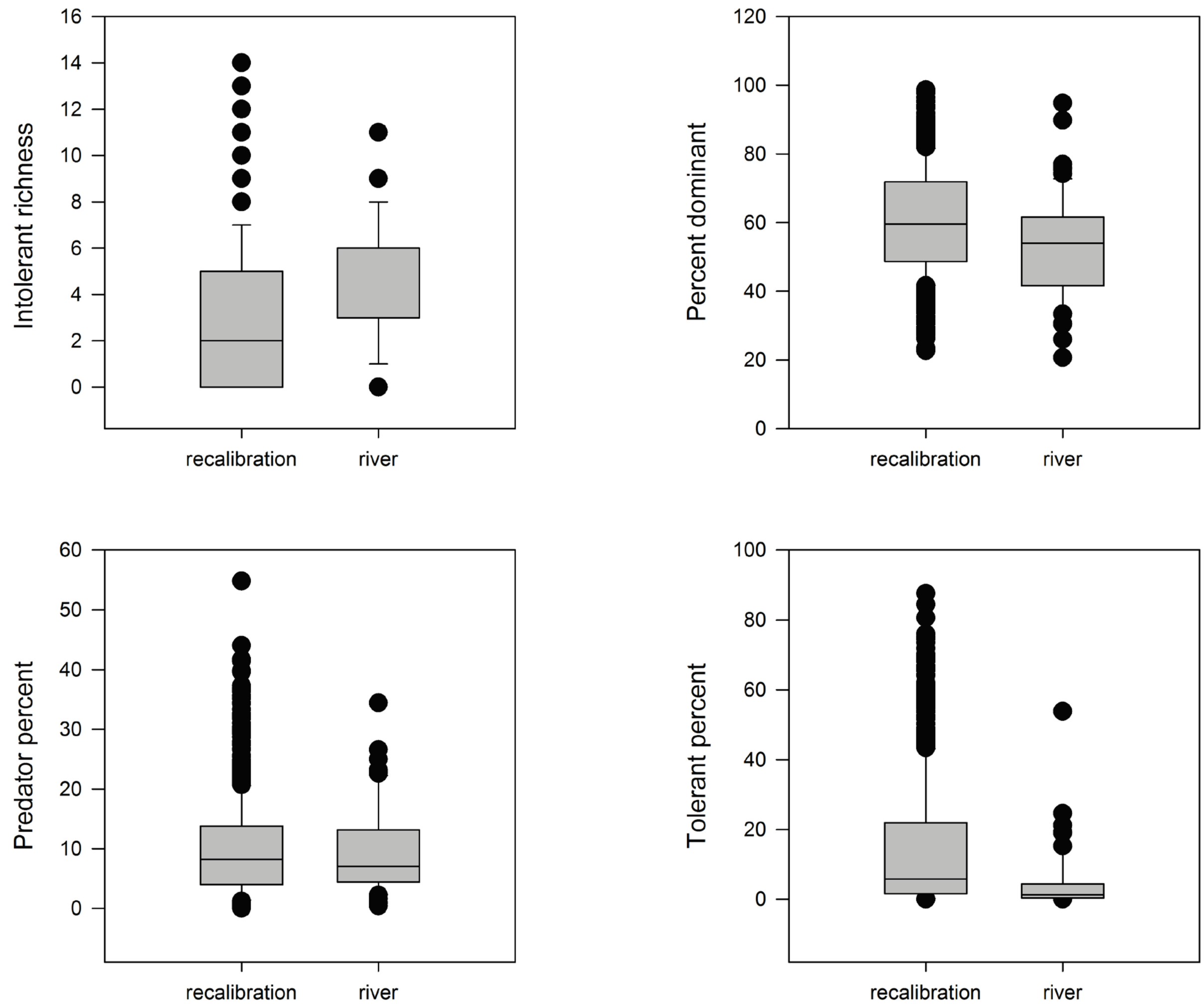


Figure E-2. Box plot for four B-IBI metrics for two data sets: Puget Lowland B-IBI recalibration (n=857, King County 2014a) and river (n = 67, this effort). Error bars extend to the 10th and 90th percentile.

APPENDIX F: B-IBI COMPONENT METRICS AND WATERSHED URBANIZATION

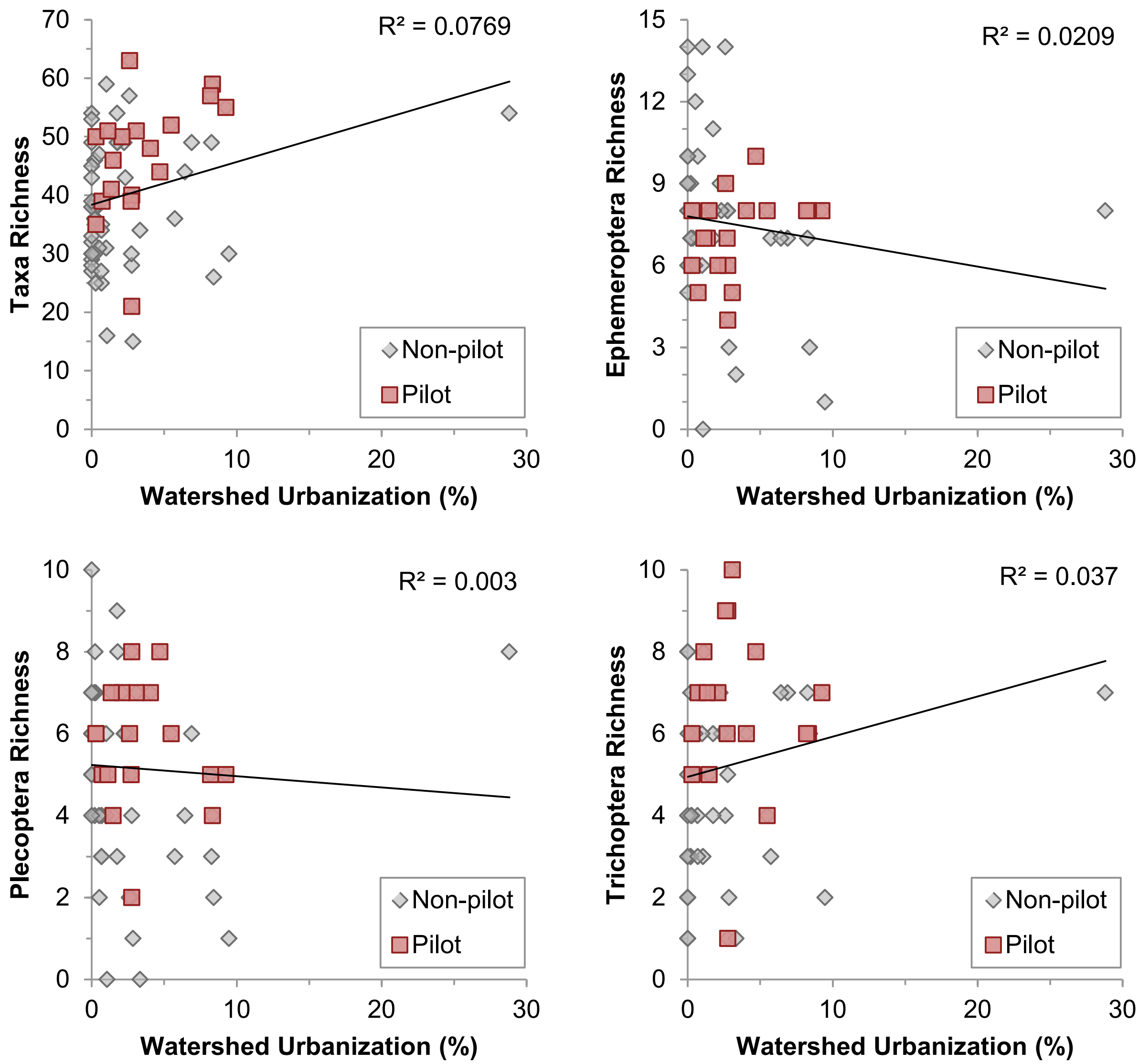


Figure F-1. Plots of B-IBI metric response to watershed urbanization (taxa, Ephemeroptera, Plecoptera, and Trichoptera richness).

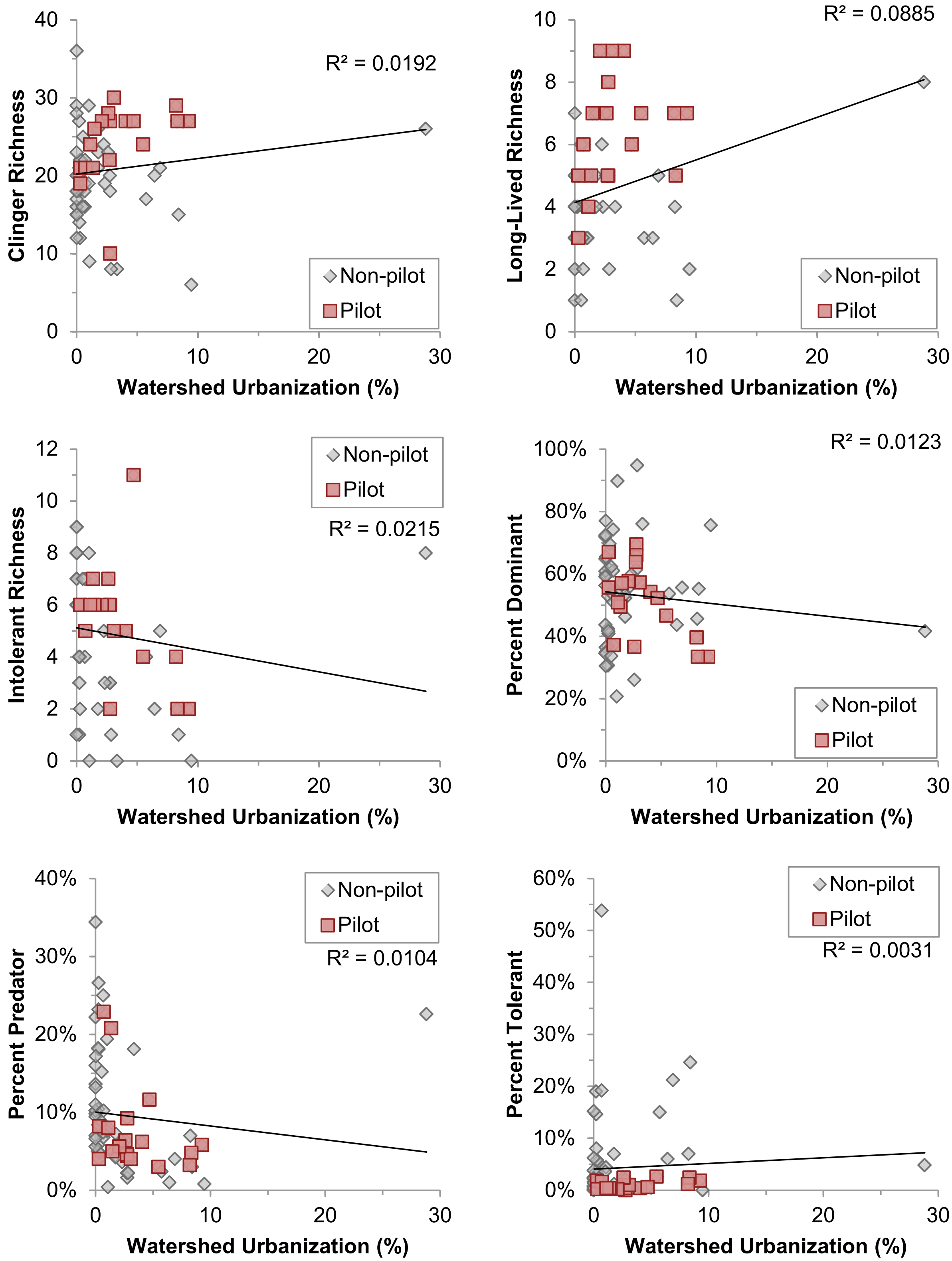


Figure F-2. Plots of B-IBI metric response to watershed urbanization (clinger, long-lived, and intolerant richness, and percent dominant, predator, and tolerant).

APPENDIX G: B-IBI COMPONENT METRICS AND LOCAL URBANIZATION

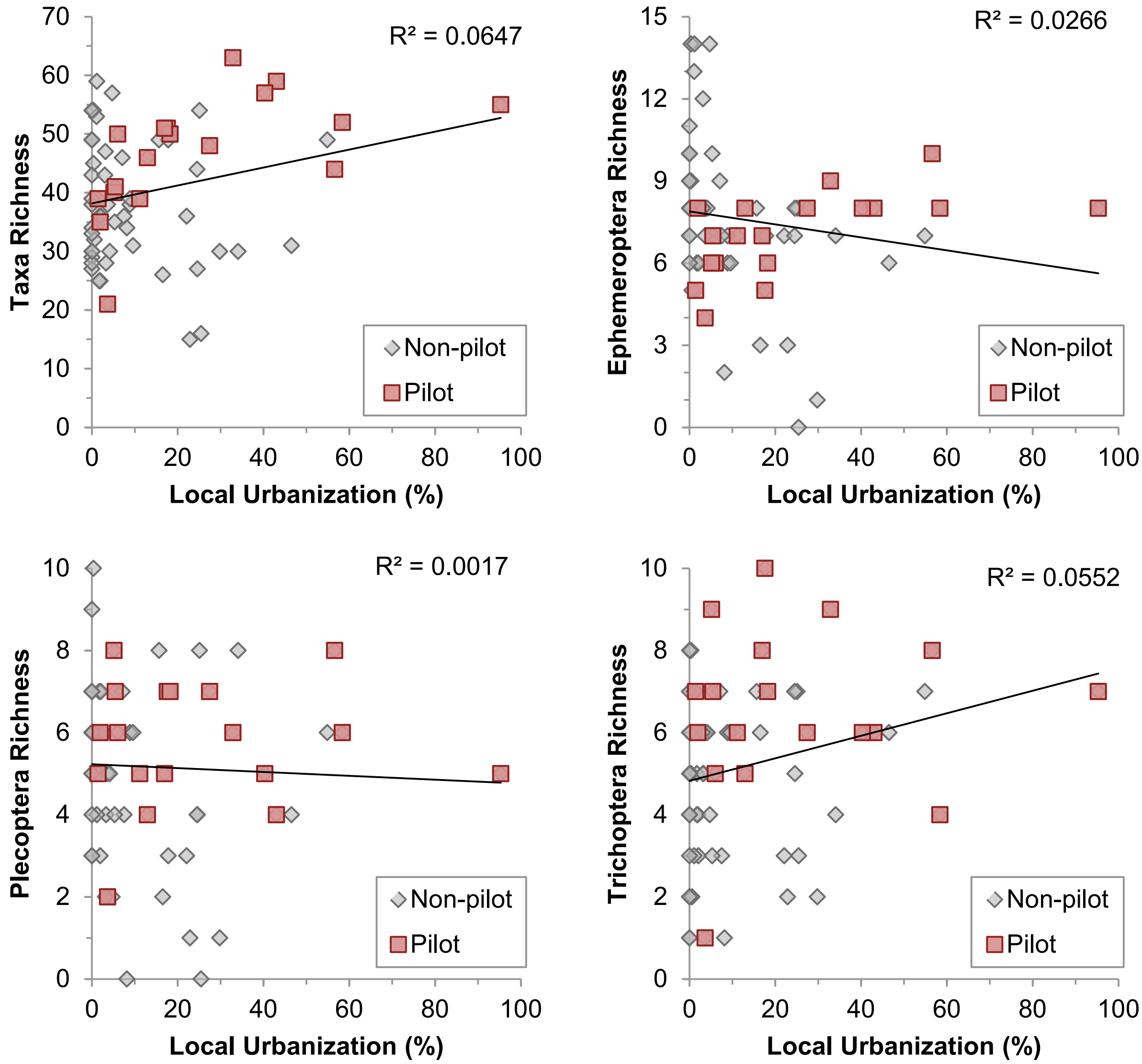


Figure G-1. Plots of B-IBI metric response to local urbanization (taxa, Ephemeroptera, Plecoptera, and Trichoptera richness).

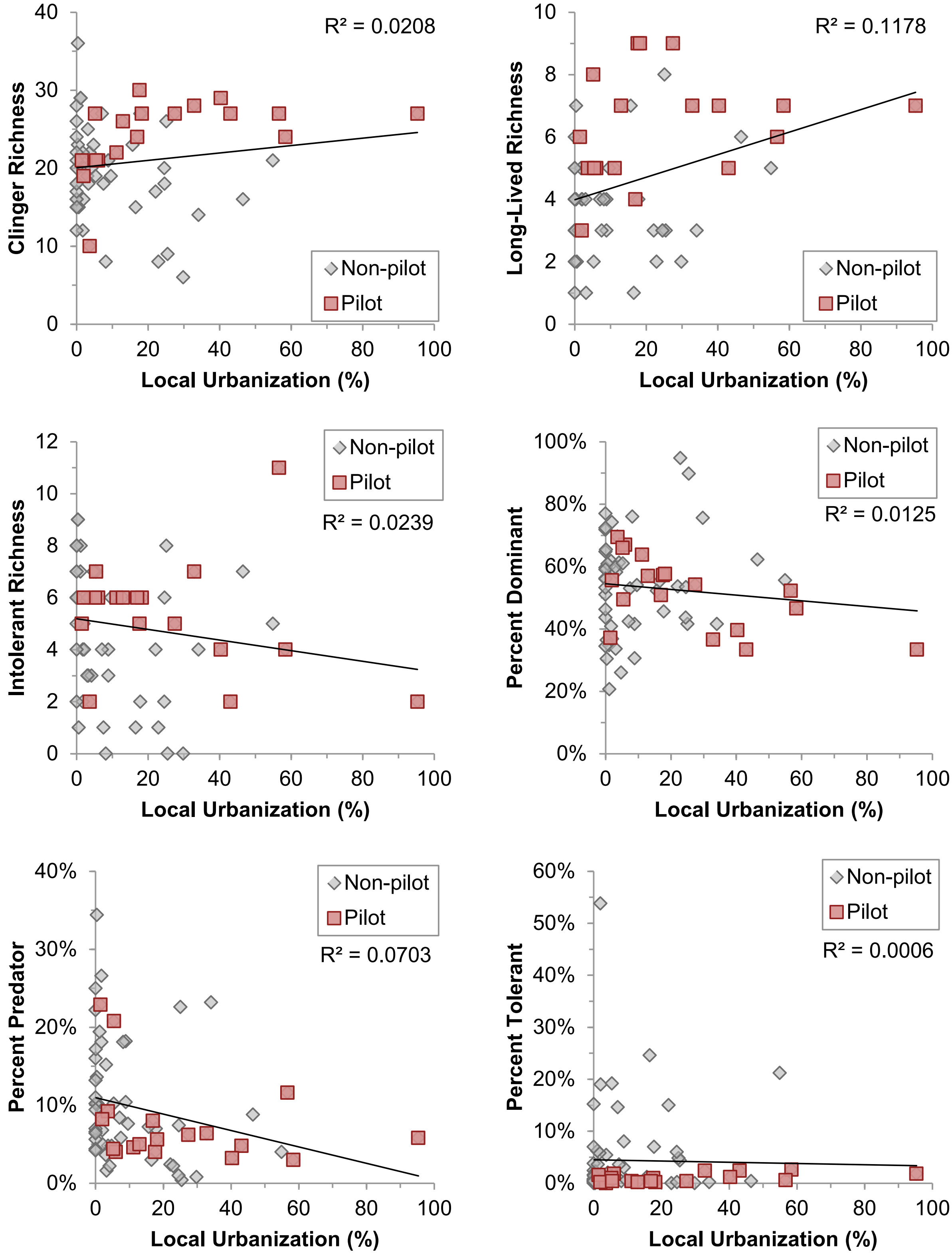


Figure G-2. Plots of B-IBI metric response to watershed urbanization (clinger, long-lived, and intolerant richness, and percent dominant, predator, and tolerant).

APPENDIX H: PLOTS OF CANDIDATE METRICS AND WATERSHED URBANIZATION

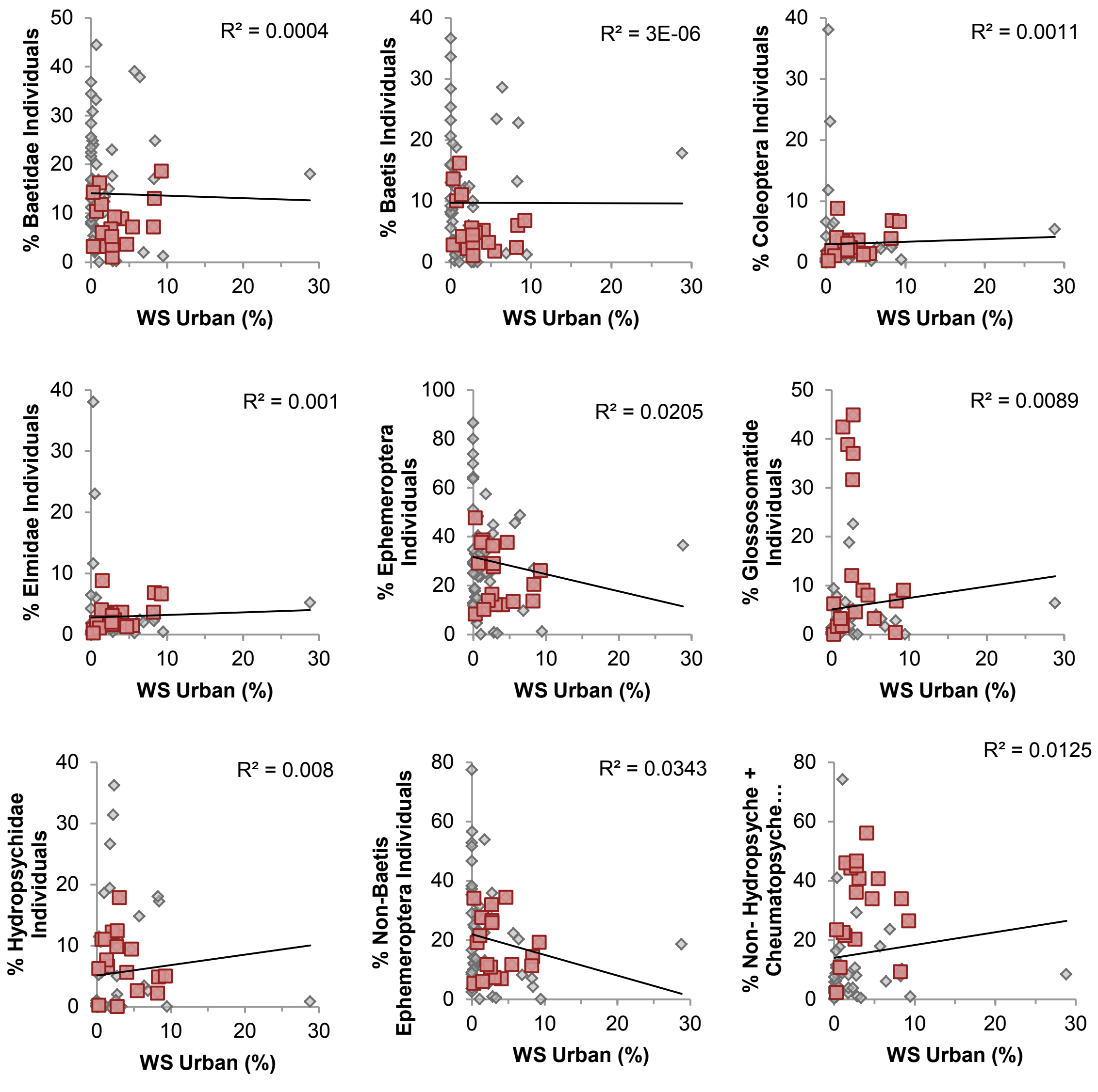


Figure H-1. Plots of non B-IBI metric response to watershed urbanization (1-9 of 18 metrics).

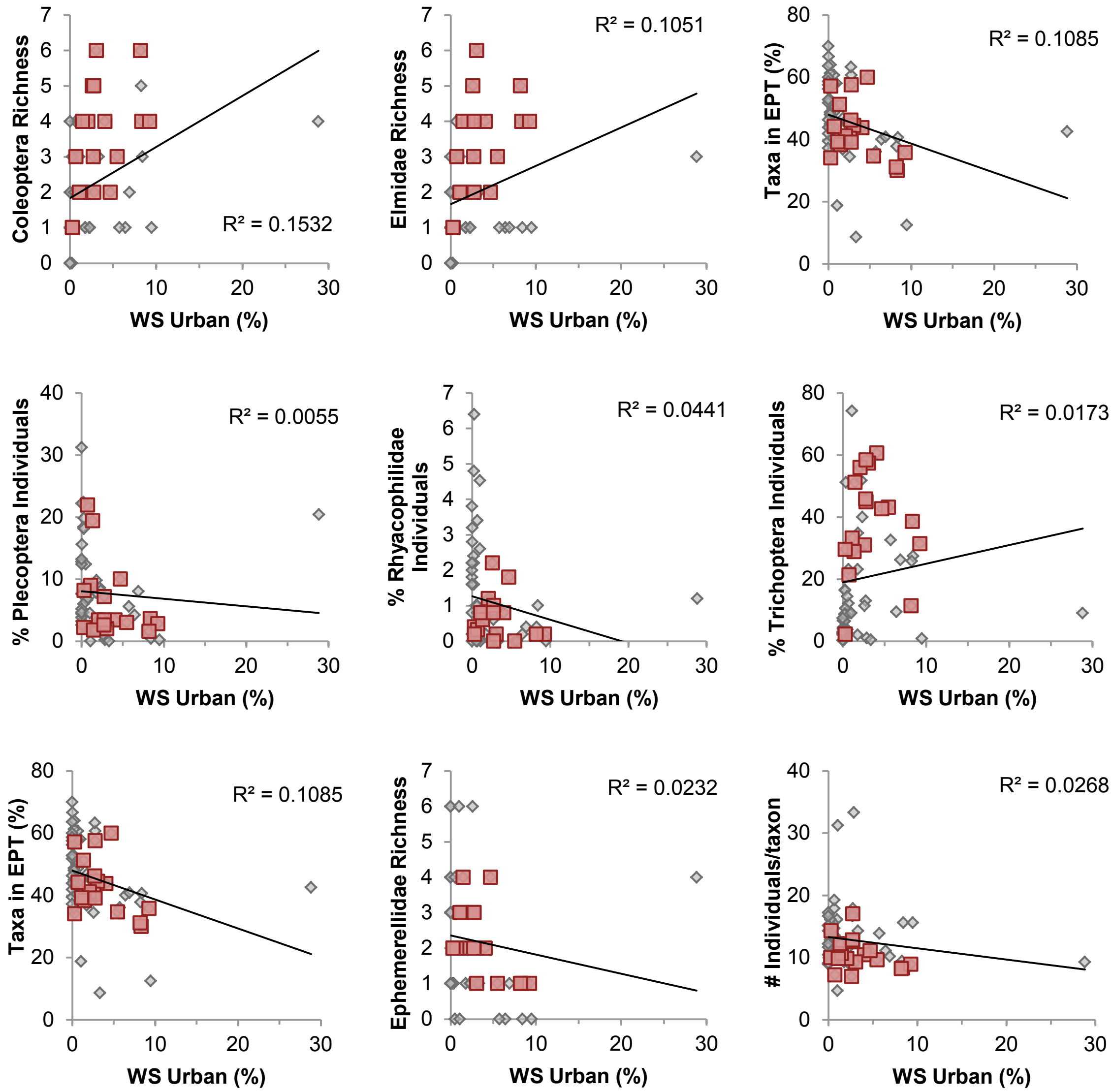


Figure H-2. Plots of non B-IBI metric response to watershed urbanization (10-18 of 18 metrics).

APPENDIX I: PLOTS OF CANDIDATE METRICS AND LOCAL URBANIZATION

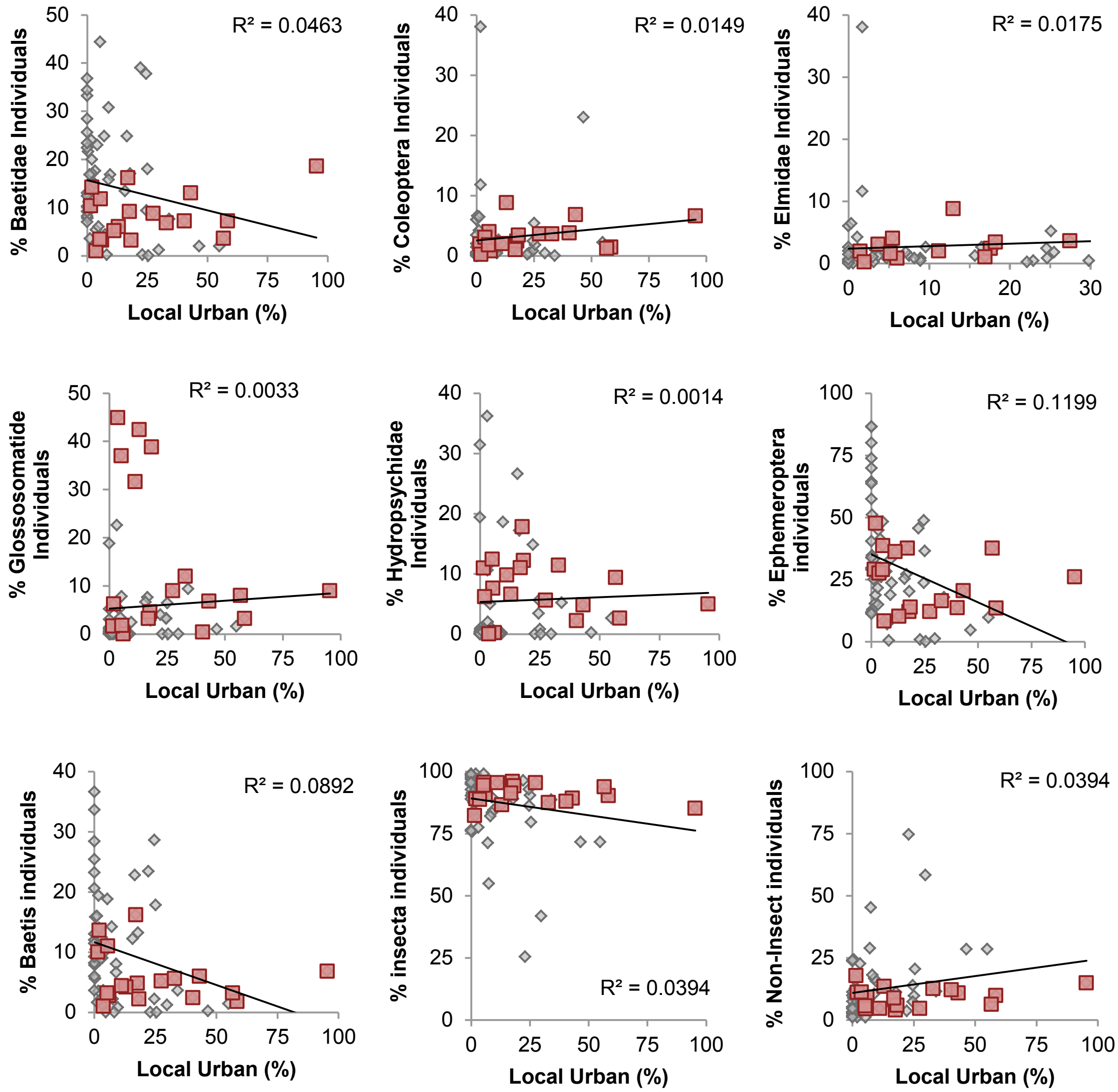


Figure I-1. Plots of non B-IBI metric response to local urbanization (9 of 20 metrics).

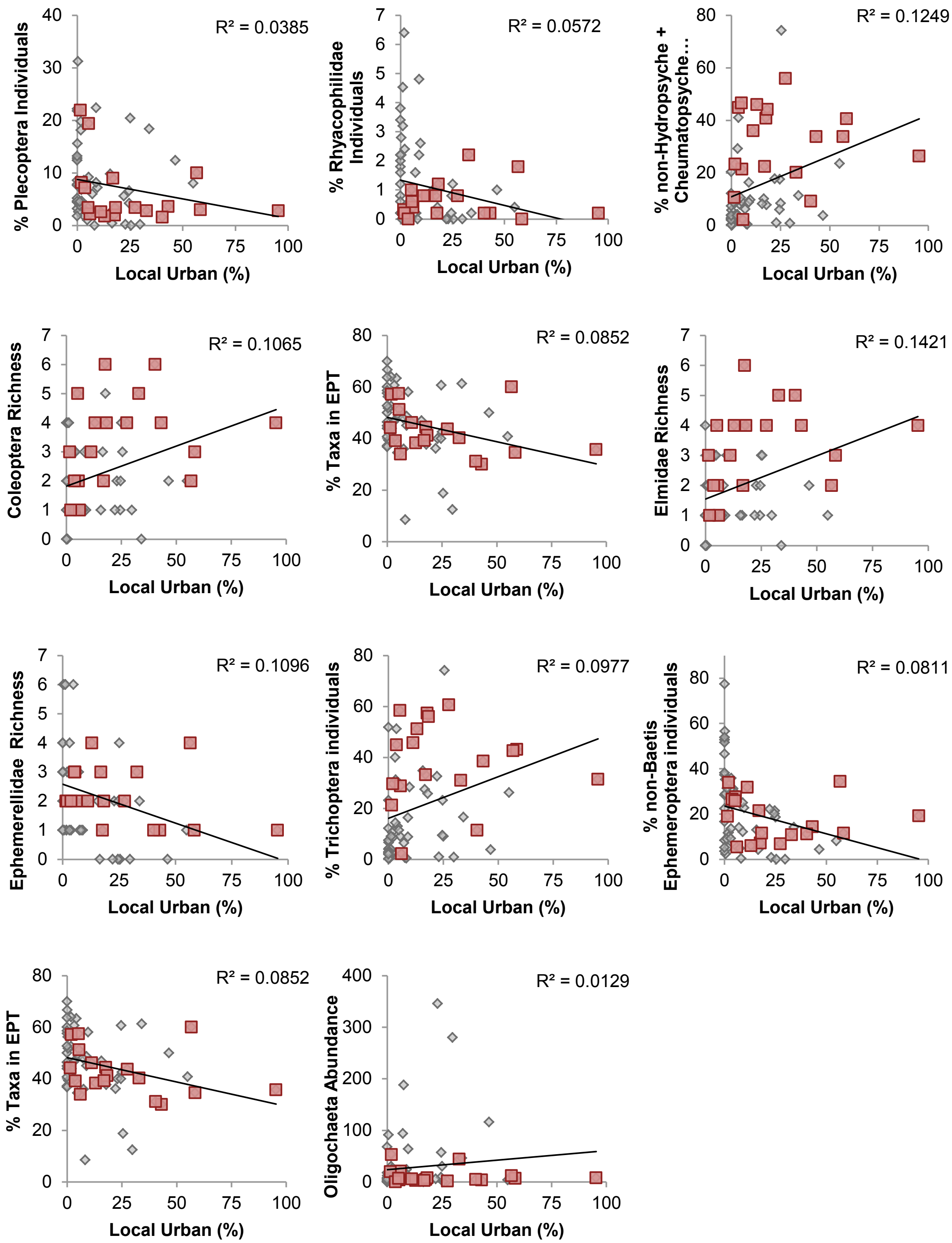


Figure I-2. Plots of non B-IBI metric response to local urbanization (11 of 20 metrics).

APPENDIX J: SEPTEMBER 2013 PRECIPITATION

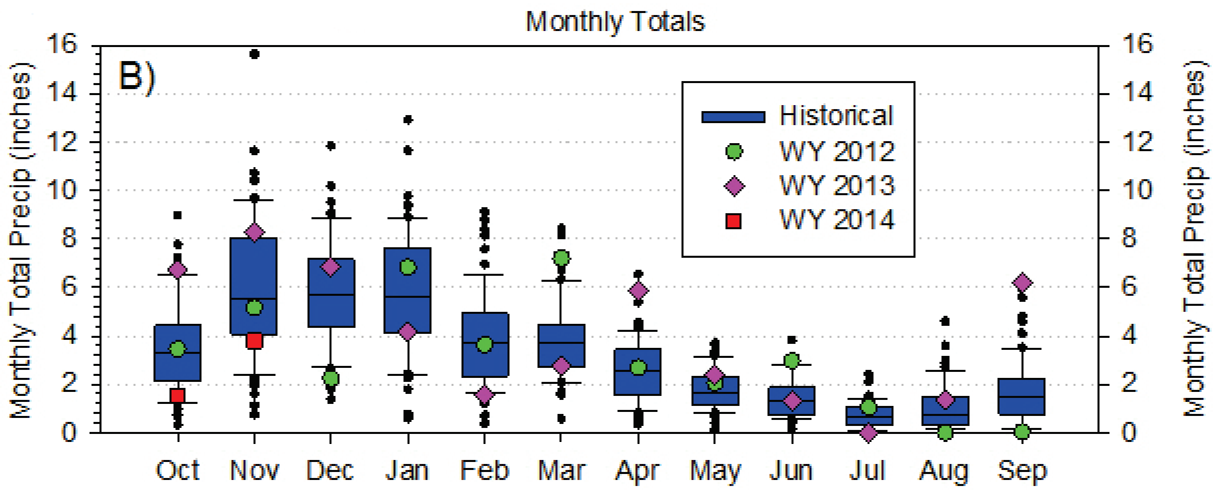


Figure J-1. Monthly precipitation for the SeaTac gauge. September 2013 was the wettest September on record. Data were compiled by King County from the NOAA National Weather Service Report for SeaTac (King County 2013d).

APPENDIX K: SKAGIT RIVER FLOW CONDITIONS (SEPT. & OCT. 2013)

USGS 12194000 SKAGIT RIVER NEAR CONCRETE, WA

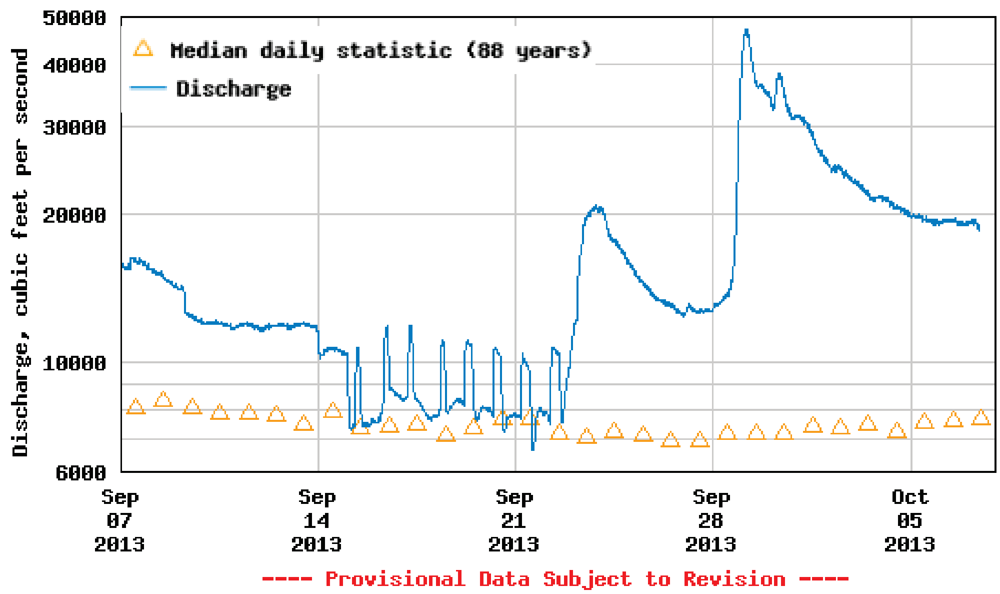


Figure K-1. Hydrograph for the USGS Skagit River gauge near Concrete (12194000), Sept. 7 to Oct. 7, 2013 (USGS 2013a).

USGS 12181000 SKAGIT RIVER AT MARBLEMOUNT, WA

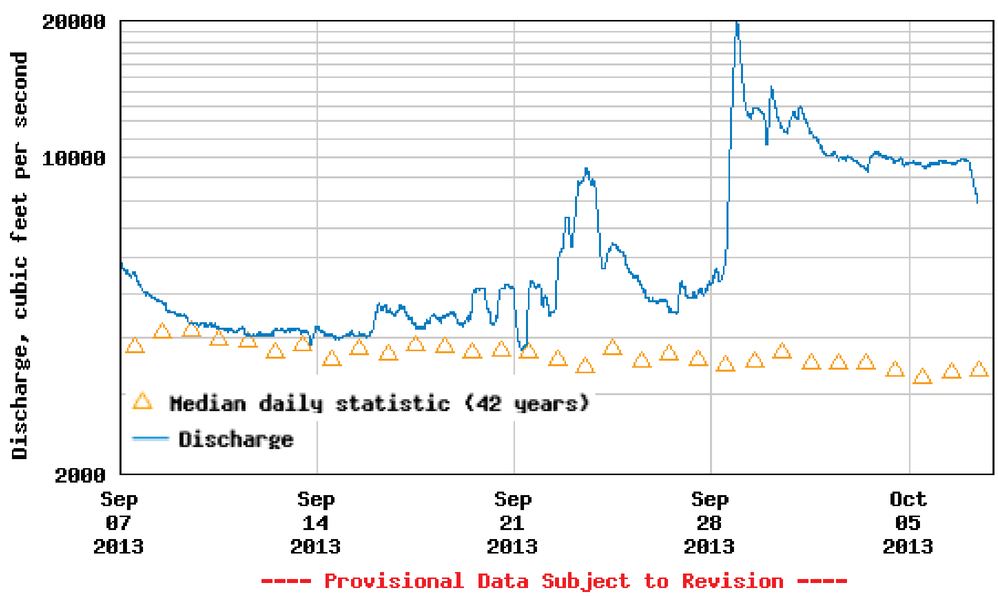


Figure K-2. Hydrograph for the USGS Skagit River gauge at Marblemount, Sept. 7 to Oct. 7, 2013 (USGS 2013b).

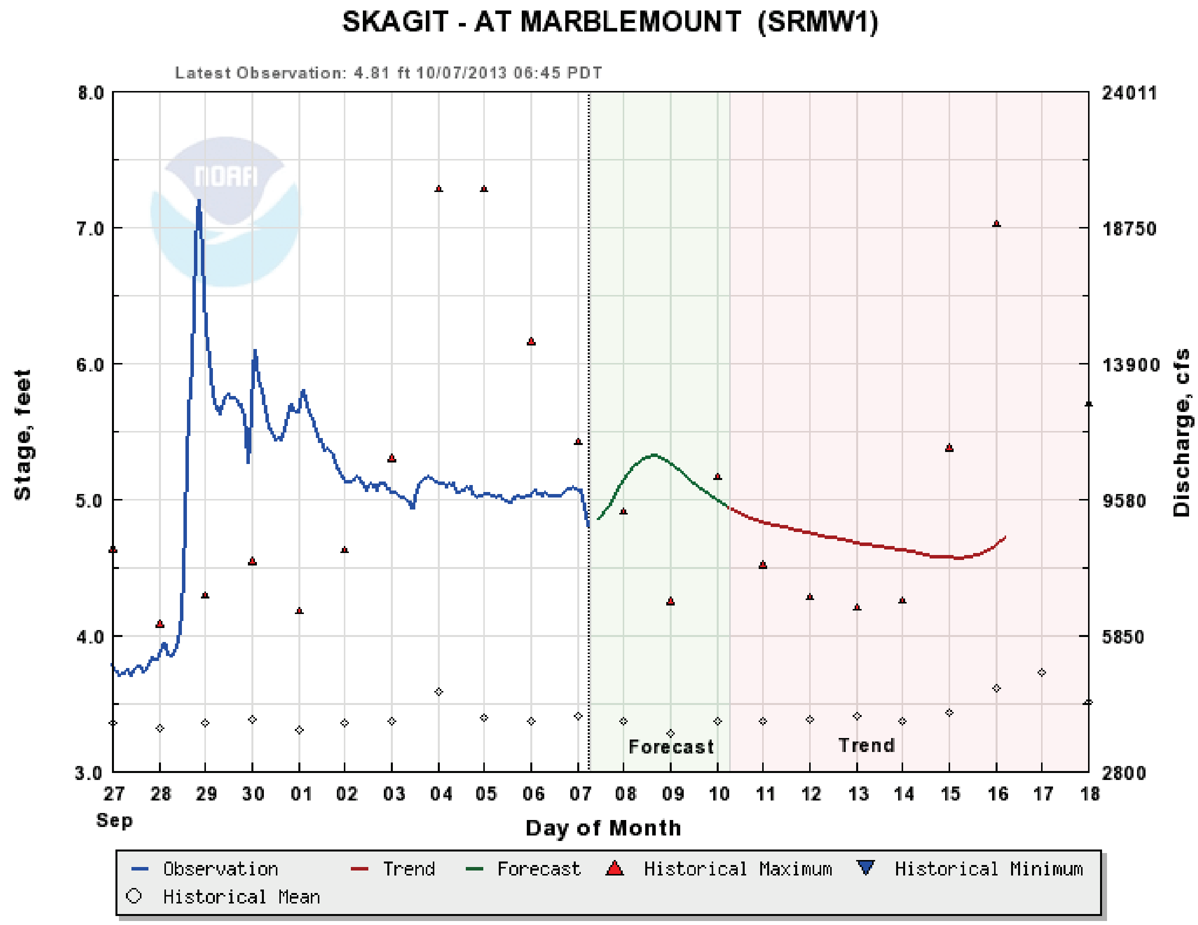


Figure K-3. Hydrograph for the Skagit River at Marblemount, Sept 27- Oct 7, 2013 with projects through Oct 16th and stage (NOAA 2013a).

APPENDIX L: SNOQUALMIE RIVER FLOW CONDITIONS (SEPT. AND OCT. 2013)

Sampling was attempted on the Snoqualmie River on September 23, 2013 near the peak of the hydrograph, but flows created unsafe conditions and no samples were collected (Figures L-1 and L-2).

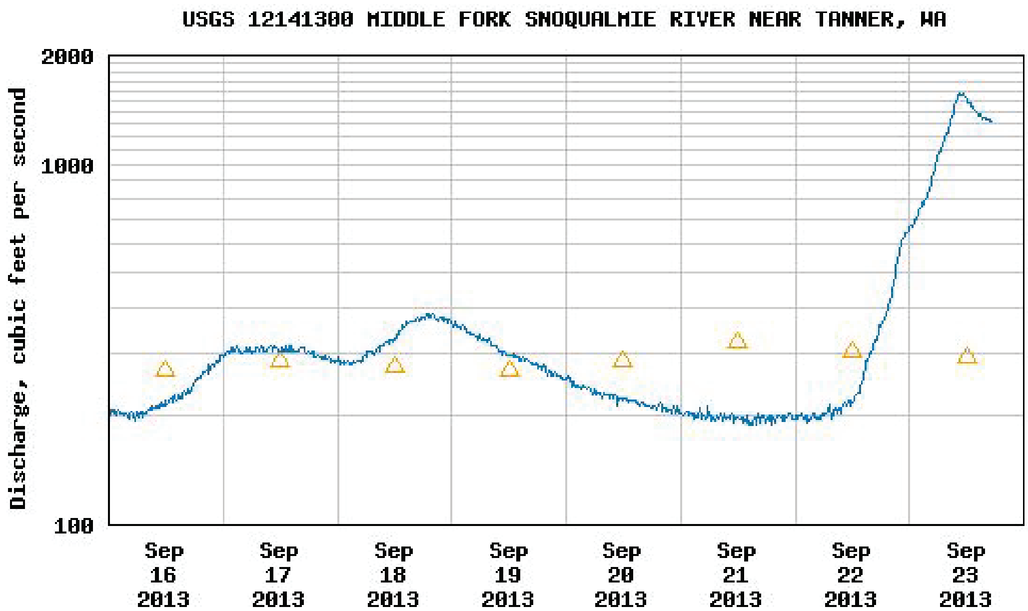


Figure L-1. Hydrograph for the Middle Fork Snoqualmie River USGS gauge generated on September 23, 2013 (USGS 2013c).

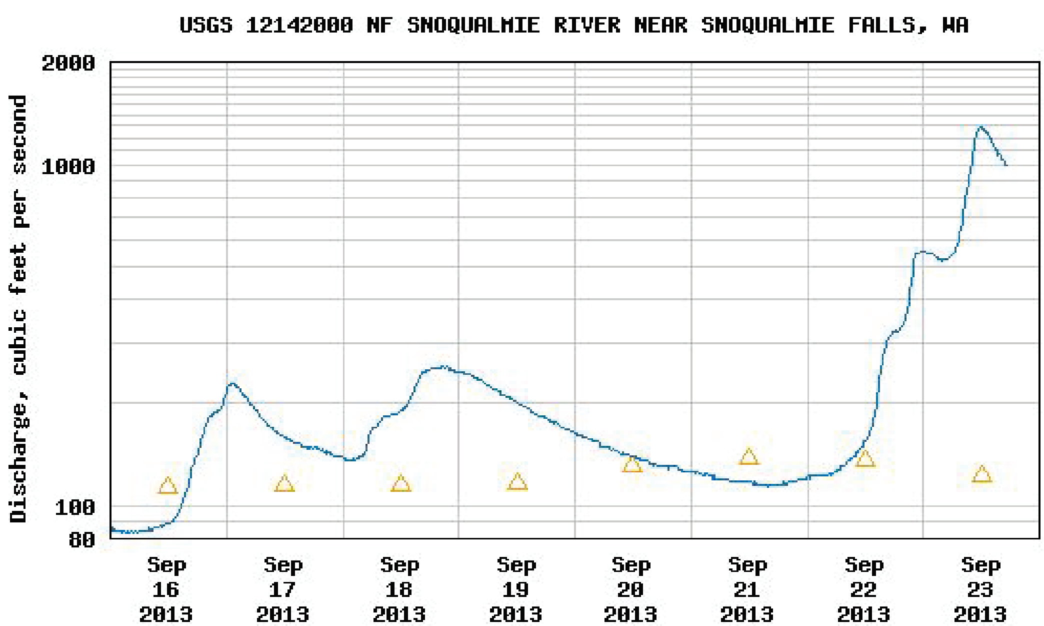
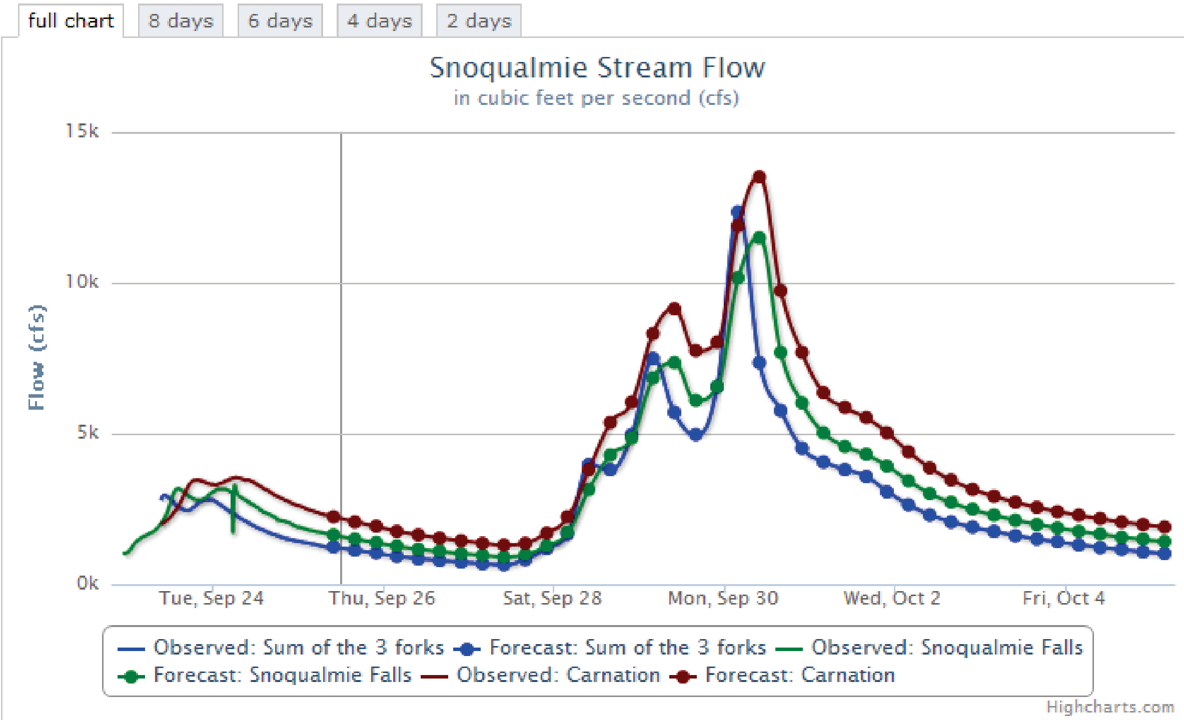


Figure L-2. Hydrograph for the North Fork of the Snoqualmie River USGS gauge generated on September 23, 2013 (USGS 2013d).

September 24–October 4: Sampling was planned for September 30 or October 1, 2013, but was called off because of high flow projections (Figure L-3).



Sum of the 3 forks - Station Details, NOAA Hydrograph: GARW1 SNQW1 TANW1

Latest reading:

Wed 09/25/13 11:15 AM	1182 cfs	+20.0 cfs/hr

Past 24hr max:

Tue 09/24/13 11:15 AM	2031 cfs

Forecasted crests: (published Wed 09/25/13 08:48 AM)

Sat 09/28/13 11:00 AM	3981 cfs
Sun 09/29/13 05:00 AM	7504 cfs
Mon 09/30/13 05:00 AM	**12349 cfs**

Figure L-3. Hydrograph for the Snoqualmie River generated on September 25, 2013 and including data from Sept. 24 and forecasts through Oct. 4 (Floodzilla 2013)

Raft sampling for October 9, 2013 was proactively cancelled because of high flow projections of stage approximately 1.5 feet higher than pre-storm summer baseflow conditions. Raft sampling was successfully conducted on October 15 after flows dropped (Figures L-4 and L-5).

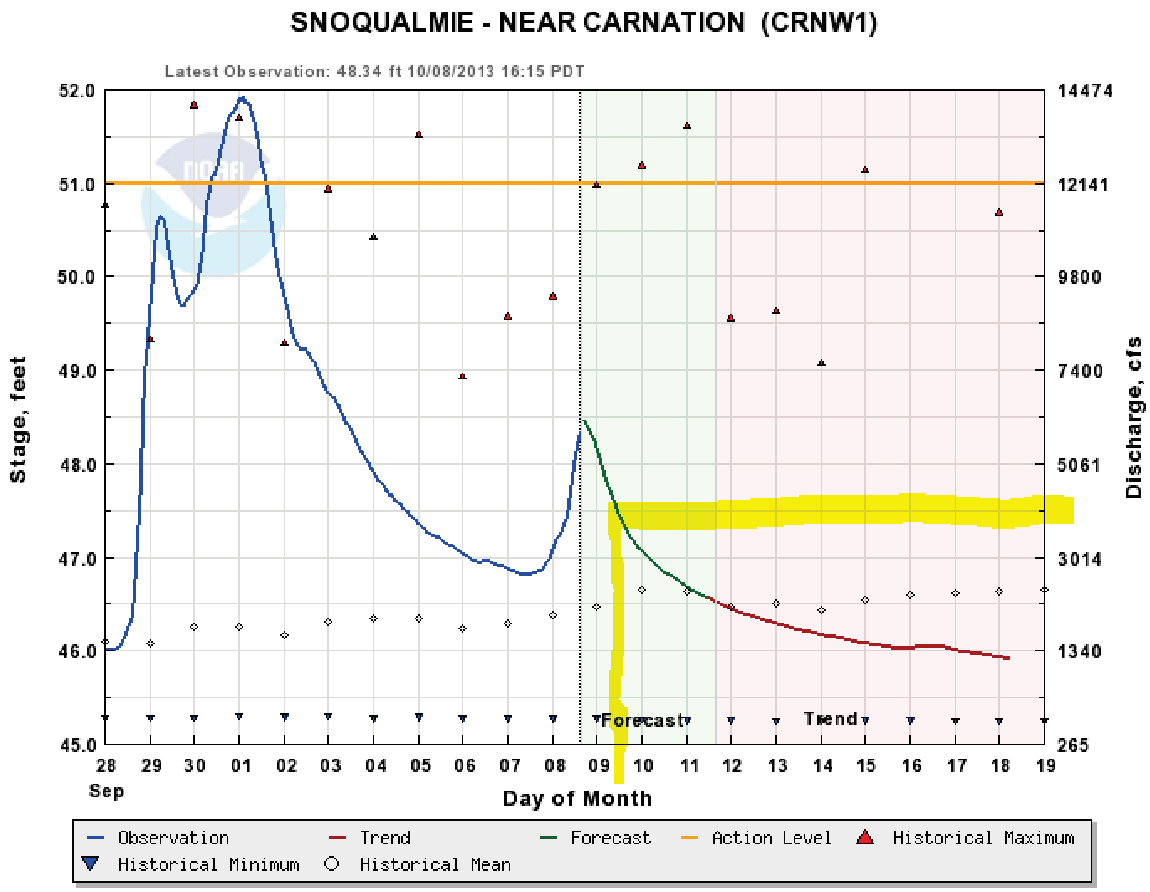


Figure L-4. Hydrographs for the mainstem Snoqualmie River USGS gauge near Carnation, Washington generated on October 8, 2013 (NOAA 2013b). Boat sampling had been scheduled for October 9th (shown by the yellow highlighting) but was proactively cancelled based on this forecast because the stage was approximately 1.5 feet higher than pre-storm summer baseflow prior to September 28.

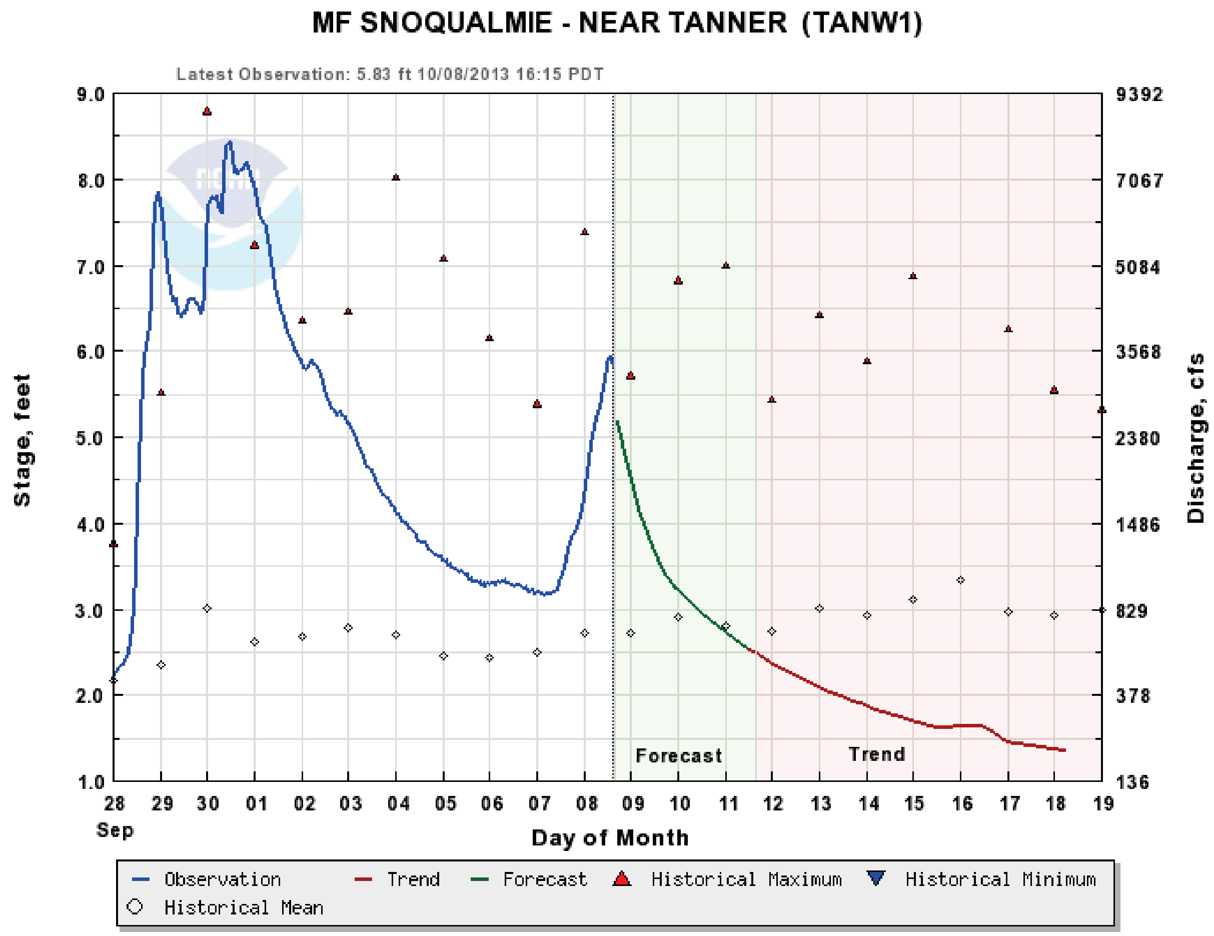


Figure L-5. Hydrographs for the mainstem Snoqualmie River USGS gauge near Tanner, Washington generated on October 8, 2013 (NOAA 2013c). Boat sampling had been scheduled for October 9th but was proactively cancelled based on this forecast because the stage was approximately 1.5 feet higher than pre-storm summer baseflow prior to September 28.