Development of an Index of Biotic Integrity (IBI) for Deer Creek, Nevada County, California

Family-level IBI for citizen-science bioassessment

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Introduction

Bioassessment is the science of using aquatic organisms as indicators of the ecological condition of streams and rivers. While several types of organisms (fish, benthic macroinvertebrates, amphibians, diatoms, riparian birds, periphyton, macrophytes, etc.) can be used for bioassessment, benthic macroinvertebrates are the most commonly used biota for stream ecosystem assessment. Benthic macroinvertebrates are small aquatic animals without backbones that live on and under submerged rocks, logs, sediment and debris at some period in their life. Some benthic macroinvertebrates are highly sensitive to changes in their aquatic environment and can act as continuous indicators of the conditions of their stream habitat. Benthic macroinvertebrates are good subjects for bioassessment because invertebrates are easy to sample, have a wide range of responses to anthropogenic disturbance stressors, and are relatively sedentary and long-lived. Human activities that disrupt the natural processes in a watershed can have a significant impact on the types and abundances of benthic macroinvertebrates found in a stream reach.

Benthic macroinvertebrate data sets can be simplified into measures of biological condition known as indices of biotic integrity (IBIs). An index of biotic integrity uses multiple characteristics of the benthic macroinvertebrate assemblages that describe the structure and function of the aquatic community. These metrics are effective measures for bioassessment if they respond to anthropogenic disturbances that disrupt the natural processes in a watershed in a predictable way (Barbour et al. 1996). The purpose of an index of biotic integrity is to use these community metrics of benthic macroinvertebrate assemblages to classify and assess the biological health of streams and their respective watersheds.

Biological monitoring and assessment is a key step for the protection of the integrity of clean and healthy streams. Resident aquatic biota reflect the habitat quality of a waterway in a more comprehensive manner than many chemical or physical measures because they integrate all of the biogeochemical influences to which they are exposed throughout their lifetimes (Karr 1991, Barbour et al. 1996, 2000, Karr and Chu 2000). Biological systems can also respond to changes that are generally not detected by chemical toxicity tests including temperature changes, sediment deposition, nutrient runoff and habitat degradation (Karr and Chu 1999, Barbour et al. 2000). Biological integrity is defined as the ability to support and maintain a balanced assemblage of organisms having species composition, diversity, and functional organization comparable to that of the natural habitat of the region (Karr 1991). The idea that improvements in biological integrity will follow improvements in chemical water quality has not always been supported by experience, suggesting that other factors, invisible to chemical monitoring, concurrently degrade water and aquatic habitat quality (Yoder and Rankin 1998, Karr and Chu 1999). IBIs use reference sites, which are considered to be the least disturbed sites in a region, to understand the range of natural variability of benthic macroinvertebrate assemblages at sites having few human impacts (Karr 1991).

The Deer Creek family-level Index of Biotic Integrity fills in a gap for citizen-science based monitoring programs. Most developed IBIs require genus or species level identification, which is expensive, time intensive, and requires expert knowledge. In contrast, family level identification is feasible for groups operating with limited budgets, time, and expertise, provided they receive adequate training, equipment and ongoing support. An IBI is advantageous for citizen-scientists since it is relatively easy to calculate from collected data and presents biological community data in a very straightforward way. An IBI uses a broader array of responsive biological signals than multivariate analyses based solely on species composition and abundance matrices (Karr 1999, Karr and Chu 2000). The Deer Creek family-level IBI can be viewed as a model showing that rapid bioassessment analysis using benthic macroinvertebrates is feasible using citizen-science generated data. The objective of the Deer Creek family-level IBI is to create a bioassessment system to assess changes in the Deer Creek biological community using family-level taxonomic identification of biological samples collected by volunteer, citizen-scientists.

Methods

Study area

Deer Creek is located on the west slope of the Sierra Nevada mountain range near Nevada City, California. The main stem of Deer Creek flows through three reservoirs on the 30-mile path from the headwaters at 4,800 feet (1,500 m) to the confluence with the Yuba River at 300 feet (90 m). The Deer Creek watershed is over 57,000 acres (230 km^2) and contains 120 miles of perennial streams and creeks. The creek meanders though mixed-conifer forest, residential areas, parks, steep-walled granite canyons, oak woodlands, and agricultural areas. The watershed has a long legacy of human impacts including hydraulic mining during the California gold rush. The water quality and health of the creek continues to be threatened today by residential development, storm runoff, water management, logging, and agriculture. In 1999, the United States Geological Survey found high levels of mercury from past gold mining in the creek (May et al. 2000). Sierra Streams Institute (formally known as Friends of Deer Creek) created a citizen science monitoring program in 2000 to measure water quality and biological conditions in Deer Creek. The lower section of the creek has been labeled a 303(d) impaired waterway by the California State Water Resources Control Board, for its high pH (CRWQCB-CVR 2009, Wood et al. 2011).

Citizen-scientists at Sierra Streams Institute collect water quality data (dissolved oxygen, pH, water temperature, nutrients, conductivity, bacteria, turbidity) at 17 sites in the Deer Creek watershed every month (Figure 1). Monitoring sites are located at junctions of major tributaries as well as below dams and the effluent pipes of wastewater treatment plants. Benthic macroinvertebrates are sampled at 13 of these sites bi-annually (June and October since the fall of 2000), following the California State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP) protocols. Targeted riffle composite protocol (CSBP 1999) was used from 2000 to 2009 and reach wide benthos (multi habitat) protocol (SWAMP 2007) has been used since 2010. Targeted-riffle and reach-wide benthic macroinvertebrate samples were used interchangeably for the development of the IBI and analysis (Rehn et al. 2007). Benthic macroinvertebrates are collected at each transect by sampling a 1-foot by 1-foot area in front of an aquatic D-net (0.5 mm mesh size). The larger rocks in the sample area are picked up, rubbed and rinsed to remove sessile and clinging taxa, and placed outside the sample area. Benthic macroinvertebrates from all the sample areas are then transferred from the D-net to a 500 µm mesh screen and any coarse organic matter or large stones are removed. Benthic macroinvertebrates are preserved in 95% Ethanol. The BMI composite samples are randomly subsampled using a gridded tray to reach a minimum of 500 individuals in each sample. The BMIs were identified by trained Sierra Stream Institute volunteers who followed standardized quality control and assurance procedures. All insects were identified to family while non-insects were identified to either order or class. Quantitative and qualitative measurements of physical habitat at each stream reach were assessed following the June benthic macroinvertebrate collection (SWAMP 2007).

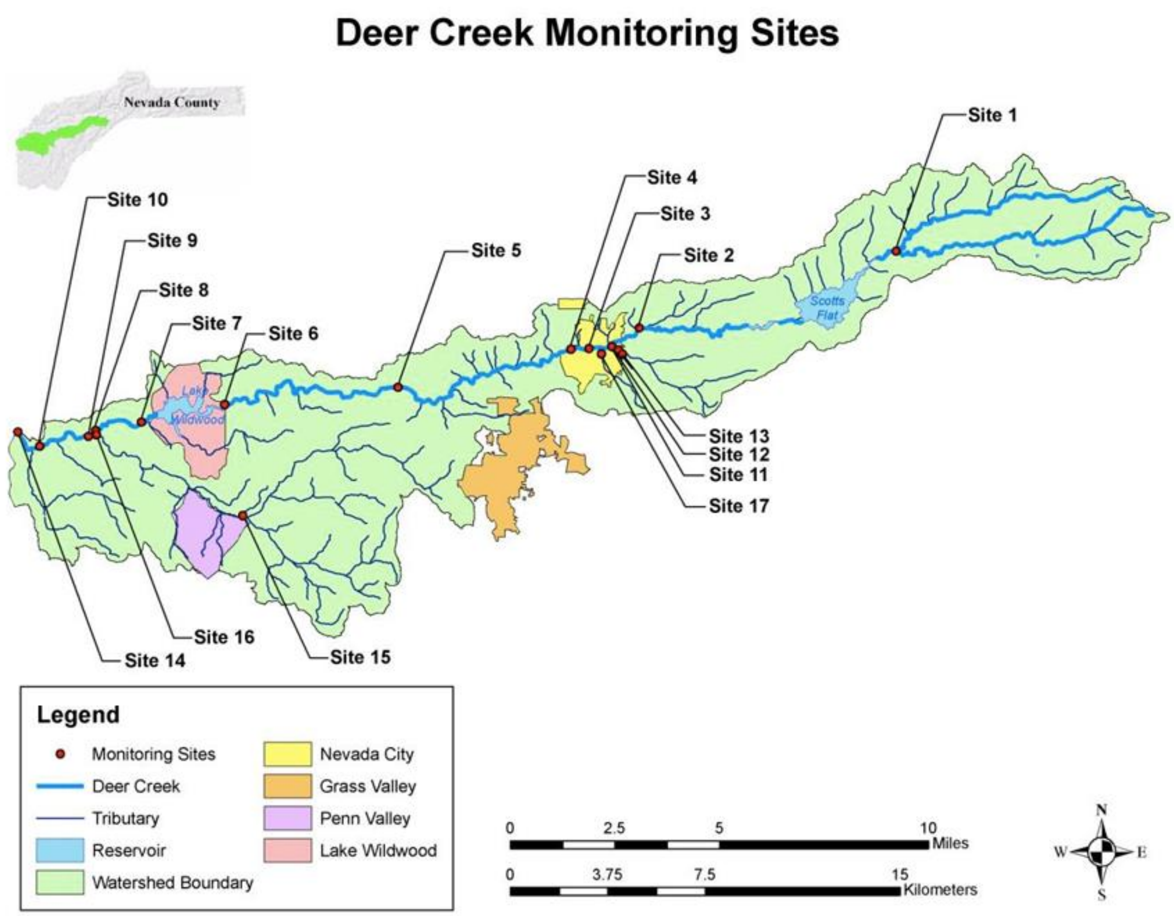

Figure 1. Map of monitoring sites on Deer Creek, Nevada County, California.

Reference sites

Reference sites represent biological conditions when human disturbance is absent or minimal (Hughes 1995, Stoddard et al. 2005). The search for reference sites focused on finding the best available sites within the Sierra Nevada foothill region. Many of the local watersheds in the Sierra foothills region have been permanently altered by gold mining, making minimally disturbed sites difficult to find. Reference sites were selected using quantitative GIS analysis (ESRI ArcMAP 10) and field visits to candidate sites. The initial search was limited to a 40 km buffer around Deer Creek to find best attainable sites similar to the physical conditions within the Deer Creek watershed. Twenty candidate sites from streams and creeks in the 40 km buffer area were assessed for land cover disturbance, water quality, site access, elevation and watershed area. Watershed-scale disturbance was measured using land cover classification from the National Land Cover Dataset (Fry et al. 2011). Watershed boundaries were delimited using AGWA 2.0 (Automated Geospatial Watershed Assessment Tool). Site elevation was calculated using a digital elevation model from the National Elevation Dataset. Candidate reference sites were required to pass a series of chemical and physical criteria to be considered minimally disturbed. Reference candidate sites were evaluated using landscape-scale screens of urban development, impervious surfaces, road density and riparian development (**Table 1**). The landscape disturbances were evaluated on two spatial scales: percentage of the entire watershed and percentage of a 2 km by 200 m upstream riparian zone bordering the creek and upstream tributaries measured from the bottom of the sampling reach. Candidate reference sites were removed from the reference pool if the watershed area was larger than 232 km^2, the elevation was outside the range of 90-1500 m, the streams were non-wadable, and/or access points required crossing through private property (physical conditions similar to sites on Deer Creek). Site visits to the candidate reference sites evaluated reach-scale disturbance measurements including vegetation management, bank stability, erosion, recent logging, development in riparian corridor, and water quality. Three sites passed the land-use and local conditions screens and were selected as reference sites. Benthic macroinvertebrates and water quality samples were collected at the three reference sites in June and October 2012. Physical habitat assessment at the reference sites was done following the sampling in June. The development group dataset consisted of the benthic macroinvertebrate data from the 2009 and 2010 sampling seasons from Deer Creek which were the two most recent years of complete data.

Table 1. Disturbance thresholds for reference sites

Disturbance Measure	Threshold
Urban Development	<5% of watershed <5% riparian zone (2 km by 200 m upstream)
Impervious Surfaces	<10% of watershed <10% of riparian zone
Density of Roads	<2.5 km of roads/km^2 in watershed

Metrics screening and IBI evaluation

Forty-seven benthic macroinvertebrate metrics (**Appendix A**) adapted from published literature were evaluated for inclusion in the Deer Creek family-level IBI (Barbour et al. 1996, Fore et al. 1996, Everta 2006, Herbst and Silldorff 2009). The metrics describe taxonomic richness, assemblage composition, tolerance/intolerance values, or feeding ecology of the collection of benthic macroinvertebrates in a sample. Metrics were evaluated for inclusion in the Deer Creek family-level IBI based on five criteria: sufficient range for scoring, discrimination of reference conditions, limited seasonality, responsiveness to reach-scale and watershed-scale disturbance gradients and lack of correlation with other responsive metrics.

We evaluated metrics with sufficient range variability in order to distinguish the reference conditions from the disturbed conditions by graphically visualizing the distribution of metric values of the development set and the reference set. Metrics were then screened to select the most robust metrics that reflected anthropogenic disturbance gradients. Pearson correlation between stressor gradients was used to find non-redundant disturbance variables against which to test biological response (correlation coefficients $|r| \geq 0.7$ were considered redundant). The six stressor gradients used to screen metrics include percent of the watershed in urban development, percent of riparian zone (2 km x 200 m upstream from the bottom of the sampling reach) with impervious surfaces, Dissolved Oxygen (mg/L), pH, Turbidity (NTU) and Nitrate (mg/L).

Responsiveness of each potential metric was assessed using visual inspection of biotic metric vs. stressor gradient scatter plots and linear regression coefficients. Metrics were selected as responsive if they showed ether a linear or wedge shaped relationship with the stressor gradient (Blackburn et al. 1992). Metrics were individually tested for seasonality using a t-test to compare metric scores between the two sampling seasons for the entire Deer Creek dataset (2000-2011). Metrics that passed the range, responsiveness, seasonality and discrimination tests were checked for redundancy. Metrics with Pearson correlation coefficients $|r| \geq 0.7$ were considered redundant and the least responsive metric was eliminated.

Metrics were scored using a five point scoring system (See Appendix B for scoring thresholds for the individual metrics). A score of ‘5’ was given to the minimally disturbed end of the metric’s range and a score of ‘1’ was the most impaired end of the metrics range. If a metric had integer values (i.e. number of families), scoring breaks were established at every 20th percentile of the metric’s range. If a metric had decimal data, scores were split at every 20th data percentile of the developmental data set. Since the natural breakpoints in the distribution of a metric probably reflect relevant biology, the score scoring cutoffs were adjusted accordingly when these occurred (Fore et al. 1996, Karr and Chu 1999). The total IBI score for each site was combined into a composite index by summing the eight individual metric scores together. The Deer Creek family-level IBI has scores that range for 40 (reference-like conditions) to 8 (heavily impaired).

Results

Selection of reference sites

Three of the twenty sites within the 40 km buffer of Deer Creek (**Figure 2**) passed all land use and water quality screens and were considered best-available reference sites for Deer Creek. Five candidate reference sites (Rattlesnake Creek, Wolf Creek 1, Wolf Creek 2, Galen Creek and Boardman Canal) were removed from the reference candidate pool due to having a watershed with more than 5% of the area in urban development. Two sites (Yuba River and North Fork American River) were considered non-wadeable since the watershed area above each of the two sites was significantly larger than the Deer Creek watershed (232 km^2). Three additional sites (New York Creek, Martin Creek, French Creek) were removed from consideration because access points to the creeks went through private property. Ground-truthing the GIS analysis with site visits eliminated several sites due to pronounced reach-scale human disturbance. Rock Creek and Greenhorn Creek were considered unsuitable as reference conditions due to excessive riparian alteration/development and proximity to an EPA Superfund site (Lava Cap Mine), respectively. Macroinvertebrate lab volunteers were able to process additional samples from a maximum of three reference sites within the time frame of the project, thus determining the final number of reference sites chosen.

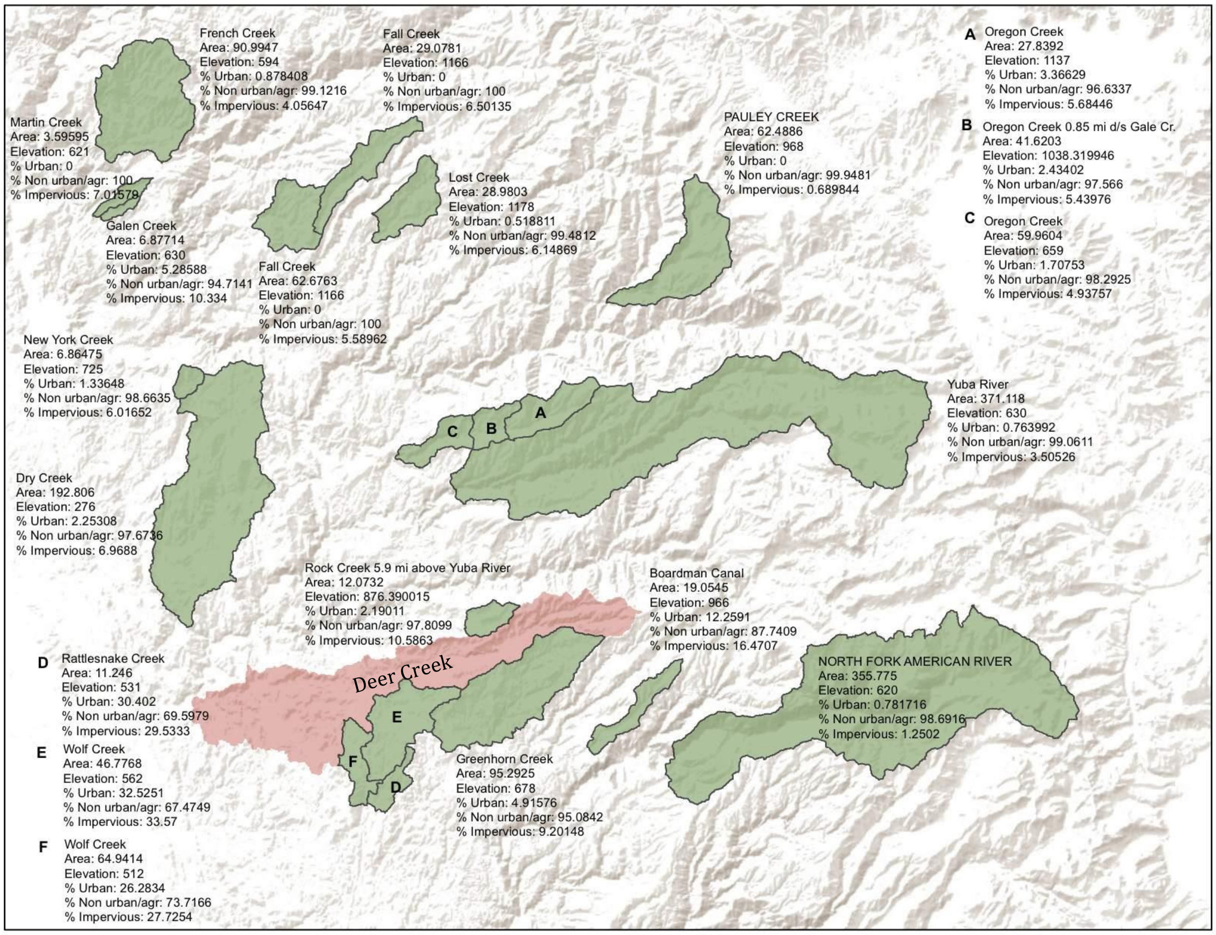

Figure 2. Map of the candidate reference sites for the Deer Creek index of biotic integrity. The polygons show the location of Deer Creek watershed and the watershed area above each candidate reference site. For each candidate site, the watershed area (km^2), elevation (m), percentage of watershed in urban development, percentage of watershed natural (nonurban or agriculture land cover) and percentage of watershed with impervious surfaces are listed.

The three candidate reference sites used for the development on the Deer Creek family-level IBI are Oregon Creek at Camptonville (R1), Dry Creek below Collins Reservoir (R2), and Oregon Creek at Tippe Canoe Mine Rd (R3). The watersheds of the three reference sites had less urban development and impervious surfaces in their watersheds than the monitoring sites on

Deer Creek (**Figure 3**). The sites near the headwaters of Deer Creek (Sites 1 & 2) and Squirrel Creek (Site 15) were the only sites in the Deer Creek watershed that had urban development and impervious area below the reference condition thresholds.

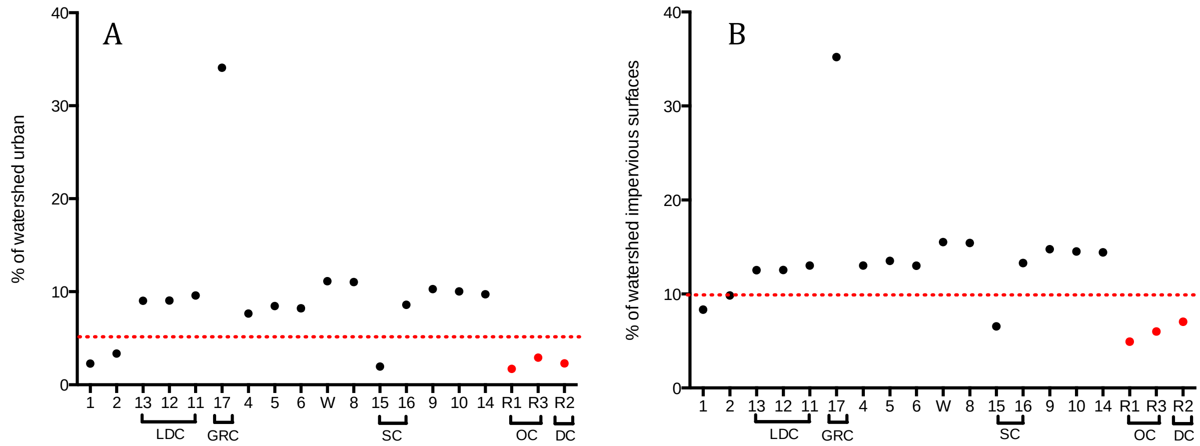

Figure 3. The percentage of A) urban development and B) impervious surfaces in the watershed above the monitoring sites on Deer Creek and IBI reference sites. LDC= Little Deer Creek, GRC= Gold Run Creek, SC= Squirrel Creek, OC= Oregon Creek, DC= Dry Creek. The dashed horizontal line shows the 5% urban development and 10% impervious surfaces, which are the thresholds for reference conditions.

<u>Selection of metrics</u>

Three metrics had little or no variation in range and were excluded from consideration for the family-level IBI. Eight metrics were unable to clearly discriminate reference conditions from the disturbed sites. Nine metrics exhibited strong seasonality with a significant difference in raw metric scores between the samples collected in October and the samples collected in June. Eleven metrics were unresponsive to one or more of the disturbance gradients. Eight metrics were removed due to correlations with other more responsive metrics. See **Appendix A** for the rationale for exclusion of each individual metric.

We selected eight metrics for inclusion in the family-level IBI (**Figure 4**): Insect family richness, Plecoptera family richness, Trichoptera family richness, percent EPT (Ephemeroptera, Plecoptera and Trichoptera), percent tolerant (tolerance values ≥7), percent intolerant (tolerance values ≤ 3), Hilsenhoff's biotic index, and percent predators. These eight metrics passed the range, discrimination and responsiveness disturbance tests. The metrics % intolerant and % predators showed seasonality but were retained due to good responsiveness to disturbance gradients. The metrics included in the IBI are comprised of three richness metrics, one composition metric, three tolerance metrics and one trophic metric.

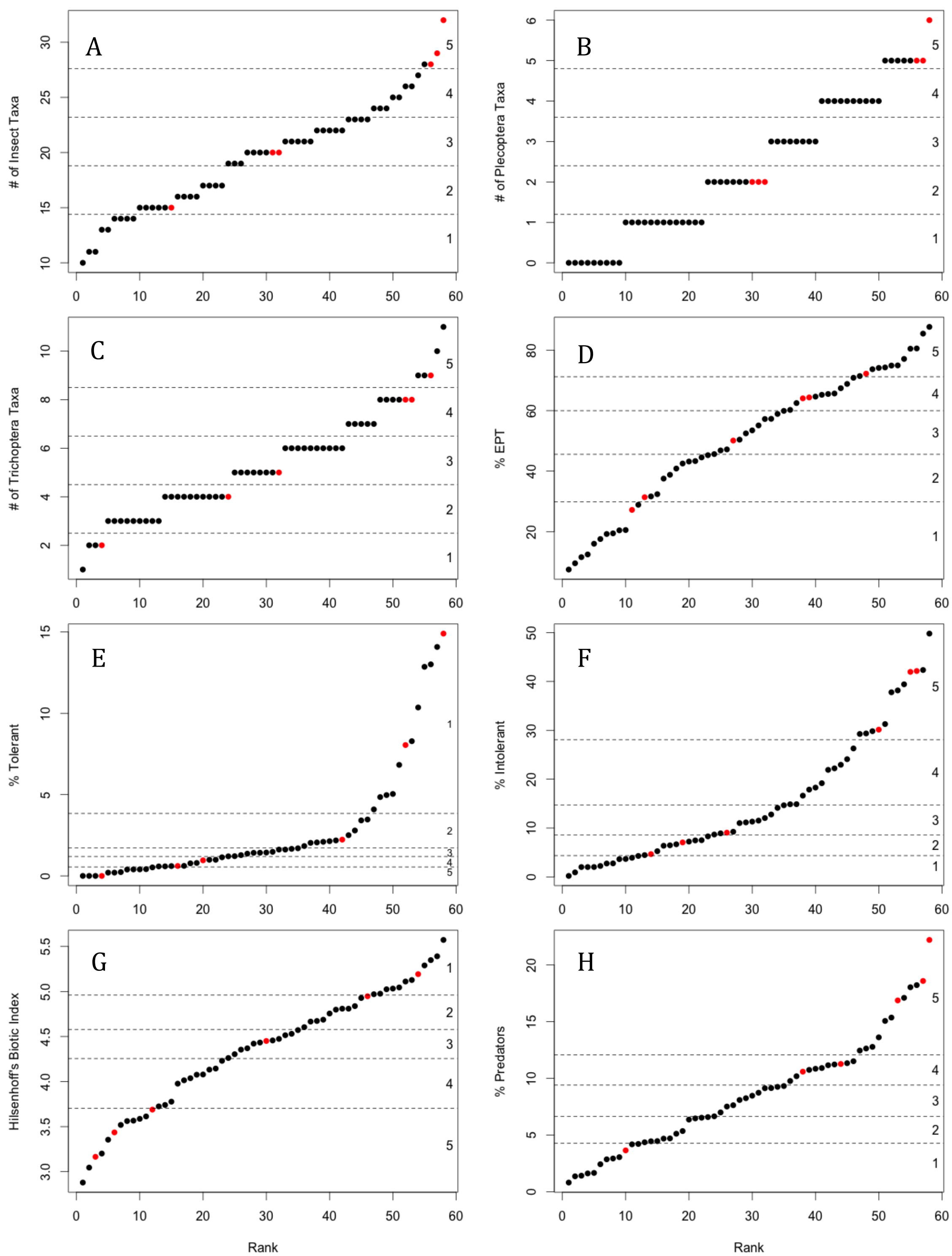

Figure 4. Ranked metrics retained for inclusion in the Deer Creek family-level IBI: A) Number of insect families B) Number of Plecoptera families C) Number of Trichoptera families D) Percent EPT E) Percent tolerant F) Percent intolerant G) Hilsenhoff's biotic index H) Percent predators. The metric values for the reference sites are shown in red and the development set in black.

Validation of IBI

Deer Creek benthic macroinvertebrate samples collected in June 2003 were identified to SAFIT level I by DFG Aquatic Bioassessment Lab. Since the samples were collected using the CSBP integrated riffle protocol, to reach a target of 500 individuals the results were subsampled using a Monte Carlo randomization. The genus/species identification was backed down to the family-level in order to enter into the Deer Creek family-level IBI. The family-level IBI was compared to several different IBIs that have been developed for finer taxonomic resolution (**Figure 6**). IBI scores for the data from Deer Creek were calculated using the Central Valley IBI (Rehn et al. 2008), North Coast IBI for the Chaparral and Oak Woodlands ecoregion as well as for the Klamath mountains ecoregion (Rehn et al. 2005) and the Eastern Sierra IBI (Herbst and Silldorff 2009). The Deer Creek family-level IBI performed most similarly to the North Coast IBI which is the ecoregion most comparable to the western Sierra foothills, where Deer Creek is located.

The composite IBI score was more correlated with land use disturbance (% of watershed urban and % of watershed impervious surfaces) than any individual metric (See **Appendix C** for Pearson correlation between IBI metrics, IBI score, water quality and land use). The metric % tolerant was the metric with the lowest level of correlation ($|r| = 0.28$) with the final IBI score. The IBI score was highly correlated (Pearson correlation coefficients $|r| \geq 0.7$) with several water quality variables including PO_4, Conductivity and water temperature.

The final composite IBI exhibited no obvious seasonality between the June and October sampling periods. The average IBI score for the entire twelve-year dataset was not significantly different between the summer and fall sampling seasons (t-test, $p = 0.5733$).

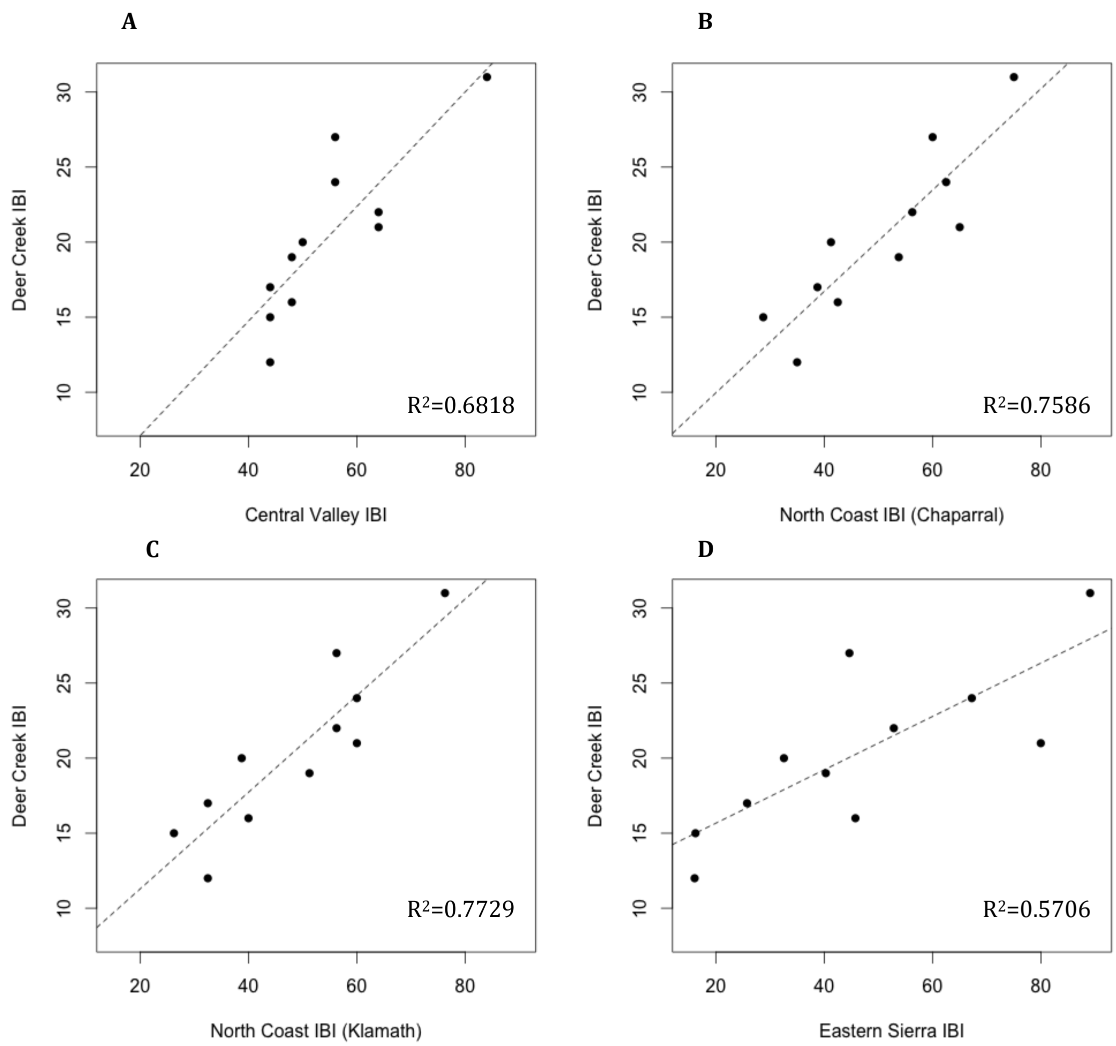

Figure 6. Comparison of the Deer Creek family-level IBI with A) Central Valley IBI (Rehn et al. 2008), B) North Coast IBI for Chaparral and Oak Woodlands (Rehn et al. 2005), C) North Coast IBI for the Klamath Mountains (Rehn et al. 2005), and D) Eastern Sierra IBI (Herbst and Silldorff 2009). Data from Deer Creek monitoring sites sampled in June 2003.

Discussion

This family level index of biotic integrity can be used as a general interpretive framework for citizen-science groups studying benthic macroinvertebrate samples collected at perennial streams in the western Sierra Foothills. The Deer Creek family-level index of biotic integrity fills in a gap for citizen-science based monitoring programs. Family-level identification is a low-cost option for assessing watershed health that is feasible for all watershed groups with enough proper training and equipment. An IBI is useful for citizen-scientists since it is easy to calculate from collected samples and simplifies complex biological community data into a single score. An IBI uses a broader array of biological signals that respond to human-induced changes than do multivariate analyses based solely on species composition and abundance matrices (Karr 1999, Karr and Chu 2000).

While having only three reference sites is a small sample that may not capture the total variability of the benthic macroinvertebrate community in Deer Creek, this dataset is sufficient for a citizen-science based group with limited resources. The three reference sites that were selected for the Deer Creek family-level IBI represent the best attainable sites in our local area. The reference sites should not be considered pristine, especially after field visits to the sites revealed small scale human disturbances such as mining claims, but rather viewed as a point of comparison to help score the upper range of benthic macroinvertebrate community metrics. Reference sites represent the best attainable conditions in a rapidly changing landscape. It would be beneficial to summarize physical and chemical data on habitat quality to serve as an additional indicator of ecological integrity of the survey stream reaches.

While there was no evidence of seasonal differences in IBI performance, the question of whether summer and fall samples need separate scoring scales could be more thoroughly answered if the reference sites had been sampled for multiple years. The comparison of the seasonality of the IBI was based on the Deer Creek data, not on the conditions at the reference sites. It is necessary to continue to sample at the reference sites for multiple years to gain a better understanding of the natural annual and seasonal variability at unimpaired sites. In addition, it is crucial to test the IBI model with other validation data sets of new reference and test sites generated by other citizen-science watershed monitoring groups.

A family-level IBI may not be sensitive enough to differentiate subtle changes in water quality, largely due to the low insensitivity of family-level identification. A rapid field biotic index based on family-level identification usually indicates greater pollution in clean streams and less pollution in stressed streams than an index based on genus and species (Hilsenhoff 1988). Volunteers were unable to collect or identify the cryptic or rare families needed for a site to receive an excellent bioclassification (Penrose and Call 1995). Family-level classification has the potential to lose significant biological data with the loss of resolution. An individual species may show far greater sensitivity than its family in respect to water quality, flow preference, food, etc. A family often contains taxa covering a wide range of tolerance values at the genus/species level, but the reduction of the information to the family level inevitably produces intermediate tolerance values (Lenat and Resh 2001). There has been success using family-level volunteer-collected data in educating local communities about river health, establishing long-term trends for streams, identifying streams in need of restoration, locating pollution problems and providing baseline information on locations were state and local governments lack data (Firehock and West

1995). The Deer Creek family-level index of biotic integrity can be used as an interpretive framework to allow citizen-science groups to use bioassessment to monitor the health of streams and rivers.

Literature Cited

Barbour, M., J. Gerritsen, G. Griffith, R. Frydenborg, E. McCarron, J. White, and M. Bastian. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. Journal of the North American Benthological Society 15:185–211.

Barbour, M. T., W. F. Swietlik, S. K. Jackson, D. L. Courtemanch, S. P. Davies, and C. O. Yoder. 2000. Measuring the attainment of biological integrity in the USA: a critical element of ecological integrity. Hydrobiologia 422-423:453–464.

Blackburn, T. M., J. H. Lawton, and J. N. Perry. 1992. A method for estimating the slope of upper bounds of plots of body size and abundance in natural animal assemblages. Oikos 65:107–112.

CRWQCB-CVR. 2009. Clean Water Act Sections 305(b) and 303(d) Integrated Report for The Central Valley Region. Pages 1–13. . Rancho Cordova, CA.

CSBP. 1999. California Stream Bioassessment Procedure. Pages 1–9.

Everta, J. 2006. Benthic Index of Biological Integrity (B-IBI) for the South Fork Trinity River Watershed. . Humboldt State University.

Firehock, K., and J. West. 1995. A brief history of volunteer biological water monitoring using macroinvertebrates. Journal of the North American Benthological Society 14:197–202.

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

Fry, J. A., G. Xian, S. Jin, J. A. Dewitz, C. G. Homer, L. Yang, C. A. Barnes, N. D. Herold, and J. D. Wickham. 2011. National Land Cover Database for the Conterminous United States. Photogrammetric Engineer & Remote Sensing 77:858–864.

Herbst, D., and E. Silldorff. 2009. Development of a Benthic Macroinvertebrate Index of Biological Integrity (IBI) for Stream Assessments in the Eastern Sierra Nevada of California. Pages 1–89.

Hilsenhoff, W. L. 1988. Rapid Field Assessment of Organic Pollution with a Family-Level Biotic Index. Journal of the North American Benthological Society 7:65–68.

Karr, J. 1991. Biological Integrity : A Long-Neglected Aspect of Water Resource Management. Ecological applications 1:66–84.

Karr, J. R. 1999. Defining and Measuring river health. Freshwater Biology 41:221–234.

Karr, J. R., and E. W. Chu. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Pages 1–206.

Karr, J. R., and E. W. Chu. 2000. Sustaining living rivers. Hydrobiologia 422-423:1–14.

Lenat, D. R., and V. H. Resh. 2001. Taxonomy and stream ecology: the benefits of genus-and species-level identifications. Journal of the North American Benthological Society 20:287–298.

May, J., R. Hothem, C. Alpers, and M. Law. 2000. Mercury bioaccumulation in fish in a region affected by historic gold mining: the South Yuba River, Deer Creek, and Bear River Watersheds, California, 1999.

Penrose, D., and S. Call. 1995. Volunteer Monitoring of Benthic Macroinvertebrates : Regulatory Biologists ' Perspectives. Journal of the North American Benthological Society 14:203–209.

Rehn, A. C., J. T. May, and P. R. Ode. 2008. An Index of Biotic Integrity (IBI) for Perennial Streams in California's Central Valley. . Rancho Cordova, CA.

Rehn, A. C., P. R. Ode, and C. P. Hawkins. 2007. Comparisons of targeted-riffle and reach-wide benthic macroinvertebrate samples: implications for data sharing in stream-condition assessments. Journal of the North American Benthological Society 26:332–348.

Rehn, A., P. Ode, and J. May. 2005. Development of a benthic index of biotic integrity (B-IBI) for wadeable streams in northern coastal California and its application to regional 305 (b). … , California.(Available from: http://www. swrcb. ca. gov/ …. . Rancho Cordova, CA.

SWAMP. 2007. Standard Operating Procedures for Collecting Benthic Macroinvertebrate Samples and Associated Physical and Chemical Data for Ambient Bioassessments in California. Pages 1–48.

Wood, J., M. O'Connor, K. Leach, G. Coney, F. Cunningham, M. Ben Ortiz, J. Sellen, and J. Hild. 2011. The Deer Creek Watershed Restoration Plan. Pages 1–326. . Nevada City, CA.

Yoder, C., and E. Rankin. 1998. The role of biological indicators in a state wwater quality management process. Environmental monitoring and assessment 51:61–88.

Appendix A: List of metrics evaluated for the Deer Creek family-level IBI

Metric	Hypothesized response to human influence[1]	Included in IBI?	Rational
Richness Measures			
Total Taxa	Decrease	No	Correlated with other metrics
Insect Taxa	Decrease	Yes	
Non-insect Taxa	Increase	No	Unclear reference separation
Ephemeroptera Taxa	Decrease	No	Unresponsive to disturbance
Plecoptera Taxa	Decrease	Yes	
Trichoptera Taxa	Decrease	Yes	
Diptera Taxa	Decrease	No	Unresponsive to disturbance
Coleoptera Taxa	Decrease	No	Insufficient range for scoring
Plecoptera & Trichoptera Taxa	Decrease	No	Correlated with other metrics
EPT Taxa	Decrease	No	Correlated with other metrics
Composition Measures			
% Non-insect	Increase	No	Unresponsive to disturbance
% EPT	Decrease	Yes	
% EPT excluding Baetidae	Decrease	No	Strong seasonality
% Ephemeroptera	Decrease	No	Unclear reference separation
% Eph excluding Baetidae	Decrease	No	Unresponsive to disturbance
% Plecoptera	Decrease	No	Unclear reference separation
% Trichoptera	Decrease	No	Strong seasonality
% Plecoptera & Trichoptera	Decrease	No	Strong seasonality
% Coleoptera	Decrease	No	Strong seasonality
% Odonata	Decrease	No	Unresponsive to disturbance
% Diptera	Decrease	No	Unresponsive to disturbance
% Chironomidae	Increase	No	Correlated with other metrics
% Amphipoda	Increase	No	Insufficient range for scoring
% Gastropoda	Increase	No	Unresponsive to disturbance
% Isopoda	Increase	No	Insufficient range for scoring
% Oligochaeta	Increase	No	Correlated with other metrics
Shannon-Wiener Index	Decrease	No	Strong seasonality
Margaleff's Index	Decrease	No	Correlated with other metrics
Simpson's Index	Increase	No	Strong seasonality
% Dominant Taxon	Increase	No	Strong seasonality
% 3 most dominant taxa	Increase	No	Strong seasonality

Tolerance Measures			
% Tolerant	Increase	Yes	
% Intolerant	Decrease	Yes	
Tolerant taxa	Increase	No	Unclear reference separation
Intolerant taxa	Decrease	No	Unclear reference separation
Beck's Biotic Index	Decrease	No	Unclear reference separation
Hilsenhoff's Biotic Index	Increase	Yes	
Trophic Measures			
% Collector/gatherers (CG)	Decrease	No	Unresponsive to disturbance
% Filterer (FC)	Variable	No	Unresponsive to disturbance
% Predator (P)	Variable	Yes	
% Scraper (SC)	Decrease	No	Correlated with other metrics
% Shredder (SH)	Decrease	No	Strong seasonality
CG Taxa	Decrease	No	Unresponsive to disturbance
FC Taxa	Variable	No	Unresponsive to disturbance
P Taxa	Variable	No	Correlated with other metrics
SC Taxa	Decrease	No	Unclear reference separation
SH Taxa	Decrease	No	Unclear reference separation

[1]Adapted from (Barbour et al. 1996, Fore et al. 1996, Everta 2006, Herbst and Silldorff 2009)

Appendix B: Scoring System for Deer Creek Family-level IBI

Metric	Range	IBI Score
Insect Family Richness	5-32	5 if >27 4 if 23<x≤27 3 if 18<x≤23 2 if 14<x≤18 1 if ≤14
Plecoptera Family Richness	0-8	5 if >4 4 if 3<x≤4 3 if 2<x≤3 2 if 1<x≤2

		1 if ≤1
Trichoptera Family Richness	0-11	5 if >8 4 if 6<x≤8 3 if 4<x≤6 2 if 2<x≤4 1 if ≤2
% EPT	1.4-95.0%	5 if >71.2 4 if 60.0<x≤71.2 3 if 45.6<x≤60.0 2 if 29.9<x≤44.6 1 if ≤29.9
% Tolerant	0-33.8%	5 if <0.55 4 if 0.55≤x<1.19 3 if 1.19≤x<1.73 2 if 1.73≤x<3.84 1 if ≥3.84
% Intolerant	0-54.0%	5 if >28.1 4 if 14.7<x≤28.1 3 if 8.6<x≤14.7 2 if 4.36<x≤8.6 1 if ≤4.36
Hilsenhoff's Biotic Index	2.76-5.94	5 if <3.7 4 if 3.7 ≤x<4.26 3 if 4.26≤x<4.58 2 if 4.58≤x<4.96 1 if ≥4.96
% Predators	0.564-31.9%	5 if >12.1 4 if 9.4<x≤12.1 3 if 6.64<x≤9.4 2 if 4.28<x≤6.64 1 if ≤4.28
IBI Score	**8-40**	

Appendix C: Pearson correlations between IBI metrics, IBI scores, water quality and watershed land cover.

	Insect Taxa	Plecoptera Taxa	Trichoptera Taxa	% EPT	% Tolerant	% Intolerant	Hilsenhoff Index	% Predators	IBI Score	PO_4	NO_3	pH	Conductivity	Turbidity	D.O.	H_2O temp	% Urban	% Impervious	Road Density
Insect Taxa	-																		
Plecoptera Taxa	**0.73**	-																	
Trichoptera Taxa	**0.77**	0.40	-																
% EPT	0.08	0.15	0.18	-															
% Tolerant	0.01	0.29	0.04	0.10	-														
% Intolerant	0.61	0.68	0.44	0.43	0.16	-													
Hilsenhoff Index	0.42	0.47	0.41	**0.83**	0.19	**0.80**	-												
% Predators	0.57	0.36	0.40	0.16	0.23	0.32	0.12	-											
IBI Score	**0.78**	**0.81**	0.65	0.49	0.28	**0.84**	**0.79**	0.43	-										
PO_4	0.51	0.56	0.31	0.10	0.14	0.40	0.31	0.23	0.53	-									
NO_3	0.46	0.47	0.31	0.08	0.06	0.35	0.27	0.25	0.43	**0.84**	-								
pH	0.35	0.50	0.19	0.17	0.22	0.38	0.14	0.26	0.40	0.38	0.30	-							
Conductivity	0.53	**0.74**	0.30	0.05	0.27	0.54	0.34	0.27	0.63	0.69	0.60	0.59	-						
Turbidity	0.00	0.07	0.02	0.24	0.12	0.16	0.21	0.04	0.11	0.14	0.12	0.10	0.09	-					
D.O.	0.08	0.07	0.18	0.14	0.06	0.16	0.18	0.05	0.17	0.17	0.07	0.06	0.04	0.06	-				
H_2O temp	0.44	0.54	0.31	0.02	0.19	0.51	0.31	0.27	0.52	0.34	0.29	0.55	0.53	0.07	0.29	-			
% Urban	0.46	0.50	0.48	0.41	0.17	0.50	0.59	0.24	0.66	0.44	0.36	0.20	0.37	0.12	0.15	0.34	-		
% Impervious	0.52	0.54	0.48	0.26	0.20	0.50	0.51	0.32	0.67	0.49	0.40	0.28	0.41	0.04	0.11	0.36	**0.96**	-	
Road Density	0.21	0.14	0.36	0.47	0.01	0.26	0.49	0.09	0.39	0.18	0.14	0.13	0.05	0.16	0.13	0.04	**0.87**	**0.80**	-

Correlations >0.7 are in bold.