**Development of Benthic Macroinvertebrate and Algal Biological Condition Gradient Models for California Wadeable Streams**

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# ABSTRACT

The Biological Condition Gradient (BCG) is a conceptual model that describes changes in aquatic communities with increasing levels of anthropogenic stress. The BCG helps decision-makers connect narrative water quality goals (WQG) to quantitative measures of ecological condition by linking the protective value of targets based on statistical distributions (e.g., percentiles of reference distributions) to narrative descriptions of biological condition (e.g., maintenance of natural structure and function) that are more meaningful to managers and the public. To develop a BCG model, biological response to stress is divided into 6 levels of condition, represented as changes in biological structure (abundance and diversity of pollution sensitive versus tolerant taxa) and function. Here, we developed algae and benthic macroinvertebrates (BMI) BCG models for California perennial wadeable streams to support interpretation of “percentile of reference” thresholds used to apply existing bioassessment indices (California Stream Condition Index [CSCI] for BMI and the algal stream condition index [ASCI]). Panels of BMI and algal experts calibrated the general BCG model by independently assigning test samples (261 BMI and 241 algae samples) to BCG Levels 1 to 6, then developed consensus on those assignments, using a modified Delphi method. Experts then developed a detailed narrative of changes in BMI and algal taxa that correspond to those levels. Consensus among experts was high, with 81% and 100% of final expert assigned BMI BCG site scores within 0.5 and 1 BCG level of the median assigned scores, respectively; for algae these numbers were 82% and 94%. The 10th percentiles of the distributions of CSCI and ASCI scores at reference sites corresponded to a BCG Level 3. The BCG provides a framework to interpret changes in aquatic biological condition along a gradient of stress that expands the portfolio of support for making decisions related to biological impacts from stress in California streams.

# INTRODUCTION

Quantitative water quality goals (WQG) that protect biological integrity are cornerstones of federal and state water quality protection programs (e.g., California Porter Cologne Act 1969, US Clean Water Act 1972, EU Water Framework Directive 2000), but can be challenging because of complexities in the relationship between species diversity and abundance to biological condition. As a result, many states have developed bioassessment indices to measure and assess attainment of biointegrity goals (Davis and Simon 1995, Council of European Communities 2000, USEPA 2002, Yoder and Barbour 2009), based on assemblage structure, relative to structure at minimally disturbed reference sites with comparable environmental settings (Reynoldson et al. 1997, Hawkins et al. 2010). These indices rely on empirical, present-day reference conditions quantified from existing reference sites to anchor their measurement systems; biological integrity goals are frequently characterized by deviation from the natural range of variability, calculated as a statistical characteristic (e.g., 30th, 10th, or 1st percentile) of reference site bioassessment index score distributions (e.g. Barbour et al. 1999, Mazor et al. 2016). While these indices and thresholds can provide statistically reproducible and unbiased assessments of biological integrity, communicating to the public the import of a selected statistical value as biointegrity protection can be challenging without a clear narrative of biological structure or functions that are protected or lost. In addition, because reference sites are typically based on a “best available” definition (Stoddard et al. 2006), moderately disturbed reference sites can be a part of the reference pool, meaning that reference-based indices potentially may assess sites against an already degraded benchmark.

The Biological Condition Gradient (BCG) model was developed, in part, to help provide this information for decision-makers. The BCG is a conceptual model that describes changes in aquatic systems with increasing levels of human disturbance (Davies and Jackson 2006, USEPA 2016). It includes theoretical changes in structural and functional characteristics of stream systems as they degrade in response to human disturbance (Figure 1). The BCG is a standard biological response gradient that has a universal meaning, so that the interpretation does not vary across regions, and the theoretical levels mean the same thing everywhere. It is a useful construct, therefore, for interpreting biological indices and for comparing and reconciling regional differences in reference condition, types of indices, or even indices for different assemblages. Supplementing statistical interpretations with ecological information on “taxa richness, species composition, tolerance and functional organization” or comparable narrative language is intended to help managers interpret where along a numeric biological index a protective value lies. BCG models are developed by asking multiple experts trained in the BCG narratives, to place sites into one of the 6 BCG levels based on taxonomic composition and abundance information alone but informed by biogeographic information to inform expectation. Experts know nothing about the degree of disturbance in the watershed. Experts are also asked to record their decision-making process, in ecological terms. The BCG calibration efforts, thus capture the breadth and depth of expert ecological interpretation regarding sample composition along disturbance gradients. The final levels can be cross walked with index values calculated at the assigned sites to compare scores with BCG levels and with the consensus narrative ecological descriptions along the BCG gradient and associated biological index scores.

These BCG narrative expressions are often very similar to the concepts and goals embodied in aquatic life use narrative criteria. As a result, BCG output can be useful in informing the interpretation of thresholds for biological indicators, when those biological indicators can be related to BCG levels. Policy development to protect wadeable stream biointegrity in the state of California (USA) provided a powerful impetus to strengthen narrative interpretation behind scoring of existing bioassessment indices. The California State Water Resources Control Board (Water Board) staff is proposing to implement a program to protect biointegrity in wadeable streams. The Water Board has adopted the use of the California Stream Condition Index (CSCI; Mazor et al. 2016) to score the condition of benthic macroinvertebrate (BMI) bioassessment data and is currently supporting the development of its algal complement, the Algal Stream Condition Index (ASCI, Theroux et al. in prep), based on both diatom and soft-bodied algal assemblages. BMI and algal bioassessment have seen widespread implementation in California water quality protection programs, including routine ambient condition assessments (e.g. Mazor et al. 2017), waterbody biointegrity impairment listings and associated regulatory actions, and routine monitoring in point source and nonpoint source discharge permits. The implementation program for stream bioassessment is supported by well-established protocols, training and quality assurance, and a broad network of minimally disturbed reference sites (Ode et al. 2016). As a result, a robust statewide bioassessment dataset exists, representing both BMI and algal assemblage as well as a comprehensive set of data on stressors (e.g., chemical, physical habitat). Both indices are expressed as ratios, with values close to 1 meaning that a sample is like reference expectations; and lower scores meaning that the biological assemblage may be altered from reference. Mazor et al. (2016) proposed narratives of “likely intact,” “possibly altered,” “likely altered,” and “very likely altered” associated with the >30th, 30-10th, 10-1st, and < 1st percentiles of reference as interpretation of the CSCI; Theroux et al. (in prep) presented similar thresholds for the ASCI. The San Diego (SD) Regional Water Quality Control Board, one the nine semi-autonomous Regional Water Boards in California, is proposing a narrative biointegrity water quality goal (WQG), using the 10th percentile of CSCI reference site distributions as numeric translator to this narrative WQG (SD Water Board Proposed Bioobjectives Policy; www.waterboards.ca.gov/sandiego/water\_issues/programs/basin\_plan/bio\_objectives/).

BCG models can help to support the interpretation of California’s bioassessment indices, providing additional rationale for the selection of a given percentile of reference of numeric biointegrity goals. The purpose of this study was to: 1) develop BMI and algal BCG models for a suite of California wadeable stream sites by creating attributes for taxa and developing narratives of specific structural and functional changes along the BCG gradient specific associated with degradation of California wadeable streams and 2) compare BCG condition categories (Figure 1, categories 1-6) with CSCI and ASCI scores to link percentile of reference thresholds (30th, 10th, 1st) to narratives of import associated with the loss of benthic invertebrate and algal community structure.

# METHODS

## The BCG Process

A multistep process was followed to calibrate a BCG to California wadeable stream conditions (Figure 2). The process included assembling data, orienting experts to the BCG and rating process, and using an expert rating framework to describe the BCG in terms of observed assemblage response to anthropogenic stressors. This calibration process is like those used in BCG development in other regions (Gerritsen et al. 2017, U.S. EPA 2016). Assessing condition of biological assemblages (e.g., by interpreting bioassessment indices), involves professional judgment, even though such judgment may be embedded within objective, quantitative approaches (e.g., Steedman 1994, Borja et al. 2004, Weisberg et al. 2008). The BCG calibration in California uses an explicit reliance on professional judgment and development of consensus, supported with targeted analyses, and is set up to use both independent and group interpretations of the data.

BCG calibration begins with the assembly and analysis of biological monitoring data. The sites were selected to represent a full gradient of natural and stressor conditions, based on existing classification schemes, stressor information, and biological indices. Data were organized for supporting analyses and reviewed by the experts. Experts in BMI (9) and algal (5) ecology in California were identified. All 9 BMI experts were from California, with specific expertise including southern to northern as well as Sierra Nevada to coastal stream assemblages. Algal experts included a California expert, and 4 experts from outside the state but experienced working with California taxa through national surveys. Experts were provided an orientation on the theoretical basis of the BCG, the rating process, and introduction to BCG attributes (taxa characteristics; SI Table 1). During the first calibration workshop, experts finalized attribute assignments and received training for rating samples along the BCG. The training demonstrated how experts were expected to interpret sample data in the context of BCG level definitions, assign BCG levels (scoring or rating) to samples independently, compose rationale for their ratings, and reconcile multiple ratings per sample. Between the first and second workshop, experts assigned sites to BCG categories (1-6, Figure 1). The second workshop was held to reconcile ratings and eventually agree on a consensus rating for each sample. The results of the expert consensus process included ratings for 250+ samples per assemblage and narrative statements describing the biological characteristics of each BCG level. The narratives were gleaned from independent expert rationales for ratings and from group discussions. The final steps in the calibration process included cross walking the BCG level assignments to CSCI and ASCI scores to translate the import of percentile of reference to managers.

## Data Preparation and Sample Selection for Expert Scoring

A selected set of sites were extracted from the California Surface Water Ambient Monitoring Program (SWAMP) Perennial Streams Assessment (PSA), Stormwater Monitoring Coalition (SMC) program databases, and other sources for use in expert review. A total of 264 selected sites were scored for macroinvertebrate BCG and 247 for algae BCG (Figure 3), covering a wide range of characteristics to represent the diverse environmental settings encountered throughout California (Table 1). Selection criteria were roughly established to distribute site types among regions, biological condition based on biological metrics and reference status, and stressor types based on land cover and water quality data. That is, sites were selected to represent diverse natural settings found across the state, as well as representation of types of stress from human activities, including: forestry, agriculture, urbanization, channelization, and hydropower. Efforts were made to include sites representing unusual or challenging circumstances

Initially, ~200 samples were reviewed by experts during the first round (with paired BMI and algal data). After initial scoring, additional sites were requested by experts to flesh out the distributions of sites for each California region (Figure 3); in contrast to the initial set of sites, these additional sites differed between the two expert panels.

Data compiled for use by experts during the review process included raw taxonomic data, taxa attribute metrics, and data descriptive of natural biogeographic gradients in California wadeable streams (e.g., elevation, mean annual precipitation, dominant geology, etc.). Raw taxonomic data were provided to experts in the form of taxa lists with enumeration per taxon. Macroinvertebrate samples had approximately 600 organisms collected using standardized methods known to the experts (Ode et al. 2016a) with a range of taxonomic resolution from species to class, but the majority identified to genus. Algal samples, similarly collected using standard methods (Fetscher et al. 2009), included 600 valve target diatom counts and soft algae listed by taxon, collection site (qualitative, macroalgae, microalgae, or epiphyte), and calculated biovolume. In addition to the raw data for each assemblage, samples were summarized using taxa attribute metrics, additional metrics that are used in assessments, and metric and taxa expectations. Basic metrics were immediately displayed with each sample, while assessment-specific expectations were initially hidden, giving experts an opportunity to interpret the sample composition before electing to reveal assessment scores. The CSCI is a combination of predictive multimetric indices (MMI) and O/E taxonomic completeness models (Mazor et al. 2016). The displayed macroinvertebrate metrics included expected taxa as calculated for the O/E index and metrics included in the MMI. For algae, ASCI collectively represents three existing indices for diatoms, soft algae, and a hybrid index based on MMI (dASCI, sbaASCI, and hASCI, respectively; Theroux et al. in prep). Metric values and modeled reference expectations were available to the experts while rating samples, but CSCI and ASCI scores were never displayed to experts. Experts could have calculated an O/E score but calculating a CSCI score would have been difficult and the ASCI had not been developed. Biogeographic data on natural gradients were based on GIS analysis and included biological regions, climate, watershed area, geology, predicted background conductivity and other predicted background water quality and geological characteristics (Olson and Hawkins 2012). These were displayed during the sample rating process. Data were formatted for analyses and for display during expert rating exercises. The format for the rating exercises was standardized to show site and sample information, taxa lists with BCG attributes, BCG attribute metrics, and other metrics (Supplemental Information, Figure S1).

Variables related to stress or human activity were compiled and used for site selection, stressor-response analysis, and *post hoc* evaluation, but were not displayed to experts during the sample rating process. These data included land use, road density, mines, dams, and field data, including chemistry and physical habitat. Water chemistry included specific conductivity, chloride, TN, TP, and pH in addition to several less common measures. Physical habitat was not available for all sites, but included dominant substrate, habitat complexity, riparian vegetation, shading, channel morphology, and more ([www.waterboards.ca.gov/water\_issues/programs/swamp/bioassessment/docs/physical\_habitat\_index\_technical\_memo.pdf](https://www.waterboards.ca.gov/water_issues/programs/swamp/bioassessment/docs/physical_habitat_index_technical_memo.pdf)).

## BCG Attribute Development

In the BCG conceptual model, biological attributes of aquatic ecosystems change along a gradient of increasing anthropogenic stress, nutrients, physical habitat degradation, or flow modification. Six attributes defined for BCG application were relevant in the California BCG calibration (Supplemental Information, Table S1). More detailed attribute definitions were thoroughly reviewed by the expert panels as they considered assigning attributes to taxa (U.S. EPA 2016). Given the sheer number of taxa (>1200 combined) experts were required to assign attributes to, initial assignments of taxa were estimated using information from existing tolerance values and California specific tolerance metric calculations, similar to approaches applied in other calibration efforts (Gerritsen et al. 2017, Hausmann et al. 2016). Experts were given this tolerance information and asked to refine the attribute assignments.

Tolerance metrics calculated as central tendencies, environmental limits and optima were calculated from environmental stress-response curves and made available to experts for the purposes of assigning attribute values to each taxon (see Yuan 2006). These analyses examined the response of taxa to stressor variables (e.g. % developed land [agricultural + urban], conductivity, TN, and TP). These tolerance metrics were ranked and translated to the attribute range, from II to V, that was most closely related to pollution tolerance, using both abundance based and presence/absence-based models. The attributes are included in the spreadsheets given to experts to evaluate sites, while the stressor information was withheld. Tolerance metrics, expressed as central tendencies, describe the average environmental conditions under which a taxon is likely to occur. Central tendencies are estimated by computing the mean of the product of taxon abundance and the environmental stressor variable, calculated on both abundance and presence/absence, assuming a normal distribution across the environmental gradient. The width of the bell shape is defined as tolerance, not to be confused with the tolerance scale used to describe general taxon sensitivity (Hilsenhoff 1987). Weighted cumulative distribution function (CDFs) were used to estimate tolerance in non-uniform sample distributions. Environmental limits attempt to capture the maximum or the minimum level of an environmental variable under which a taxon can persist, while optima define the environmental conditions that are most preferred by a given taxon. Both limits and optima can be derived from observational data or regression relationships. The area under the curve of 95th percentile cumulative percentiles (CPs) represents the environmental limits a taxon can tolerate. Optimum conditions (i.e. the central tendency) was estimated using the median values of the CDF and the CP of the regression models. Regression estimates of taxon-specific stress response relationships were developed using linear regression model (LRM), quadratic (QLRM) logistic regression models, or generalized additive models (GAM) to model the relationships. Tolerance metrics developed from these statistical methods were generally correlated or similar to each other, so variations due to statistical approaches were minimized by taking an average of results from all methods. In summary, tolerance metrics were generated from a total of 17 parametric models for any individual taxa that occurred in at least 10 samples. The stressor response analysis was applied for all 769 invertebrate taxa, while stressor response analysis was applied for 318 diatom genera and species and for 58 soft bodied algae (SBA) genera. At the species level, there were generally few SBA occurrences that could be used to model stressor-response patterns.

During the first workshop, experts refined the initial BCG attribute scores assigned to taxa based largely on their knowledge of the taxa and the conditions in which they occur, informed by calculations of the taxon-specific tolerance metrics or literature derived tolerance values, both of which were made available to them (e.g., Rott et al. 1999, Potapova and Charles 2007, Stevenson et al. 2008, Lange-Bertalot et al. 2017). Open panel discussions focused around taxa for which there was disagreement. Unlike sites scoring, attribute assignment was not done anonymously using iterative Delphi-like consensus, so the potential for biased influence in attribute assignments may have existed. Given the number of taxa (>600) and the limited disagreements, we feel this bias was likely minimal. The final taxa attribute assignments were included as information for site scoring and used by experts to rate sites along the BCG scale.

## Assignment of sites to BCG levels

Under typical BCG model development (e.g., Gerritsen et al. 2017, Hausmann et al. 2016), open discussions occur among experts during the process of rating a sample. This open discussion might allow for bias to influence the ratings if some experts are perceived to be more qualified or are more persuasive, ultimately encouraging less vocal experts to follow a leader instead of offering a new perspective. To reduce this bias, BCG development in California wadeable streams followed the Delphi consensus methods, which uses independent expert interpretation of sample information followed by reconciliation and discussion to arrive at consensus on assignment of a BCG level (Nair et al. 2011).

During the first round of BCG level assignments, experts worked independently to evaluate sites, using BCG level definitions (Figure 1), taxa lists, BCG attribute summaries, and site characteristics that were not subject to human disturbance, such as ecoregional information, collection date, catchment area, elevation, water temperature, precipitation and other predicted background water quality and geological characteristics important in understanding expectations for taxa (Olson and Hawkins 2012) (e.g., see Supplemental Information Figure S1 for an example of a data for for scoring). Excluded were site locations, stressor information (land use, water quality, and habitat assessments), and existing biological assessment scores.

After this first round, sample ratings were reviewed; ratings were considered in agreement if no more than only one-third macroinvertebrate experts and one in five algal experts rated a sample at one level above or below that of the majority of experts. For these samples, the median of expert ratings was used as the consensus for the sample. For all samples with divergent scores among experts, a reconciliation process was applied. For reconciliation, samples were anonymously presented to the experts with the independent written rationale of each expert. After considering their colleagues rationale, experts publicly shared their second-round rating, which might change towards the initial median, towards an extreme rating with convincing or previously unrecognized interpretation of the data, or not change at all. To resolve disagreements that remained after revotes, the group of experts consistently agreed to assign the BCG level that was also the median of the revotes.

After the second round of voting (the re-vote), a set of rules were approved by experts to calculate a final consensus scores for a sample from potentially disparate scores. The plurality rating (or final plurality rating) was simply the most common score selected and, if there was a tie, the mid value was selected and rounded down (the lower BCG level). Because there were 9 macroinvertebrate experts, the median score was selected. Algal experts allowed themselves to assign BCG ratings for each sample in “core” or “qualified” levels, where core refers to BCG levels I-VI and qualified indicating conditions somewhat better (+) or worse (-) than the core. Therefore, each algal BCG level had three possible ratings (e.g., 3-, 3, or 3+).

## Crosswalk Analyses

The BCG levels assigned to the approximately 250 samples throughout California were “cross walked” to existing CSCI and ASCI bioassessment indices. Proportional-odds modeling was to estimate the ranges of index values that are likely to fall within each BCG level. Proportional odds modeling is an ordinal regression model that allows illustration of the points at which an index is more likely to be associated with one BCG level in comparison to all other levels (Agresti 2002, Venables and Ripley 2002). Comparisons among natural variables and PSA regions were made to review the extent to which crosswalk responses were either universal or might be context dependent.

Box plots of BCG scores with total nitrogen (TN), total phosphorus (TP) specific conductance stressor, and percent ag/urban land use were examined to verify BCG response to stressor gradients.

## BCG Narrative Development

A narrative of characteristics of each BCG level were documented to communicate the ecological values recognized by the experts, generally paralleling the descriptive definitions for the levels (U.S. EPA 2016). The rationale for assigning samples to BCG levels was explored at several points in the BCG scoring process. In training discussions, the experts were asked to conceptually characterize the best biological conditions possible or observable in California. The best conditions were emphasized early so that the experts would calibrate amongst the group to ideal expectations. The conceptual characterizations were generally narrative and qualitative statements of taxon richness, biomass or abundance of certain types, and occurrence of indicator taxa for BCG levels 1 and 2. During this discussion, effects of naturally occurring stressors on biological conditions were also discussed, recognizing that expectations are dependent on environmental setting due to variability in natural background in stressors, the timing of sample collection, or the confounding (or compounding) of natural and anthropogenic stressors. During the sample scoring process, experts wrote and discussed rationale for assigning each sample to a BCG level. The rationale included general qualitative comparisons, qualitative and quantitative expectations based on attribute and taxonomic trait metrics, and expectations for indicator taxa. As the evidence built for assignments at each level, the group came to an agreement regarding general rules for each BCG level. This agreement was captured in narrative statements compiled through expert review and consensus.

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# RESULTS

## Attribute Assignments

In the reviewed data set, there were 769 invertebrate taxa, 546 diatom taxa, and 419 soft algal taxa considered by the expert panels, of 711, 419 and 156 respectively were assigned to BCG attribute levels. Attributes were not assigned (NA) for taxa that occurred < 10 samples, were unfamiliar to the experts, or were of ambiguous taxonomic resolution. Most taxa were assigned to BCG attributes III and IV, the sensitive and moderately tolerant categories (Table 2). There were relatively few taxa in attributes I and VI (the indigenous or specialists and the non-native taxa attributes, respectively).

## Sample Ratings

In the first round of ratings, assignments were generally more consistent for BMI then algae; but both expert groups achieved good consensus during reconciliation. For BMI, most final BCG assignments (81%) were within 0.5 unit of the final assignment and 95% were within 1 BCG level of the final BCG assignment. After the second round of review for all macroinvertebrate samples, 78% were within 0.5 level and 100% within 1 level (SI Figure S2). For the algae, 51% of independent ratings agreed with the median rating for each sample during the first round of review. In that consensus dataset, 57% of ratings were the same as the median. A total of 82% of ratings were within 1/3 of the median (no more than a + or – difference), and 94% of ratings were within 2/3 of the median. Among the five algal experts, only 6% of the individual ratings were different than the median by a whole BCG level or more. In the samples with some discrepancy, 38% of ratings were the same as the median. Following the re-vote as part of the modified Delphi method, expert agreement with the median increased to 50% of samples. Of the 85 samples that required reconsideration to arrive at consensus, only 11 samples showed a change in median ratings between rounds of more than 1/3 level (e.g. the difference between 3 and 3+).

For both assemblages, assignments were roughly evenly distributed among the intermediate BCG levels, with few assigned to Level 1 or 6; this pattern was more pronounced for algae than for BMI (Table 3). For example, of the 264 samples macroinvertebrate samples rated, approximately equal numbers were assigned to BCG levels 2 through 5, in almost equal proportions (Figure 4). Few sites were assigned to levels 1 and 6, and sample sizes were approximately 20% of the average of those identified to levels 2 through 5. Of the 247 algal samples rated, most were assigned to BCG levels 3 and 4, in equal proportions (Figure 4). Similar numbers of sites were assigned to levels 2 and 5, though less than half of those in levels 3 and 4. The fewest numbers of samples were assigned to level 6 and no level 1 samples were identified.

Although assignments to BCG levels were roughly even at the statewide level, different patterns were evident in certain regions (e.g. Figure 5). For example, most sites in the Central Valley (a heavily agricultural region with few undeveloped areas) were assigned to Level 4 or 5 by BMI experts, and none were assigned higher than 3. In contrast, BMI experts assigned more samples to Level 3 or higher than to Level 4 or lower in the largely forested Sierra Nevada and North Coast regions. A high proportion of samples were rated BCG level 5 in the Central Valley and South Coast PSA regions.

## Crosswalk of BCG levels to the CSCI and ASCI

Bioassessment index scores declined with assignment to higher BCG levels (Figure 4). There was more overlap in CSCI scores between levels 1 and 2 than between other levels, even though most adjacent level interquartile ranges overlapped. There was a gap between interquartile ranges from levels 3 to 4 and between 5 and 6. For the macroinvertebrate samples, the crosswalk between the BCG levels and the CSCI appears to be robust across PSA regions, with the possible exception of the South Coast, whose CSCI scores were consistently higher per BCG level than in other regions (Figure 5). Within BCG levels 3 and 4, CSCI scores among Desert Modoc samples were generally higher than those from other PSA regions, though Desert Modoc is not considered a coherent ecoregion. The crosswalk of BCG levels to index scores using the proportional odds model shows that CSCI values greater than 1.0 are more likely to be BCG level 2 or 1 than any other level and scores below 0.3 are more likely to be a BCG level 6 (Figure 6). It is worth noting that the CSCI and ASCI indices are ratios, with a mean expected value of 1. Therefore, sites that are richer and have more sensitive taxa than expected can get a score of 1 or greater; CSCI treats these scores as part of the natural variability, while BCG experts treated this as meaningful differences in BCG categories. The highest proportional odds for BCG levels 3, 4, and 5 are at CSCI scores of approximately 0.90, 0.65, and 0.40 respectively.

ASCI scores similarly declined with increasing BCG levels, but not as dramatically as that for the CSCI (Figure 4). Levels 2 and 3 overlapped and median ASCI scores were even higher in level 3. Beyond level 3, scores declined steadily. Interquartile ranges were generally similar across BCG levels. Scores were similar in Chaparral, Desert-Modoc, Sierra Nevada and North Coast samples across BCG levels 2-4 but declined in the other regions (Figure 5). For ASCI, values above 0.90 are more likely to be BCG level 3 or 2, whereas values below 0.15 are likely to be 6 (Figure 6). The highest proportional-odds for BCG levels 4 and 5 are at ASCI scores of approximately 0.75 and 0.35, respectively.

BCG levels showed clear relationships with environmental settings (Figure 7) and stressor/human activity gradients (Figure 8). There was not a clear relationship between BCG level and catchment size per se. However, BCG assignments for both assemblages increase at lower elevations and lower precipitation levels, and at higher temperatures. These associations with environmental factors might be driven by underlying stressors, which are likely higher at lower elevation environmental settings in California that generally reflect greater agricultural and urban development. Nutrient concentrations, conductivity, and land cover disturbance are higher in sites with BCG levels 4, 5, and 6 scores when compared to conditions in sites with lower BCG scores (levels 1-3) (Figures 8 and 9).

## Narrative BCG level descriptions for the biological assemblages

The narratives of taxa sensitivities and tolerances, embodied in their respective decisions for BCG attribute assignments, and the information on taxa presence, absence and abundance were recorded and refined as each group of experts to represent unique descriptions for California streams, attempting as much as possible to indicate region specific changes (SI Table 2). The distinctions between BCG levels are evident from the taxa present or absent and their relative abundances.

# DISCUSSION

California wadeable stream BCG models show good concordance among experts within each assemblage, as seen in BCG exercises conducted elsewhere in North America (Gerritsen et al. 2017, Hausman et al. 2016) as well as other expert processes, e.g. marine benthic invertebrates (Weisberg et al. 2008, Teixeira et al. 2010), marine sediment quality (Bay et al. 2007, Bay and Weisberg 2012), and fecal contamination (Cao et al. 2013). BCG tiers demonstrated reasonable differentiation of BMI and algal condition along representative examples of the disturbance gradient, including TN and TP, specific conductivity, and ag and urban land use, all of which are consistent with what is known about the ambient conditions of these regions (www.waterboards.ca.gov/water\_issues/programs/swamp/bioassessment/docs/psa\_memo\_121015.pdf). California’s modification of the typical BCG model development included incorporation of a modified Delphi approach, a potentially helpful innovation over previous iterations of the BCG model development in that it helps to reduce bias caused by strong opinions from individual expert panelists (Nair et al. 2011).   
 Many states have developed expert BCG models to support environmental decision-making to, for example, supplement state-supported bioassessment indices (e.g. Minnesota, Gerritsen et al. 2017). This is similar to the case in California, where the state has developed sound monitoring tools to measure biological conditions in streams, has a peer-reviewed index for macroinvertebrates (California Stream Condition Index, CSCI, Ode et al. 2008) and a recently developed one for algae (Algal Stream Condition Index, ASCI, Theroux et al. in review). The CSCI is in widely implemented for integrated reporting of waterbody status, evaluation of restoration, and in NPDES and stormwater permitting. In California, BMI and Algae BCG category I-VI narratives can help to facilitate conversations among the Water Board and public on choices of statistically-based percentiles of reference as WQG, by providing a strong narrative of the implications of different WQG selections on loss of structure and function (Davies and Jackson 2006). For example, the 10th percentile reference of CSCI (0.79), the preferred target to protect biointegrity in the proposed San Diego Regional Water Board bio-objectives policy (www.waterboards.ca.gov/sandiego/water\_issues/programs/basin\_plan/bio\_objectives/), corresponds to the bottom of BCG bin 3 (Figure 4), in which “some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but sensitive–ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system.” This narrative communicates to the public the intended protection of biointegrity at this percentile reference.

The BCG expert framework exhibited strong correspondence between BCG and CA bioassessment index scores, a finding not surprising given they are sourced from the same comprehensive monitoring program, based on a uniform set of protocols, and represent a similar range of conditions (Davies and Jackson 2006, Mazor et al. 2016), where the BCG uses expert knowledge rather than statistical predictions to infer deviation from the range of natural variability (US EPA 2016). Both have advantages that can be considered complementary in this application. Bioassessment indices, particularly those based on O/E approaches, can readily account for site-specific variability in natural gradients and thus minimize potential biases in scores among ecoregions (Mazor et al. 2016). The level of natural variability inherent in states as large and as topographically diverse as California may have exceeded experts’ capacity to fully account for during the scoring process. Statistically-based bioassessment indices have been critiqued for ambiguity at the index level and for arbitrarily combining metrics (Suter 1993), problems not inherent in expert derived models (Gerritsen et al. 2017). Here, the strong correspondence between BMI and algal BCG and their corresponding indices may reduce these concerns. BCG categories may be able to resolve meaningful differences at the lower end of the disturbance gradient, a range sometimes difficult for indices, and certainly describe the ecological conditions and consequences of sites in those settings which is particularly useful for states considering management options such as tiered aquatic life uses (Yoder and Rankin 2005a, b; Davies and Jackson 2006).

BMI BCG categories showed broad distribution across the entire range of CSCI scores, indicating good discrimination of condition categories, while algal BCG bins were somewhat compressed within a subset of the ASCI’s scoring range. Few algae taxa were designated as either a BCG Level 1 or Level 6 indicator (Table 2) therefore resulting in few sites that were assigned BCG bin 1 or 6. This trend has been observed in previous algal BCG efforts as well, including the New Jersey diatom BCG (Charles et al., 2010) where no sites were assigned to bins 1 and 6, and a combined Mid-Atlantic region algal BCG effort in which only a handful of algae taxa received a BCG Level 1 or Level 6 rating (Hausmann et al., 2016).

While the BCG framework provides a good complement to the CSCI and ASCI as decision support for forthcoming policies, certain guidelines are warranted for its use to support management decisions. First, unlike in other states where a quantitative fuzzy logic model was developed to provide an ongoing interpretive tool (e.g. Gerritsen et al. 2017), the CA BCG framework is not intended to substitute or supersede CSCI or ASCI to interpret taxonomic data, only to provide decision support on the selection of management thresholds like a percentile of reference. Second, it should not be used to determine biological potential. For example, if a site score falls within BCG bin 4, its potential BCG category could be significantly higher (i.e., 1-4), but may also be constrained by factors that are uncontrollable. Finally, BCG narratives, particularly at the BMI or algal taxa level should not be used to determine probable cause for impaired biointegrity. Causal assessment conducted through EPA-recommended Causal Analysis/Diagnosis Decision Information System (CADDIS; Cormis et al. 2000; www.epa.gov/caddis) is recommended for use in such circumstances.

The BCG can support decision-making with regards to establishing biointegrity WQG in California wadeable streams by providing an understanding the ecological implications of different thresholds. In addition, development of expert derived narrative of BCG level 1 can provide context for the existing pool of reference sites that are based on a “best available” definition; if moderately disturbed reference sites are part of the reference pool, these reference-based indices potentially may assess sites against an already degraded benchmark, which is an important consideration for establishing biointegrity WQG.

# 

# REFERENCES

Agresti, A., 2002. Categorical data analysis, 2nd ed., Wiley series in probability and statistics. Wiley-Interscience, New York.

Barbour, M.T., Gerritsen, J., Snyder, B.D. and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. EPA 841-B-99-002. US Environmental Protection Agency, Office of Water, Washington, DC. 1999.

Bay, S., Berry, W., Chapman, P.M., Fairey, R., Gries, T., Long, E., MacDonald, D., Weisberg, S.B., 2007. Evaluating consistency of best professional judgment in the application of a multiple lines of evidence sediment quality triad. Integr Environ Assess Manag 3, 491–497.

Bay, S.M., Weisberg, S.B., 2012. Framework for interpreting sediment quality triad data. Integrated Environmental Assessment and Management 8, 589–596.<https://doi.org/10.1002/ieam.118>

Borja, A., Franco, J., Muxika, I., 2004. The Biotic Indices and the Water Framework Directive: the required consensus in the new benthic monitoring tools. Marine Pollution Bulletin 48, 405–408.<https://doi.org/10.1016/j.marpolbul.2003.10.024>

Cao, Y., Hagedorn, C., Shanks, O.C., Wang, D., Ervin, J., Griffith, J., Layton, B., McGee, C.D., Riedel, T., Weisberg, S., 2013. Towards establishing a human fecal contamination Index in microbial source tracking. IJCEES 4, 46–58.

Charles, D.F., Tuccillo, A.P., Belton, T.J., 2010. Diatoms and the Biological Condition Gradient in New Jersey Rivers and Streams: A basis for developing nutrient guidance levels (No. PCER Report No. 10-03). Patrick Center for Environmental Research, Academy of Natural Sciences, Philadelphia, PA.

Davies, S.P., Jackson, S.K., 2006. The biological condition gradient: a descriptive model for interpreting change in aquatic ecosystems. Ecol Appl 16, 1251–1266.

Davis, W.S., Simon, T.P., 1995. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. CRC Press.

Fetscher, A.E., Busse, L., Ode, P., 2009. Standard Operating Procedures for Collecting Stream Algae Samples and Associated Physical Habitat and Chemical Data for Ambient Bioassessments in California (No. Bioassessment SOP 002). California State Water Resources Control Board Surface Water Ambient Monitoring Program (SWAMP).

Gerritsen, J., Bouchard, R.W., Zheng, L., Leppo, E.W., Yoder, C.O., 2017. Calibration of the biological condition gradient in Minnesota streams: a quantitative expert-based decision system. Freshwater Science 36, 427–451.<https://doi.org/10.1086/691712>

Hausmann, S., Charles, D.F., Gerritsen, J., Belton, T.J., 2016. A diatom-based biological condition gradient (BCG) approach for assessing impairment and developing nutrient criteria for streams. Sci. Total Environ. 562, 914–927.<https://doi.org/10.1016/j.scitotenv.2016.03.173>

Hawkins, C.P., Olson, J.R., Hill, R.A., 2010. The reference condition: predicting benchmarks for ecological and water-quality assessments. Journal of the North American Benthological Society 29, 312–343.<https://doi.org/10.1899/09-092.1>

Hilsenhoff, W.L., 1987. An Improved Biotic Index of Organic Stream Pollution 20, 10.

Lange-Bertalot H., Hofmann G., Werum M. & Cantonati M. 2017. Freshwater Benthic Diatoms of Central Europe: Over 800 Common Species Used in Ecological Assessment. M. Cantonati, M.G. Kelly & H. Lange-Bertalot (Eds.): 942 pp. Koeltz Botanical Books (ISBN 978-3-946583-06-6). English edition with updated taxonomy and added species of Hofmann et al. 2013.

Mazor, R.D., Rehn, A.C., Ode, P.R., Engeln, M., Schiff, K.C., Stein, E.D., Gillett, D.J., Herbst, D.B., Hawkins, C.P., 2016. Bioassessment in complex environments: designing an index for consistent meaning in different settings. Freshwater Science 35, 249–271.<https://doi.org/10.1086/684130>

Mazor, R.D., Stein, E.D., Southern California Stormwater Monitoring Coalition, 2017. 2015 Report on the Stormwater Monitoring Coalition Regional Stream Survey (Technical Report No. 963). Southern California Coastal Water Research Project, Costa Mesa, CA.

Nair, R., Aggarwal, R., Khanna, D., 2011. Methods of formal consensus in classification/diagnostic criteria and guideline development. Semin. Arthritis Rheum. 41, 95–105.<https://doi.org/10.1016/j.semarthrit.2010.12.001>

Ode, P.R., Rehn, A.C., Mazor, R.D., Schiff, K.C., Stein, E.D., May, J.T., Brown, L.R., Herbst, D.B., Gillett, D., Lunde, K., Hawkins, C.P., 2016. Evaluating the adequacy of a reference-site pool for ecological assessments in environmentally complex regions. Freshwater Science 35, 237–248.<https://doi.org/10.1086/684003>

Olson, J.R., Hawkins, C.P., 2012. Predicting natural base-flow stream water chemistry in the western United States: predicting water chemistry. Water Resources Research 48.<https://doi.org/10.1029/2011WR011088>

Potapova, M., Charles, D.F., 2007. Diatom metrics for monitoring eutrophication in rivers of the United States. Ecological Indicators 7, 48–70.<https://doi.org/10.1016/j.ecolind.2005.10.001>

Reynoldson, T.B., Norris, R.H., Resh, V.H., Day, K.E., Rosenberg, D.M., 1997. The Reference Condition: A Comparison of Multimetric and Multivariate Approaches to Assess Water-Quality Impairment Using Benthic Macroinvertebrates. Journal of the North American Benthological Society 16, 833–852.<https://doi.org/10.2307/1468175>

Rott, E., Van Dam, H., Pfister, P., Pipp, E., Pall, K., Binder, N., Ortler K. 1999. Indikationslisten für Aufwuchsalgen. Teil 2: Trophieindikation, geochemische Reaktion, toxikologische und taxonomische Anmerkungen. Publ. Wasserwirtschaftskataster, BMLF, 1-248.

Steedman, R.J., 1994. Ecosystem Health as a Management Goal. Journal of the North American Benthological Society 13, 605–610.<https://doi.org/10.2307/1467856>

Stevenson, R. J., Pan, Y., Manoylov, K., Parker, C.A., Larsen, D.P., Herlihy, A.T. 2008. Development of diatom indicators of ecological conditions for streams of the western United States. Journal of the North American Benthological Society, 27, 1000–16.

Stoddard, J.L., Larsen, P., Hawkins, C.P., Johnson, R.K., Norris, R.H., 2006. Setting expectations for the ecological condition of running waters: the concept of reference condition. Ecological Applications 16, 11.

Suter, G.W., 1993. A critique of ecosystem health concepts and indexes. Environmental Toxicology and Chemistry 12, 1533–1539.<https://doi.org/10.1002/etc.5620120903>

Teixeira, H., Borja, Á., Weisberg, S.B., Ananda Ranasinghe, J., Cadien, D.B., Dauer, D.M., Dauvin, J.-C., Degraer, S., Diaz, R.J., Grémare, A., Karakassis, I., Llansó, R.J., Lovell, L.L., Marques, J.C., Montagne, D.E., Occhipinti-Ambrogi, A., Rosenberg, R., Sardá, R., Schaffner, L.C., Velarde, R.G., 2010. Assessing coastal benthic macrofauna community condition using best professional judgement – Developing consensus across North America and Europe. Marine Pollution Bulletin 60, 589–600.<https://doi.org/10.1016/j.marpolbul.2009.11.005>

Theroux, S., Mazor, R.D., Ode, P., Sutula, M.A., Stein, E.D., n.d. A statewide algal bioassessment index for statewide wadeable streams. In prep for submission to Ecological Indicators. In prep for submission to Ecological Indicators.

USEPA, 2016. A Practitioner’s Guide to the Biological Condition Gradient: A Framework to Describe Incremental Change in Aquatic Ecosystems (No. EPA-842-R-16-001). U.S. Environmental Protection Agency, Washington, D.C.

USEPA, 2002. Summary of Biological Assessment Programs and Biocriteria Development for States, Tribes, Territories, and Interstate Commissions: Streams and Wadeable Rivers (No. EPA-822-R-02-048). U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S, Fourth Edition. ed. Springer.

Weisberg, S., Thompson, B., Ranasinghe, A., E. Montagne, D., Cadien, D., Dauer, D., Diener, D., Oliver, J., Reish, D., Velarde, R., Word, J., 2008. The level of agreement among experts applying best professional judgment to assess the condition of benthic infaunal communities. Ecological Indicators 8, 389–394.<https://doi.org/10.1016/j.ecolind.2007.04.001>

Yoder, C.O., and E.T. Rankin, 1995. The role of biological criteria in water quality monitoring, assessment and regulation. Ohio EPA Technical Report MAS/1995-1-3.  
 Yoder, C.O., and E.T. Rankin, 1995. Biological criteria program development and implementation in Ohio, pp. 109-144 (Chapter 9). In W.S. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.  
 Yoder, C.O., Barbour, M.T., 2009. Critical technical elements of state bioassessment programs: a process to evaluate program rigor and comparability. Environmental Monitoring and Assessment 150, 31–42.<https://doi.org/10.1007/s10661-008-0671-1>

Yuan, L.L., 2006. Estimation and Application of Macroinvertebrate Tolerance Values (No. EPA/600/P-04/116F). U.S. Environmental Protection Agency, ORD, National Center for Environmental Assessment, Washington, D.C.

**Figure Captions**

[Figure 1. The Biological Condition Gradient (BCG) conceptual model.](#_Toc527188027)

[Figure 2. Process diagram for calibration of the BCG in California.](#_Toc527188028)

[Figure 3. Sample site locations throughout California, showing the assemblage sampled and the Perennial Stream Assessment (PSA) region.](#_Toc527188029)

[Figure 4. Distributions of CSCI and hASCI values by BCG levels. Boxes show medians, quartiles (boxes), non-outlier extremes (whiskers), raw data, and outliers.](#_Toc527188030)

[Figure 5. CSCI and hASCI distributions in relation to final BCG levels by PSA region. Boxes show medians, quartiles (boxes), and non-outlier extremes (whiskers).](#_Toc527188031)

[Figure 6. Proportional odds diagram relating BCG levels to the CSCI (left) and ASCI (right). Curves represent the modeled proportion of expert ratings that would be expected for a sample with a given CSCI/ASCI score. The points above the curve reflect actual ratings, with marker size indicating relative frequency and color indicating BCG level corresponding to the curves.](#_Toc527188032)

[Figure 7. Distributions of selected environmental variables in relation to macroinvertebrate and algal final BCG levels. Variables include watershed area, site elevation, modeled site temperature, and modeled site precipitation. Boxes show medians and intra-quartile ranges.](#_Toc527188033)

[Figure 8. Distributions of specific conductivity, total nitrogen and total phosphorus percent urban and agricultural land cover (2011) in site catchments by final BCG levels. Boxes show medians and intra-quartile ranges.](#_Toc527188034)

[Figure 9. Crosswalk of BCG narratives and BCG-derived CSCI and ASCI scores (right side of each panel) to a percentile of reference narratives and scores (left sides of each panel). Figure not drawn to scale. Data from Paul et al. (in prep).](#_Toc527188035)

**Table Captions**

[Table 1. Descriptive statistics for natural and stressor variables in macroinvertebrate samples.](#_Toc527188036)

[Table 2. The number of taxa and representative taxa assigned to each BCG attribute level. The taxa shown represent the most abundant for each level.](#_Toc527188037)

[Table 3. Correspondence matrix of BMI and algal BCG expert site scores for the 194 samples in common.](#_Toc527188038)

**Supplemental Figure and Table Captions**

[SI Figure 1. Example rating worksheet, showing sample identifiers (A), BCG attribute metrics (B), taxa list with attributes and enumeration (C), site environmental characteristics (D), and other metrics (E).](#_Toc527188039)

SI Table 1. BCG Attribute narrative description.

[SI Table 2. BCG narratives as constructed by the macroinvertebrate and algal expert groups, describing changes in these assemblages along the biological condition gradient in California streams.](#_Toc527188040)

SI Table 3. BCG attribute assignments

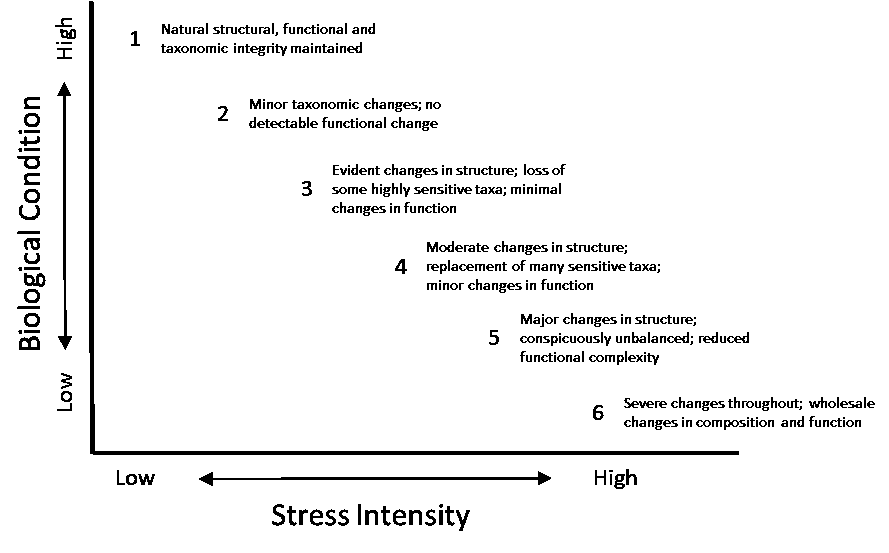


Figure 1. The Biological Condition Gradient (BCG) conceptual model.

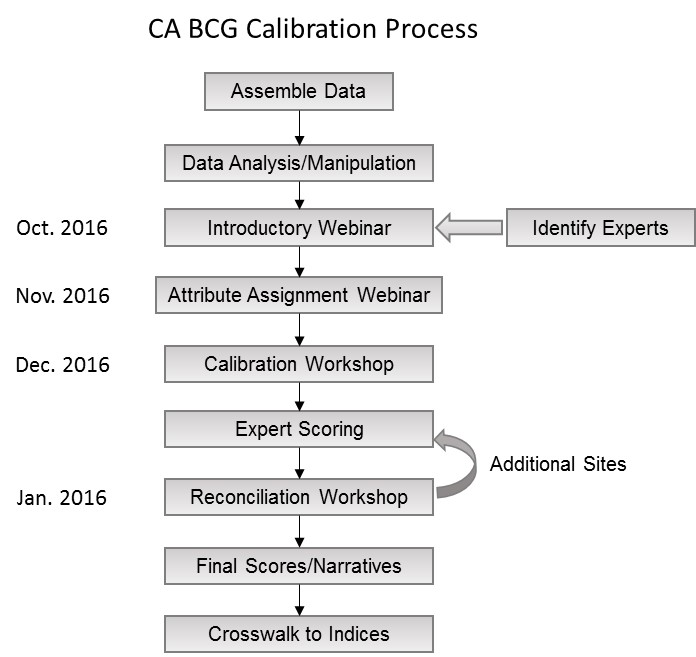


Figure 2. Process diagram for calibration of the BCG in California.

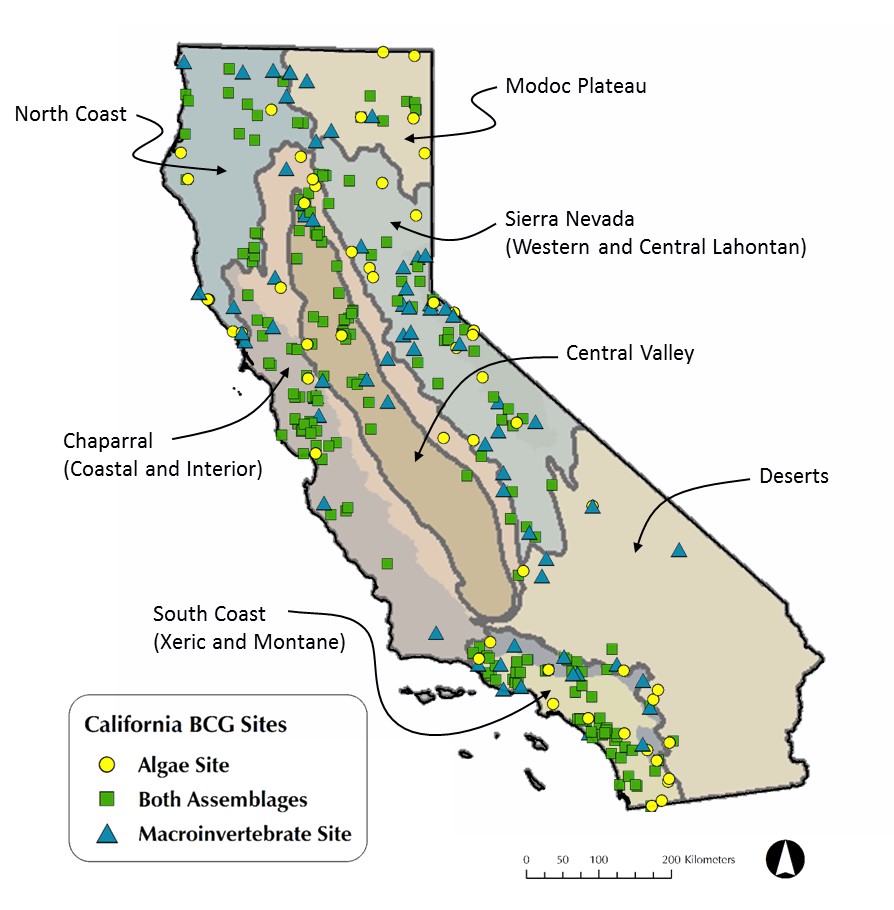


Figure 3. Sample site locations throughout California, showing the assemblage sampled and the Perennial Stream Assessment (PSA) region.

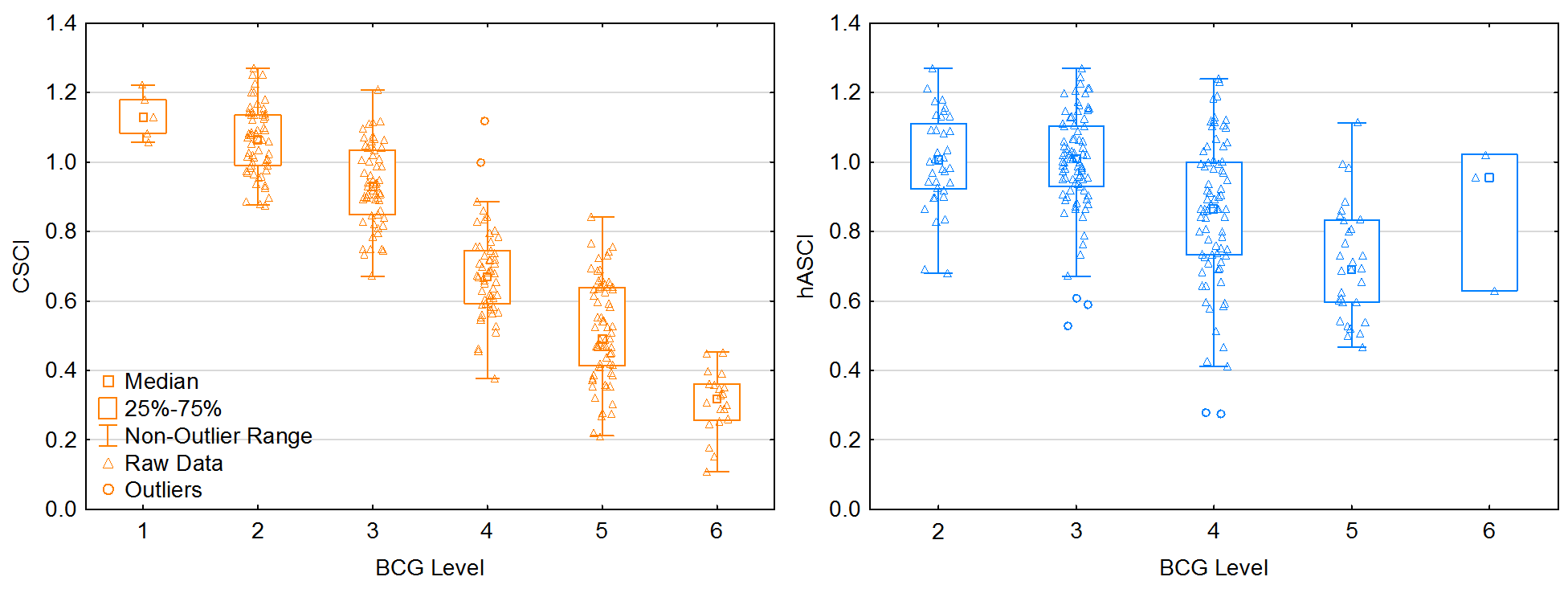


Figure 4. Distributions of CSCI and hASCI values by BCG levels. Boxes show medians, quartiles (boxes), non-outlier extremes (whiskers), raw data, and outliers.

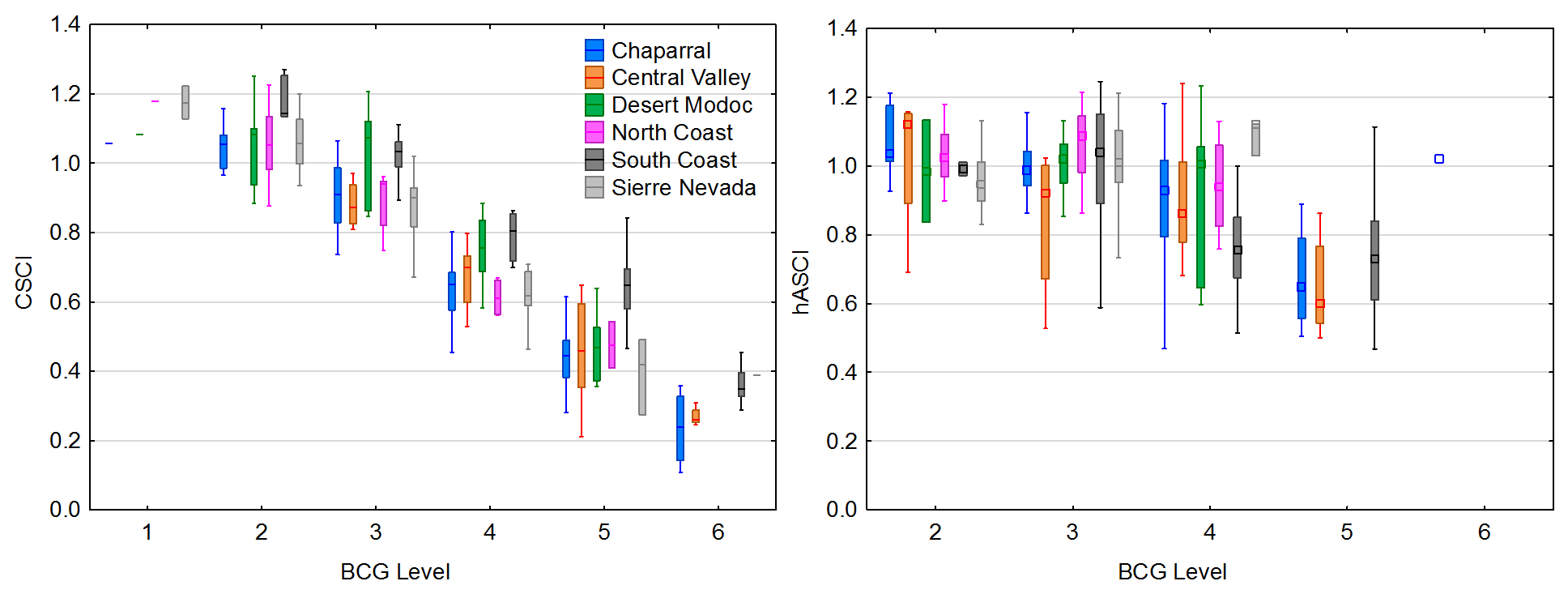


Figure 5. CSCI and hASCI distributions in relation to final BCG levels by PSA region. Boxes show medians, quartiles (boxes), and non-outlier extremes (whiskers).

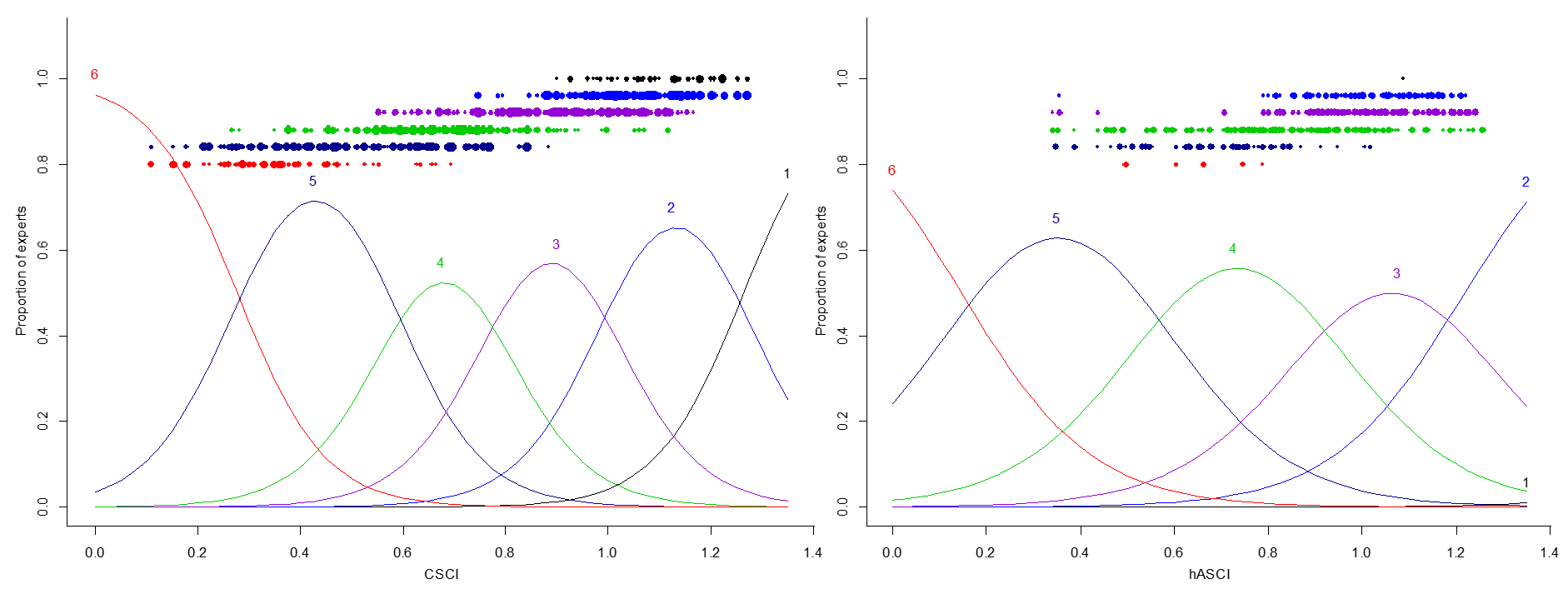


Figure 6. Proportional odds diagram relating BCG levels to the CSCI (left) and ASCI (right). Curves represent the modeled proportion of expert ratings that would be expected for a sample with a given CSCI/ASCI score. The points above the curve reflect actual ratings, with marker size indicating relative frequency and color indicating BCG level corresponding to the curves.

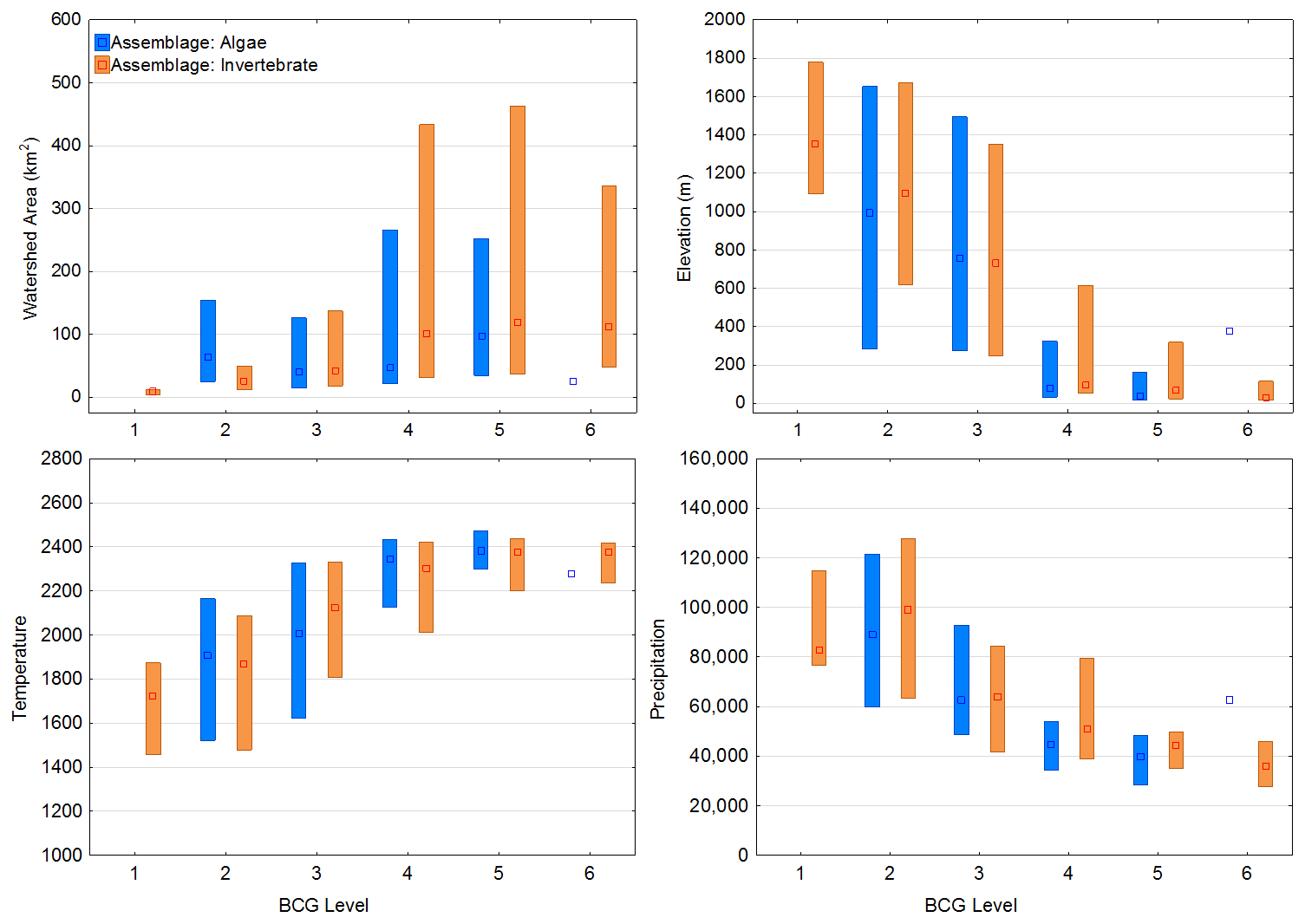


Figure 7. Distributions of selected environmental variables in relation to macroinvertebrate and algal final BCG levels. Variables include watershed area, site elevation, modeled site temperature, and modeled site precipitation. Boxes show medians and intra-quartile ranges.



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Figure 9. Crosswalk of BCG narratives and BCG-derived CSCI and ASCI scores (right side of each panel) to a percentile of reference narratives and scores (left sides of each panel). Figure not drawn to scale. Data from Paul et al. (in prep).

Table 1. Descriptive statistics for natural and stressor variables in macroinvertebrate samples.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Min | Mean | Max |
| Collection Date | 1998 | 2011 | 2015 |
| Catchment Area (km2) | 1 | 315 | 8812 |
| Elevation (m) | 3 | 651 | 3130 |
| Average Air Temperature (oC) | 6.4 | 20.9 | 29.7 |
| Precipitation (m/y) | 0.09 | 0.66 | 2.0 |
| Agricultural and Urban Cover (%) | 0 | 10.0 | 88.8 |
| Total Phosphorus (mg/L) | 0.0 | 0.18 | 5.1 |
| Total Nitrogen (mg/L) | 0.0 | 1.02 | 34 |
| Specific Conductance (uS/cm) | 8 | 540 | 6381 |

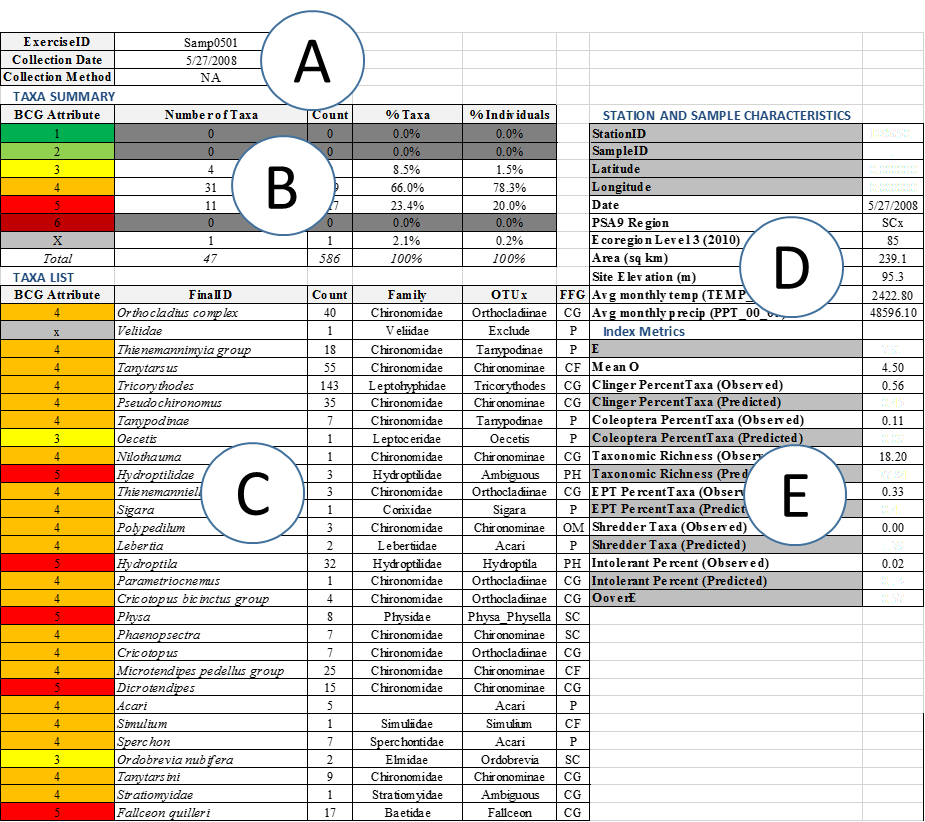
Table 2. The number of taxa and representative taxa assigned to each BCG attribute level. The taxa shown represent the most abundant for each level.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Attribute** | **Number of BMI Taxa** | **Representative BMI Taxa** | **Number of Diatom Taxa** | **Representative Diatom Taxa** | **Number of SBA Taxa** | **Representative SBA Taxa** |
| I. SPECIALISTS: Historically documented, sensitive, long-lived, or regionally endemic taxa | 9 | *Vorticifex effusa* | 3 | *Encyonema latum* | 1 | *Zygnema aplanosporum* |
| *Nerophilus californicus* | *Navicula aurora* |  |
| *Sierraperla cora* | *Gomphoneis mamilla* |  |
| II. HIGHLY SENSITIVE: Highly sensitive (typically uncommon) taxa | 95 | *Drunella doddsii* | 96 | *Reimeria sinuata* | 33 | *Chamaesiphon polymorphus* |
| *Yoraperla nigrisoma* | *Epithemia sorex* | *Homoeothrix varians* |
| *Ameletus* | *Rhopalodia gibba* | *Calothrix parietina* |
| III. SENSITIVE: Intermediate sensitive taxa | 245 | *Lepidostoma* | 129 | *Achnanthidium minutissimum* | 62 | *Nostoc verrucosum* |
| *Micrasema* | *Rhoicosphenia abbreviata* | *Calothrix epiphytica* |
| *Epeorus* | *Nitzschia dissipata* | *Aphanothece minutissima* |
| IV. INDISCRIMINATE: Taxa of intermediate tolerance | 301 | *Oligochaeta* | 134 | *Planothidium lanceolatum* | 46 | *Heteroleibleinia* sp. 1 |
| *Baetis tricaudatus* | *Nitzschia inconspicua* | *Leptolyngbya foveolarum* |
| *Orthocladius complex* | *Synedra ulna* | *Aphanocapsa delicatissima* |
| V. TOLERANT: Tolerant taxa | 56 | *Ostracoda* | 57 | *Achnanthidium exiguum* | 14 | *Scenedesmus ellipticus* |
| *Hyalella* | *Nitzschia palea* | *Rhizoclonium hieroglyphicum* |
| *Dicrotendipes* | *Navicula gregaria* | *Desmodesmus abundans* |
| VI. EXOTIC: Nonnative or intentionally introduced species | 6 | *Potamopyrgus antipodarum* |  |  |  |  |
| *Corbicula* |  |  |  |
| *Cambaridae* |  |  |  |

Table 3**. Correspondence matrix of BMI and algal BCG expert site scores for the 194 samples in common.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Algal BCG Ratings | BMI BCG Ratings | | | | | | |
|  | 1 | 2 | 3 | 4 | 5 | 6 |
| 2 | 1 | 16 | 9 | 2 |  |  |
| 3 | 6 | 24 | 20 | 9 | 6 |  |
| 4 |  | 4 | 13 | 23 | 32 | 3 |
| 5 |  |  |  | 4 | 16 | 6 |

Supplemental Figures and Tables



SI Figure 1. Example rating worksheet, showing sample identifiers (A), BCG attribute metrics (B), taxa list with attributes and enumeration (C), site environmental characteristics (D), and other metrics (E).



SI Figure 2. Histogram of agreement of individual expert ratings with the sample median rating using the plurality scoring approach for macroinvertebrate data, showing divergence from the median in units of 1/2 BCG level. Each BCG level has half units, corresponding to core ratings (e.g. 4) and qualified ratings (e.g., 2.5, 3.5) at each level. N = 264 samples, 2204 ratings.

E:\CurrentData\Documents\BCG_CA\Analysis\Ordination\Ord1_R\SampsXbcgPlot.tiff

SI Figure 3.  **Algal ordination:** NMDS ordination diagram of algal samples, showing standard deviation ellipses associated with point scores for samples with BCG levels 2 (blue), 3 (green), 4 (tan), 5 (red) and 6 (black).

SI Table 1. BCG Attribute narrative description.

|  |  |
| --- | --- |
| Attribute | Description |
| I. SPECIALISTS: Historically documented, sensitive, long-lived, or regionally endemic taxa | Taxa known to have been supported according to historical, museum, or archeological records, or taxa with restricted distribution (occurring only in a locale as opposed to a region), often due to unique life history requirements (e.g., Pupfish, many Unionid mussel species). |
| II. HIGHLY SENSITIVE: Highly sensitive (typically uncommon) taxa | Taxa that are highly sensitive to pollution or anthropogenic stressors. Tend to occur in low numbers, and many taxa are specialists for habitats and food type. These are the first to disappear with disturbance or pollution (e.g., most stoneflies, Brook Trout [in the east], Brook Lamprey). |
| III. SENSITIVE: Intermediate sensitive taxa | Common taxa that are ubiquitous and abundant in relatively undisturbed conditions but are sensitive to anthropogenic stressors. They have a broader range of tolerance than Attribute II taxa and can be found at reduced density and richness in moderately disturbed sites (e.g., many mayflies, many darter fish species). |
| IV. INDISCRIMINATE: Taxa of intermediate tolerance | Ubiquitous and common taxa that can be found under almost any conditions, from undisturbed to highly stressed sites. They are broadly tolerant but often decline under extreme conditions (e.g., filter-feeding caddisflies, many midges, many minnow species). |
| V. TOLERANT: Tolerant taxa | Taxa that typically are uncommon and of low abundance in undisturbed conditions but that increase in abundance in disturbed sites. Opportunistic species able to exploit resources in disturbed sites. These are the last survivors (e.g., tubificid worms, Black Bullhead). |
| VI. EXOTIC: Nonnative or intentionally introduced species | Any species not native to the ecosystem (e.g., Asiatic clam, zebra mussel, carp, European Brown Trout). Additionally, there are many fish native to one part of North America that have been introduced elsewhere. |

SI Table 2. BCG narratives as constructed by the macroinvertebrate and algal expert groups, describing changes in these assemblages along the biological condition gradient in California streams.

| **BCG Level** | **Davies and Jackson 2006** | **CA Macroinvertebrate Experts** | **CA Algal Experts** |
| --- | --- | --- | --- |
| 1 | Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability. | Level 1 streams contain extremely high relative observed taxa richness that meets expectation, with the greatest variety and abundance of Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa and the largest aggregation of sensitive taxa. Specialist, highly sensitive, and sensitive taxa (attribute I, II, and III) are 50% or more of the taxa and individuals present. Tolerant (attribute V) taxa are absent or rare. This diversity and complexity in taxa richness corresponds with the presence of complex and unique habitats and a balanced set of trophic groups. Dominant taxa do not occur in Level 1 streams, resulting in a uniform representation of taxa (high evenness). The effect of low level, diffuse stressors may produce impacts that are less than that from variability in composition due to natural assemblage dynamics/natural disturbance in these streams.  In areas where resources are more limited, habitats small, or growing season is short (cold water, high elevation, desert streams, springbrooks), diversity is often lower but the taxa present will often be restricted in distribution, sometimes endemic, and with specialized adaptations to local conditions. Native taxa, often with restricted biogeographic distributions, are present even where not locally endemic; locally high densities of highly sensitive taxa may occur in such systems. | No sample was reviewed and identified as Level 1 by consensus. Therefore, the description was based on conceptual conditions.  In Level 1, there is typically reduced overall taxa richness compared to other BCG levels. Low total algal biomass is expected, and low productivity is presumed. Taxa primarily belong to highly sensitive and sensitive (Attribute II and III) categories. Indiscriminant and tolerant taxa (Attribute IV and V) are missing or scarce, only to include incidental cells in the sample. Diatom cells are often small, benthic and adnate in mountain streams. Achnanthidium minutissimum may be in high abundance. In the Sierra Nevada Mountain region, Hannaea arcus is often present. Epilithic cyanobacteria (tightly adhering to rocks) should be present (e.g. Chamaesiphon and Homoeothrix). Highly motile taxa are typically absent. |
| 2 | Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability. | Level 2 streams contain high relative biological richness that reflects expectations or slight deviations from expectation. Biological communities contain many similar characteristics as Level 1. Specialist, highly sensitive, and sensitive taxa (attribute I, II, and III) are a large portion of the taxa and individuals present. Highly sensitive and sensitive taxa may be a greater proportion than in Level 1. Tolerant (attribute V) taxa are absent or rare. In Level 2, a select number of taxa may have slightly greater dominance than others. A few highly sensitive taxa are absent as a result of slight reduction in habitat condition and/or presence of low level stressors; a few taxa (e.g., sensitive) may be more abundant than naturally expected and some tolerant forms may increase. Native taxa found in these communities may be broadly distributed in several of the regions; endemics are rare. These native taxa show greater abundance and slightly higher tolerance. EPT taxa may be slightly reduced in comparison to Level 1, but they still compose a high proportion of the taxa and total abundance.  Taxonomic composition reflects a strong balance in trophic traits, indicating habitat/microhabitat complexity is still high. | Richness of algal taxa in Level II is generally greater than in Level I. Richness might depend on region or stream type. For example, the Sierra Nevada Mountains might have few taxa and regions with volcanic bedrock or naturally high water temperature (e.g., in southern California) might have more taxa. Richness of highly sensitive and sensitive (attribute II and III) taxa is high compared to indiscriminant and tolerant taxa (attributes IV and V). Abundance of highly sensitive and sensitive individuals dominate the sample and abundance of highly sensitive taxa individuals might be high. An indiscriminant taxon may, on rare occasion, dominate the sample. Tolerant taxa are missing or uncommon and in low abundance.  Highly motile taxa are absent from high gradient streams. Attached taxa typically dominate the samples, although moderately motile taxa may be present, especially those that grow in stalked colonies (Cymbella, Gomphonema, Gomphoneis). Taxa sensitive to nutrients (associated with low N and P concentrations; low N and P indicator taxa) are high (>80% of diatom individuals). Nitrogen fixers are often common, such as heterocytous cyanobacteria Nostoc, Calothrix, and Tolypothrix and diatoms Rhopalodia and Epithemia. Level II samples are characterized by the presence of Gomphonema taxa with wide central areas (G. stoermeri, G. cf. clevei, G. caperatum, G. sierrianum), as well as other Gomphonema and Gomphoneis species described from California. Rhoicosphenia (an endemic in CA) might also be present. Small monoraphids, such as Achnanthidium (A. minutissimum, A. rivulare), can be in high abundance. Soft algae described from California and considered to be endemic (e.g. Attribute I Zygnema aplanosporum) might be present. Epilithic cyanobacteria (tightly adhering to rocks) typically are present (e.g. Chamaesiphon, Homoeothrix, Schizothrix). Biovolume of Zygnemataceae, heterocytous cyanobacteria, and Rhodophyta (ZHR metric) are usually high. |
| 3 | Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but sensitive–ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system. | Level 3 streams have noticeable shifts in richness below expectation, but loss of less than 50% of expected taxa. Level 3 streams have moderate overall diversity, with taxonomic and functional diversity reduced relative to BCG levels 1-2, lower abundance of sensitive taxa (but still present), and increases in dominance. Changes in community composition in the presence of typical stressors include increasing dominance of generalist sensitive taxa (migrants, colonizers, opportunist feeders) and indiscriminant taxa. A distinct loss of highly sensitive taxa (attribute II) occurs with replacement by sensitive and indiscriminant taxa (Attributes III and IV). Tolerant (attribute V) taxa are still rare or absent. Examples of taxa present that indicate a response to measureable, low-level stressors include: Baetis, Cricotopus, Simulium, and Hydropsyche. Level 3 biological communities exhibit a decrease in EPT with filtering caddisflies having greater dominance and the loss of Plecoptera taxa noted (e.g., replacement of Plecoptera with Trichopteran shredder taxa like Lepidostoma); as a result, the ratio of EPT to Diptera:Chironomidae and non-insects is reduced.  Changes in composition reflect changes in the resource base, such as more filamentous algae or detritus or declines in terrestrial inputs or increases in suspended particles benefitting filter feeders. As a result, certain taxa may increase in numbers such as Trichoptera:Hydroptilidae and collector-gatherers or Trichoptera:Hydropsychidae and Diptera:Simuliidae.  In regions where historical disturbance has occurred or is still present, Level III may be the best condition in a region (e.g., Southern California Mountains or Coastal Chaparral). | Richness in Level 3 samples is usually greater than in Level 2. Taxa belonging to all attributes (II, III, IV, and V) are typically present. Greater richness and abundance of indiscriminant taxa (attribute IV) are expected, though highly sensitive taxa and sensitive taxa (Attribute II and III) are expected in greater richness and abundance relative to indiscriminant and tolerant taxa. Tolerant taxa (attribute V) may be present, but occur in low abundance.  A decrease in nutrient sensitive taxa (low N and P metric) is expected in Level 3 as compared to Level 2. Nitrogen-fixing cyanobacteria may be present (most commonly Nostoc verrucosum), particularly in southern California. Level 3 samples have an increased frequency of occurrence of Cladophora. A decrease in Zygnemataceae + heterocytous cyanobacteria + Rhodophyta (ZHR) metric as compared to Level 2, but there may be an increase in some green algal taxa. A mixture of epilithic cyanobacteria and large filamentous green algae is expected. Level 3 samples contain a greater number of Attribute 3 diatoms and generally have greater species richness than Level 2 sites. Level 3 samples contain a number of Attribute 4 and 5 taxa, particularly motile diatoms increase in composition and abundance. |
| 4 | Moderate changes in structure due to replacement of some sensitive–ubiquitous taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes. | Level 4 streams have ever more noticeable shifts in richness below expectation, with loss of 25% to 60% of expected taxa. Assemblages in this BCG level are comprised primarily of taxa that are widespread, common and opportunistic. These streams have lower diversity and abundance or even absence of highly sensitive taxa (Attribute II, including EPT or others with tolerance values of 0-2), greatly reduced abundance and richness of sensitive taxa (Attribute III), and dominance by indiscriminant taxa (Attribute IV). Unexpected taxa may occur at high abundances, indicating opportunistic replacement. Identifiable changes in structure within the community occur where dominance is attributable to mostly widespread, common, tolerant taxa (e.g., Caenis, Baetis, Simulium, and Hydropsyche). In regions were these common taxa are natural, they may not indicate degradation unless they are dominant. However, even in natural stressed regions, their sensitive taxa (e.g., Tinodes), are declining. Increased dominance of tolerant taxonomic groups (Ostracoda, Oligochaeta, Diptera:Chironomidae, Turbellaria, and Gastropoda) that may constitute half of the taxa.  The variety of trait states is more limited than at Levels 1-3 and traits are often dominated by one or another state for any of a variety of categories (e.g., trophic state, voltinism, size, development, habit, habitat preference). | In Level 4, there is a reduction in taxa richness and relative abundance of highly sensitive and sensitive (attribute II and III) taxa in comparison to Level 3. The abundance of indiscriminant (attribute IV) taxa should increase, so that they tend to dominate the assemblage. The abundance of motile taxa is expected to increase. Sensitive monoraphid taxa (Achnanthidium minutissimum, A. deflexum, A. rivulare) are replaced with A. exiguum and species of Planothidium, especially P. frequentissimum, P. delicatulum, and P. lanceolatum. Cladophora and associated diatom epiphyte Cocconeis placentula are often dominant. Large, filamentous chlorophytes are often present (such as Cladophora + Rhizoclonium + Ulva +Stigeoclonium (CRUS metric), and sometimes also the xanthophyte Vaucheria. Nitrogen-fixing diatoms and cyanobacteria decrease or are absent. Nutrient sensitive diatoms (low N and P metric) are absent or sparse. Zygnemataceae + heterocytous cyanobacteria + Rhodophyta (ZHR metric) taxa are sparse or absent. Naviculoid biraphid diatoms increase in comparisonto Level 3. There is an increase in the abundance of larger diatom taxa, particularly Surirella, Pleurosira and Tryblionella and an increase in the presence of chain forming araphid taxa such as Staurosira and Pseudostaurosira in Level 4 as compared to Level 3. |
| 5 | Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased buildup or export of unused materials. | Level 5 streams have greatly reduced richness, well below expectation, with frequent loss of more than 50% of expected taxa. Level 5 biological communities are completely comprised by indiscriminant (Attribute IV) and tolerant (Attribute V) taxa with potential for appearance of exotic taxa (Attribute VI). Tolerant taxa are represented by Ostracoda, Gastropoda, Oligochaeta, Diptera:Chironomidae:Chironominae, and genera like Hyalella. Non-insect taxa are often dominant and representation of EPT taxa limited to replacement by tolerant forms: Ephemeroptera that may be found in Level V biological communities include Tricorythodes, Fallceon, Caenis, and Baetis; Trichoptera include taxa from Hydroptilidae/Hydropsychidae (Trichoptera). Diptera:Chironomidae sub-families present will be dominated by the Chironominae and Tanypodinae indicating soft-sediments with higher oxygen demand from overlying surface water.  The variety of trait states is even more reduced. Most taxa in communities are small-bodied, multiple cohort taxa. With reduction of specialized habitat niches comes a reduction in presence of functional feeding groups. Small predators increase and large predators are restricted to air-breathers like those of the Coleoptera and Hemiptera. If shredder or clinger taxa are present, they will be severely reduced in abundance. Collector-gatherer taxa are dominant. | In Level 5, there is a loss or significant reduction in the number and abundance of highly sensitive and sensitive (attribute II and III) taxa (<40%), and replacement with indiscriminant and tolerant (attribute IV and V) taxa (>50%). Distinctive tolerant taxa (e.g., Navicula rhynchocephala, Gyrosigma attenuatum and Nitzschia acicularis) are typically present. There is a conspicuous reduction or absence of keystone taxa, such as Rhopalodia and Epithemia. There might also be a loss of species within the genus Fragilaria, as their epilithic habitat may be no longer available. At the same time, there could be an increase in taxa living in silt habitats (epipelic) (e.g., Nitzschia, Tryblionella, Gyrosigma). There could also be an increase in the occurrence and abundance of the diatom Bacillaria paradoxa and toxigenic filamentous cyanobacteria (Geitlerinema). There is a loss or significant reduction of nitrogen-fixing cyanobacteria and nutrient sensitive taxa (low N and P metric) are sparse (<10%). There could also be an increase in the number of taxa that are characteristic of high specific conductance (e.g., Tabularia, Pleurosira, Fallacia). In Level 5 Cocconeis species are sparse, and tend not to be abundant in the presence of Cladophora on which they are commonly epiphytic (Table \_\_). Taxa belonging to ZHR metric are absent, replaced by Cladophora glomerata, Rhizoclonium hieroglyphicum, Ulva flexuosa, and Stigeoclonium spp. (taxa belonging CRUS metric). |
| 6 | Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism conditioning is often poor; ecosystem functions are severely altered. | Level 6 streams have extremely impacted richness, with frequent loss of more than 75% of expected taxa. Highly sensitive and sensitive (attribute II and III) taxa are absent. Abundance is characterized by high densities of a few tolerant taxa or even low densities of tolerant taxa (extreme stress). Sites can be completed dominated by exotic taxa acting as a source of disturbance preventing re-colonization by native fauna. Tolerant taxa are represented by the Ostracoda, Turbellaria, Oligochaeta, Gastropoda (e.g., Physa), Diptera:Chironomidae (Chironominae and Tanypodinae), and Hyalella colonizing degraded habitat characterized by fine sediment highly enriched with organics, high water temperature and low dissolved oxygen concentrations near the benthos.  The variety of trait states is completely reduced. Life history traits are dominated by organisms with small body size, short life spans, rapid development, and adaptations for extreme stress that may result in dense numbers of those taxa, or conversely very low densities of the few taxa present. The food web is completely disrupted with dominant taxa represented solely by collector-gathers and micro-predators. | Level 6 systems can be difficult to characterize using algae. The difficulty may be that, at the extremes, different stressors have different "press" or "chronic" influence on the algal assemblage. For example, extremes in pH, low dissolved oxygen, high concentration of toxic substances, or loss of habitat may all cause a site to be disturbed to the point of being a Level 6. Algal assemblages, however, may have different responses to each of these extreme stresses. For example, algae in Level 6 sites might - or might not - be taxonomically depauperate, that is, with low species richness. Similarly, these sites may have high biomass (such as in the example of algal blooms fueled by organic enrichment) or low biomass (such as in sites with toxins, such as metals or pesticides and herbicides) compared to the other levels. Also, Level 6 assemblages may be dominated (> 80 – 90%) by one or a few taxa (usually indiscriminant or tolerant), regardless of species richness. Furthermore, cyanotoxins and low dissolved oxygen may be harmful to macroinvertebrates, but not to algae. In addition, some highly disturbed settings yield no algae present. For example, a surface mining field might be highly disturbed, but covered in floc and the number of cells is low, or even no algae may be present.  Species richness may not be a good indicator for these sites because the tolerant attribute IV and V taxa (and unattributed taxa) can be diverse in disturbed settings. Regardless of richness, indiscriminant and tolerant (attribute IV and V) taxa dominate in Level 6 samples. Highly sensitive (attribute II) taxa are absent and sensitive (attribute III) taxa are low in richness and abundance (generally <5% of diatom individuals). Soft algae biomass is expected to be low, though this is not always the case in sites with nutrient enrichment. An abundance of biraphid diatoms (highly motile) (e.g., Nitzschia) can indicate intensive disturbance. Characteristic diatoms with high abundance in BCG Level 6 are Cyclotella meneghiniana, Gomphonema parvulum, Nitzschia inconspicua, Nitzschia microcephala, and Nitzschia palea. The cyanobacteria (Chroococcus spp., Geitlerinema spp.) and green coccoids Scenedesmus spp. may also be present in these sites. |

SI Table 3. BCG attribute assignments

(N = count of samples, TN = total nitrogen, TP = total phosphorus, FS = few samples)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **BCG Attribute** | **N** | **Scientific Name** | Developed Land | Conductivity | TN | TP | Grand Average | BCGestimate | SRcomment |
| 5 | 11 | *Hydra* | 4.7 | 4.7 | 4.9 | 4.6 | 4.6 | 5 |  |
| 4 | 1 | *Nematoda* |  |  |  |  |  |  |  |
| 5 | 46 | *Prostoma* | 4.6 | 4.6 | 5.0 | 5.0 | 4.7 | 5 |  |
| 5 | 1 | *Planariidae* | 4.5 | 4.7 | 4.4 | 4.7 | 4.5 | 5 |  |
| 2 | 1 | *Polycelis* | 2.1 | 2.3 | 2.3 | 2.8 | 2.3 | 2 |  |
| 5 | 107 | *Turbellaria* | 4.6 | 4.8 | 4.4 | 4.9 | 4.6 | 5 |  |
| 5 | 2 | *Hirudinea* |  |  |  |  |  |  |  |
| 5 | 12 | *Erpobdellidae* | 4.9 | 4.9 | 4.7 | 4.6 | 4.7 | 5 |  |
| 5 | 2 | *Mooreobdella microstoma* |  |  |  |  |  |  |  |
| 5 | 3 | *Glossiphoniidae* | 4.6 | 4.6 | 4.4 | 4.9 | 4.6 | 5 |  |
| 5 | 2 | *Helobdella* |  |  |  |  |  |  |  |
| 5 | 6 | *Helobdella stagnalis* |  |  |  |  |  |  |  |
| x | 6 | *Lumbricina* |  |  |  |  |  |  |  |
| x | 1 | *Megadrili* |  |  |  |  |  |  |  |
| 4 | 192 | *Oligochaeta* | 4.1 |  |  |  | 4.1 | 4 |  |
| 5 | 1 | *Enchytraeidae* | 3.4 |  |  |  | 3.3 | 3 |  |
| 5 | 1 | *Lumbricidae* |  |  |  |  |  |  |  |
| 4 | 4 | *Dero* |  |  |  |  |  |  |  |
| 4 | 1 | *Naididae* | 4.3 |  |  |  | 4.0 | 4 |  |
| 4 | 2 | *Nais* |  |  |  |  |  |  |  |
| 4 | 1 | *Pristina* |  |  |  |  |  |  |  |
| 4 | 1 | *Slavina appendiculata* |  |  |  |  |  |  |  |
| 4 | 1 | *Branchiura sowerbyi* |  |  |  |  |  |  |  |
| 4 | 7 | *Tubificidae* | 4.6 |  |  |  | 4.1 | 4 |  |
| 4 | 1 | *Lumbriculus* |  |  |  |  |  |  |  |
| 4 | 2 | *Polychaeta* |  |  |  |  |  |  |  |
| x | 4 | *Nereis limnicola* |  |  |  |  |  |  |  |
| x | 1 | *Bivalvia* |  |  |  |  |  |  |  |
| 1 | 1 | *Margaritifera falcata* |  |  |  |  |  |  |  |
| 6 | 34 | *Corbicula* | 4.8 | 4.8 | 4.9 | 4.9 | 4.8 | 5 |  |
| 4 | 47 | *Pisidium* |  |  |  |  |  |  |  |
| 4 | 30 | *Sphaeriidae* | 3.9 | 3.0 | 3.8 | 4.3 | 3.8 | 4 |  |
| 4 | 6 | *Gastropoda* |  |  |  |  |  |  |  |
| x | 1 | *Ancylidae* |  |  |  |  |  |  |  |
| 4 | 20 | *Ferrissia* | 4.8 | 4.1 | 4.4 | 4.6 | 4.5 | 5 |  |
| 4 | 25 | *Lymnaea* | 4.3 | 3.8 | 3.9 | 4.1 | 4.0 | 4 |  |
| 4 | 2 | *Lymnaeidae* | 4.3 | 3.7 | 4.0 | 4.2 | 4.1 | 4 |  |
| 5 | 96 | *Physa* |  |  |  |  |  |  |  |
| 4 | 34 | *Gyraulus* | 4.2 | 4.1 | 4.4 | 4.6 | 4.1 | 4 |  |
| 4 | 1 | *Gyraulus deflectus* |  |  |  |  |  |  |  |
| 4 | 26 | *Helisoma* | 4.6 | 4.7 | 4.1 | 4.5 | 4.4 | 4 |  |
| 4 | 6 | *Menetus* | 4.6 | 3.5 | 4.2 | 4.6 | 4.2 | 4 |  |
| 4 | 21 | *Menetus opercularis* |  |  |  |  |  |  |  |
| 4 | 9 | *Planorbidae* | 4.4 | 4.4 | 4.4 | 4.9 | 4.5 | 4 |  |
| 1 | 1 | *Vorticifex effusa* |  |  |  |  |  |  |  |
| x | 17 | *Hydrobiidae* | 4.8 | 4.8 | 5.0 | 4.9 | 4.6 | 5 |  |
| 6 | 4 | *Potamopyrgus antipodarum* |  |  |  |  |  |  |  |
| x | 3 | *Pyrgulopsis* |  |  |  |  |  |  |  |
| 3 | 2 | *Fluminicola* |  |  |  |  |  |  |  |
| 3 | 12 | *Juga* | 3.9 | 2.8 | 2.1 | 3.9 | 3.1 | 3 |  |
| x | 1 | *Hypsogastropoda* |  |  |  |  |  |  |  |
| 1 | 1 | *Tryonia* |  |  |  |  |  |  |  |
| x | 1 | *Cyclopoida* |  |  |  |  |  |  |  |
| 5 | 128 | *Ostracoda* |  |  |  |  |  |  |  |
| 4 | 3 | *Amphipoda* |  |  |  |  |  |  |  |
| 4 | 1 | *Ramellogammarus* |  |  |  |  |  |  |  |
| 4 | 2 | *Americorophium* | 3.9 |  |  |  | 3.8 |  | FS |
| 4 | 5 | *Americorophium spinicorne* |  |  |  |  |  |  |  |
| 4 | 12 | *Crangonyx* | 4.7 | 3.7 | 4.3 | 4.4 | 4.3 | 4 |  |
| x | 2 | *Stygobromus* | 2.9 | 3.7 | 4.1 |  | 3.4 |  | FS |
| 4 | 10 | *Gammarus* | 4.7 | 3.5 | 4.6 | 4.6 | 4.3 | 4 |  |
| 5 | 56 | *Hyalella* | 4.9 | 4.8 | 4.8 | 4.9 | 4.7 | 5 |  |
| 4 | 2 | *Decapoda* |  |  |  |  |  |  |  |
| x | 2 | *Pacifastacus* |  |  |  |  |  |  |  |
| 6 | 11 | *Cambaridae* | 5.0 | 4.7 | 4.1 | 4.3 | 4.5 | 4 |  |
| 6 | 1 | *Orconectes virilis* |  |  |  |  |  |  |  |
| 6 | 4 | *Procambarus clarkii* |  |  |  |  |  |  |  |
| 6 | 1 | *Mysida* |  |  |  |  |  |  |  |
| 5 | 1 | *Neomysis mercedis* |  |  |  |  |  |  |  |
| 4 | 7 | *Acari* |  |  |  |  |  |  |  |
| 4 | 1 | *Oribatei* |  |  |  |  |  |  |  |
| 3 | 1 | *Eylais* | 2.6 |  |  |  | 2.8 |  | FS |
| 3 | 1 | *Feltria* | 3.1 | 2.1 | 4.4 | 2.4 | 2.9 | 3 |  |
| 4 | 1 | *Hydrachna* |  |  |  |  |  |  |  |
| 4 | 3 | *Hydrodroma* | 2.3 |  | 2.6 |  | 2.5 | 2 |  |
| 3 | 31 | *Protzia* | 2.9 | 2.8 | 3.7 | 3.1 | 3.1 | 3 |  |
| 4 | 57 | *Atractides* | 3.5 | 3.8 | 3.9 | 3.1 | 3.6 | 4 |  |
| 4 | 42 | *Hygrobates* | 3.5 | 3.2 | 3.4 | 4.3 | 3.6 | 4 |  |
| 4 | 1 | *Hygrobatidae* | 3.5 | 3.8 | 3.9 | 3.6 | 3.7 | 4 |  |
| 4 | 3 | *Mesobates* |  |  |  |  |  |  |  |
| 4 | 2 | *Estelloxus* |  |  |  |  |  |  |  |
| 4 | 11 | *Limnesia* |  |  |  |  |  |  |  |
| 4 | 1 | *Limnesiidae* | 3.4 | 4.5 | 2.7 | 4.0 | 3.7 | 4 |  |
| 3 | 1 | *Limnochares* |  |  |  |  |  |  |  |
| 4 | 1 | *Limnodrilus hoffmeisteri* |  |  |  |  |  |  |  |
| 4 | 33 | *Mideopsis* | 3.9 | 3.9 | 3.1 | 3.8 | 3.7 | 4 |  |
| 3 | 1 | *Frontipoda* |  |  |  |  |  |  |  |
| x | 6 | *Pionidae* | 2.9 |  |  |  | 2.7 | 3 |  |
| 4 | 101 | *Sperchon* | 3.8 | 4.4 | 4.6 | 4.5 | 4.3 | 4 |  |
| 3 | 16 | *Sperchonopsis* | 2.8 | 3.1 | 2.1 | 3.1 | 2.8 | 3 |  |
| 4 | 3 | *Sperchontidae* | 3.9 | 4.3 | 4.3 | 4.3 | 4.1 | 4 |  |
| 2 | 3 | *Stygothrombium* | 2.0 |  |  |  | 2.0 | 2 |  |
| 3 | 14 | *Testudacarus* | 2.8 | 2.2 | 4.0 | 2.8 | 2.9 | 3 |  |
| 4 | 2 | *Unionicolidae* | 3.9 | 4.8 | 3.4 | 4.1 | 4.0 | 4 |  |
| x | 36 | *Trombidiformes* |  |  |  |  |  |  |  |
| 3 | 1 | *Utaxatax* |  |  |  |  |  |  |  |
| 4 | 1 | *Arrenuridae* | 3.5 | 4.6 | 4.3 | 3.8 | 4.0 | 4 |  |
| 4 | 5 | *Arrenurus* | 3.5 | 4.6 | 4.3 | 3.8 | 4.0 | 4 |  |
| 3 | 4 | *Aturus* |  |  |  |  |  |  |  |
| 2 | 1 | *Hydrovolzia* | 2.0 |  |  |  | 2.0 |  | FS |
| 2 | 1 | *Wandesia* | 2.1 | 2.6 | 2.4 | 2.9 | 2.4 | 2 |  |
| 4 | 101 | *Lebertia* |  |  |  |  |  |  |  |
| x | 1 | *Piona* |  |  |  |  |  |  |  |
| 3 | 72 | *Torrenticola* | 2.9 | 3.1 | 2.7 | 2.6 | 2.9 | 3 |  |
| 3 | 3 | *Torrenticolidae* | 2.9 | 3.1 | 2.9 | 2.6 | 3.0 | 3 |  |
| 4 | 1 | *Neumania* |  |  |  |  |  |  |  |
| x | 2 | *Ephemeroptera* |  |  |  |  |  |  |  |
| 2 | 43 | *Ameletus* | 2.3 | 2.2 | 2.4 | 2.3 | 2.4 | 2 |  |
| 3 | 7 | *Acentrella* | 3.6 | 2.6 | 2.7 | 2.8 | 3.0 | 3 |  |
| 3 | 4 | *Acentrella insignificans* | 3.8 | 2.6 | 3.7 |  | 3.4 | 3 |  |
| 3 | 7 | *Acentrella turbida* | 2.6 | 2.8 | 2.4 | 2.3 | 2.6 | 3 |  |
| 4 | 16 | *Baetidae* | 4.5 | 4.3 | 4.3 | 4.5 | 4.3 | 4 |  |
| 4 | 83 | *Baetis* | 4.1 | 4.5 | 4.1 | 4.5 | 4.3 | 4 |  |
| 4 | 18 | *Baetis adonis* | 4.6 | 4.9 | 4.8 | 5.0 | 4.7 | 5 |  |
| 4 | 3 | *Baetis bicaudatus* |  |  |  |  |  |  |  |
| 4 | 14 | *Baetis flavistriga* | 3.6 | 2.4 | 2.1 | 2.1 | 2.7 | 3 |  |
| 4 | 105 | *Baetis tricaudatus* | 3.7 | 3.6 | 3.3 | 3.9 | 3.6 | 4 |  |
| 5 | 15 | *Callibaetis* | 4.4 | 5.0 | 3.8 | 4.6 | 4.4 | 4 |  |
| 5 | 2 | *Camelobaetidius* | 4.8 | 3.6 | 4.6 |  | 4.3 |  | FS |
| 5 | 1 | *Camelobaetidius warreni* | 4.5 | 3.9 | 4.6 |  | 4.4 |  | FS |
| 3 | 51 | *Centroptilum* | 3.6 | 3.8 | 2.9 | 3.6 | 3.5 | 3 |  |
| 3 | 5 | *Cloeodes excogitatus* | 3.4 | 3.1 | 3.3 |  | 3.2 | 3 |  |
| 3 | 57 | *Diphetor hageni* | 2.6 | 3.1 | 2.3 | 3.1 | 2.9 | 3 |  |
| 5 | 30 | *Fallceon* | 4.8 | 4.9 | 5.0 | 4.8 | 4.6 | 5 |  |
| 5 | 23 | *Fallceon quilleri* | 4.8 | 4.9 | 5.0 | 4.8 | 4.6 | 5 |  |
| 4 | 1 | *Paracloeodes minutus* | 4.8 |  |  |  | 4.3 |  | FS |
| 3 | 2 | *Procloeon* | 2.0 | 3.5 | 2.5 | 2.8 | 2.7 | 3 |  |
| 4 | 2 | *Procloeon venosum* |  |  |  |  |  |  |  |
| 4 | 10 | *Caenis* | 3.1 | 4.3 | 3.6 | 3.4 | 3.5 | 4 |  |
| 4 | 13 | *Caenis bajaensis* | 2.4 | 4.3 | 2.8 | 2.8 | 3.0 | 3 |  |
| 4 | 10 | *Caenis latipennis* | 3.4 | 3.9 | 3.8 | 3.9 | 3.7 | 4 |  |
| 3 | 8 | *Attenella* | 2.8 | 2.1 | 4.1 | 3.3 | 3.1 | 3 |  |
| 3 | 5 | *Attenella delantala* | 2.6 | 2.1 | 4.2 | 3.4 | 3.1 | 3 |  |
| 3 | 2 | *Attenella margarita* |  |  |  |  |  |  |  |
| 3 | 2 | *Attenella soquele* | 2.5 | 2.1 | 4.1 | 2.3 | 2.8 | 3 |  |
| 2 | 15 | *Caudatella* | 2.3 | 2.1 | 3.8 | 2.1 | 2.5 | 2 |  |
| 2 | 1 | *Caudatella edmundsi* |  |  |  |  |  |  |  |
| 2 | 2 | *Caudatella heterocaudata* | 2.5 | 2.1 | 3.3 | 2.3 | 2.5 | 2 |  |
| 2 | 4 | *Caudatella hystrix* | 2.2 | 2.0 | 4.1 | 2.2 | 2.5 | 3 |  |
| 3 | 23 | *Drunella* | 2.4 | 2.4 | 2.6 | 2.2 | 2.5 | 2 |  |
| 3 | 19 | *Drunella coloradensis* | 2.7 | 2.5 | 2.3 | 3.8 | 2.9 | 3 |  |
| 2 | 34 | *Drunella doddsii* | 2.5 | 2.1 | 2.7 | 2.3 | 2.4 | 2 |  |
| 3 | 7 | *Drunella flavilinea* | 2.4 | 2.8 | 2.4 | 2.3 | 2.5 | 3 |  |
| 3 | 8 | *Drunella grandis* | 2.6 | 2.0 | 3.1 | 2.1 | 2.5 | 2 |  |
| 2 | 1 | *Drunella pelosa* |  |  |  |  |  |  |  |
| 2 | 8 | *Drunella spinifera* | 2.3 | 2.0 | 2.8 | 2.3 | 2.3 | 2 |  |
| 3 | 16 | *Ephemerella* | 2.7 | 4.1 | 2.3 | 3.6 | 3.0 | 3 |  |
| 3 | 2 | *Ephemerella aurivillii* | 3.4 |  | 2.4 | 2.9 | 2.9 |  | FS |
| 2 | 1 | *Ephemerella dorothea* |  |  |  |  |  |  |  |
| 2 | 1 | *Ephemerella dorothea\_excrucians* | |  |  |  |  |  |  |
| 2 | 1 | *Ephemerella excrucians* |  |  |  |  |  |  |  |
| 3 | 8 | *Ephemerella maculata* | 2.3 | 4.2 | 2.6 | 3.6 | 3.1 | 3 |  |
| 2 | 6 | *Ephemerella tibialis* | 2.1 |  |  |  | 2.0 |  | FS |
| 3 | 41 | *Ephemerellidae* | 2.7 | 2.8 | 3.1 | 2.3 | 2.8 | 3 |  |
| 3 | 7 | *Matriella teresa* | 2.1 |  |  |  | 2.0 |  | FS |
| 3 | 12 | *Serratella* | 2.6 | 3.6 | 2.9 | 2.4 | 2.8 | 3 |  |
| 2 | 1 | *Serratella levis* | 2.1 |  |  |  | 2.2 | 2 |  |
| 3 | 14 | *Serratella micheneri* | 2.6 | 4.0 | 3.1 | 2.8 | 3.1 | 3 |  |
| 3 | 5 | *Serratella teresa* | 2.3 | 3.4 | 2.6 | 2.3 | 2.7 | 3 |  |
| 3 | 2 | *Serratella tibialis* | 2.9 | 2.3 | 2.1 | 2.6 | 2.6 | 3 |  |
| 3 | 1 | *Timpanoga hecuba* | 2.4 | 2.5 | 3.6 | 2.3 | 2.8 | 3 |  |
| 2 | 14 | *Cinygma* | 2.1 | 2.1 | 2.1 | 2.8 | 2.3 | 2 |  |
| 3 | 37 | *Cinygmula* | 2.5 | 2.1 | 3.3 | 2.2 | 2.5 | 2 |  |
| 3 | 4 | *Ecdyonurus* | 2.4 | 2.6 |  | 3.5 | 2.8 | 3 |  |
| 3 | 12 | *Ecdyonurus criddlei* |  |  |  |  |  |  |  |
| 3 | 56 | *Epeorus* | 2.3 | 2.6 | 2.2 | 2.6 | 2.6 | 3 |  |
| 3 | 1 | *Epeorus albertae* |  |  |  |  |  |  |  |
| 3 | 1 | *Epeorus grandis* |  |  |  |  |  |  |  |
| 3 | 5 | *Epeorus longimanus* |  |  |  |  |  |  |  |
| 4 | 2 | *Heptagenia* |  |  |  |  |  |  |  |
| 3 | 65 | *Heptageniidae* | 2.6 | 2.8 | 3.2 | 2.8 | 2.9 | 3 |  |
| 2 | 39 | *Ironodes* | 2.4 | 2.4 | 2.1 | 2.3 | 2.4 | 2 |  |
| 3 | 1 | *Leucrocuta* | 2.9 |  |  |  | 2.6 |  | FS |
| 3 | 29 | *Rhithrogena* | 2.3 | 2.2 | 3.1 | 2.2 | 2.5 | 3 |  |
| 4 | 2 | *Isonychia velma* |  |  |  |  |  |  |  |
| 4 | 1 | *Asioplax* |  |  |  |  |  |  |  |
| 3 | 1 | *Homoleptohyphes dimorphus* | |  |  |  |  |  |  |
| 4 | 1 | *Leptohyphidae* | 4.3 | 4.5 | 5.0 | 4.8 | 4.5 | 4 |  |
| 4 | 66 | *Tricorythodes* |  |  |  |  |  |  |  |
| 4 | 4 | *Tricorythodes explicatus* |  |  |  |  |  |  |  |
| 3 | 5 | *Leptophlebiidae* | 2.3 | 3.2 | 3.2 | 3.2 | 3.0 | 3 |  |
| 4 | 83 | *Paraleptophlebia* |  |  |  |  |  |  |  |
| 4 | 1 | *Siphlonuridae* | 2.7 | 3.6 | 3.4 |  | 3.1 | 3 |  |
| 3 | 4 | *Siphlonurus* | 2.7 | 3.6 | 3.4 |  | 3.1 | 3 |  |
| x | 9 | *Plecoptera* |  |  |  |  |  |  |  |
| 3 | 13 | *Capniidae* | 2.3 | 2.3 | 3.5 | 2.5 | 2.7 | 3 |  |
| 3 | 1 | *Eucapnopsis brevicauda* |  |  |  |  |  |  |  |
| 3 | 34 | *Chloroperlidae* | 2.7 | 2.4 | 2.6 | 2.1 | 2.6 | 3 |  |
| 3 | 1 | *Haploperla* | 2.8 | 2.5 | 3.0 | 2.1 | 2.6 | 3 |  |
| 3 | 3 | *Haploperla chilnualna* |  |  |  |  |  |  |  |
| 2 | 2 | *Kathroperla* | 2.0 |  |  |  | 2.1 |  | FS |
| 2 | 2 | *Paraperla* | 2.1 |  |  |  | 2.3 |  | FS |
| 3 | 7 | *Suwallia* | 2.3 | 2.1 | 2.2 | 2.3 | 2.3 | 2 |  |
| 3 | 48 | *Sweltsa* | 2.6 | 2.1 | 2.8 | 2.3 | 2.6 | 3 |  |
| 3 | 1 | *Triznaka pintada* |  |  |  |  |  |  |  |
| 2 | 13 | *Despaxia augusta* | 2.2 | 2.8 | 2.1 | 2.9 | 2.5 | 2 |  |
| 2 | 4 | *Leuctridae* | 2.2 | 2.2 | 2.1 | 2.6 | 2.3 | 2 |  |
| 2 | 10 | *Moselia infuscata* |  |  |  |  |  |  |  |
| 3 | 44 | *Malenka* | 3.1 | 3.7 | 2.6 | 3.3 | 3.2 | 3 |  |
| 3 | 45 | *Nemouridae* | 2.9 | 3.3 | 2.8 | 3.0 | 3.1 | 3 |  |
| 2 | 1 | *Podmosta* |  |  |  |  |  |  |  |
| 2 | 7 | *Visoka cataractae* |  |  |  |  |  |  |  |
| 3 | 17 | *Zapada* | 2.9 | 2.3 | 2.1 | 2.5 | 2.5 | 2 |  |
| 3 | 16 | *Zapada cinctipes* | 3.0 | 2.3 | 2.4 | 2.6 | 2.6 | 3 |  |
| 2 | 4 | *Zapada columbiana* | 2.0 |  |  |  | 2.1 | 2 |  |
| 2 | 3 | *Zapada frigida* | 2.4 |  |  |  | 2.3 |  | FS |
| 3 | 5 | *Zapada oregonensis group* |  |  |  |  |  |  |  |
| 2 | 9 | *Glutops* | 2.2 | 2.1 | 2.1 | 2.5 | 2.2 | 2 |  |
| 1 | 4 | *Sierraperla cora* |  |  |  |  |  |  |  |
| 2 | 5 | *Soliperla* | 2.1 | 2.6 | 2.4 |  | 2.3 | 2 |  |
| 2 | 16 | *Yoraperla* | 2.5 | 2.1 | 2.8 | 2.3 | 2.6 | 3 |  |
| 2 | 12 | *Yoraperla nigrisoma* |  |  |  |  |  |  |  |
| 3 | 1 | *Calineuria* | 2.2 | 2.9 | 2.3 | 2.3 | 2.4 | 2 |  |
| 3 | 56 | *Calineuria californica* |  |  |  |  |  |  |  |
| 2 | 20 | *Doroneuria baumanni* | 2.5 | 2.0 | 2.2 | 2.3 | 2.4 | 2 |  |
| 3 | 8 | *Hesperoperla* | 2.3 | 2.9 | 2.3 | 3.0 | 2.7 | 3 |  |
| 2 | 2 | *Hesperoperla hoguei* | 2.4 |  |  |  | 2.3 | 2 |  |
| 3 | 11 | *Hesperoperla pacifica* | 2.3 | 2.9 | 2.3 | 3.0 | 2.7 | 3 |  |
| 3 | 22 | *Perlidae* | 2.3 | 2.8 | 2.3 | 2.2 | 2.5 | 3 |  |
| 3 | 4 | *Cultus* | 2.7 | 2.2 | 3.6 | 2.1 | 2.6 | 3 |  |
| 2 | 3 | *Frisonia picticeps* | 2.2 | 2.1 | 3.5 | 2.2 | 2.5 | 2 |  |
| 3 | 10 | *Isoperla* | 2.4 | 3.6 | 3.8 | 2.6 | 3.1 | 3 |  |
| 3 | 2 | *Isoperla denningi* |  |  |  |  |  |  |  |
| 3 | 3 | *Isoperla mormona* |  |  |  |  |  |  |  |
| 3 | 1 | *Isoperla sobria* |  |  |  |  |  |  |  |
| 2 | 4 | *Oroperla barbara* |  |  |  |  |  |  |  |
| 3 | 8 | *Perlinodes aurea* |  |  |  |  |  |  |  |
| 3 | 22 | *Perlodidae* | 2.8 | 2.8 | 3.1 | 2.4 | 2.9 | 3 |  |
| 2 | 5 | *Kogotus\_Rickera* |  |  |  |  |  |  |  |
| 2 | 1 | *Rickera sorpta* |  |  |  |  |  |  |  |
| 3 | 18 | *Skwala* | 2.9 | 2.4 | 3.7 | 2.6 | 3.0 | 3 |  |
| 3 | 2 | *Pteronarcella* | 3.1 | 2.6 | 3.7 | 3.1 | 3.0 | 3 |  |
| 3 | 10 | *Pteronarcys* | 2.3 | 2.5 | 3.8 | 2.6 | 2.8 | 3 |  |
| 2 | 2 | *Pteronarcys princeps* |  |  |  |  |  |  |  |
| 3 | 1 | *Taeniopterygidae* | 3.9 | 4.0 |  |  | 3.5 | 4 |  |
| x | 9 | *Trichoptera* |  |  |  |  |  |  |  |
| 2 | 20 | *Apatania* | 2.4 | 2.1 | 2.1 | 2.1 | 2.3 | 2 |  |
| 2 | 6 | *Pedomoecus sierra* |  |  |  |  |  |  |  |
| 3 | 16 | *Amiocentrus aspilus* |  |  |  |  |  |  |  |
| 3 | 4 | *Brachycentridae* | 3.3 | 3.6 | 3.5 | 3.4 | 3.5 | 3 |  |
| 3 | 1 | *Brachycentrus* | 2.9 | 2.4 | 4.9 | 3.5 | 3.4 | 3 |  |
| 3 | 6 | *Brachycentrus americanus* | 2.4 | 2.1 | 3.6 | 2.4 | 2.7 | 3 |  |
| 3 | 1 | *Brachycentrus echo* | 3.1 |  |  |  | 3.1 |  | FS |
| 3 | 2 | *Brachycentrus occidentalis* | 2.7 | 2.7 | 4.7 | 4.1 | 3.4 | 3 |  |
| 3 | 66 | *Micrasema* | 3.3 | 3.6 | 3.6 | 3.3 | 3.5 | 3 |  |
| 3 | 27 | *Heteroplectron californicum* | |  |  |  |  |  |  |
| 3 | 27 | *Agapetus* | 2.7 | 3.4 | 2.5 | 3.1 | 3.0 | 3 |  |
| 3 | 1 | *Agapetus taho* |  |  |  |  |  |  |  |
| 2 | 6 | *Anagapetus* | 2.2 | 2.3 | 2.4 | 2.8 | 2.4 | 2 |  |
| 3 | 40 | *Glossosoma* | 2.9 | 2.6 | 3.9 | 3.1 | 3.1 | 3 |  |
| x | 14 | *Glossosomatidae* | 3.1 | 3.0 | 3.6 | 3.2 | 3.2 | 3 |  |
| 4 | 9 | *Protoptila* | 3.7 | 3.0 | 4.9 | 4.1 | 3.9 | 4 |  |
| x | 1 | *Goera archaon* |  |  |  |  |  |  |  |
| 4 | 20 | *Helicopsyche* | 3.7 | 3.6 | 4.2 | 4.2 | 3.8 | 4 |  |
| 4 | 1 | *Helicopsyche borealis* |  |  |  |  |  |  |  |
| 3 | 19 | *Arctopsyche* | 2.2 | 2.1 | 3.4 | 2.1 | 2.5 | 3 |  |
| 3 | 1 | *Arctopsyche californica* |  |  |  |  |  |  |  |
| 3 | 4 | *Arctopsyche grandis* |  |  |  |  |  |  |  |
| 3 | 4 | *Ceratopsyche* | 2.7 | 2.1 | 4.3 | 2.6 | 2.9 | 3 |  |
| 4 | 19 | *Cheumatopsyche* | 3.8 | 4.5 | 4.0 | 2.9 | 3.8 | 4 |  |
| 4 | 97 | *Hydropsyche* | 3.9 | 3.9 | 3.9 | 4.3 | 4.0 | 4 |  |
| 4 | 1 | *Hydropsyche californica* |  |  |  |  |  |  |  |
| 4 | 1 | *Hydropsyche occidentalis* |  |  |  |  |  |  |  |
| 4 | 48 | *Hydropsychidae* | 3.7 | 3.8 | 3.9 | 4.1 | 3.9 | 4 |  |
| 2 | 16 | *Parapsyche* | 2.2 | 2.1 | 3.1 | 2.7 | 2.4 | 2 |  |
| 5 | 87 | *Hydroptila* | 4.8 | 4.9 | 5.0 | 4.9 | 4.7 | 5 |  |
| 5 | 1 | *Hydroptila arctia* |  |  |  |  |  |  |  |
| 5 | 33 | *Hydroptilidae* | 4.6 | 4.9 | 4.8 | 4.9 | 4.6 | 5 |  |
| 3 | 2 | *Leucotrichia* | 3.4 | 3.1 |  |  | 3.3 |  | FS |
| 3 | 2 | *Leucotrichia pictipes* |  |  |  |  |  |  |  |
| 3 | 10 | *Neotrichia* | 3.3 | 4.7 | 2.8 | 3.1 | 3.4 | 3 |  |
| 2 | 3 | *Nothotrichia shasta* | 2.0 |  |  |  | 2.0 |  | FS |
| 3 | 20 | *Ochrotrichia* | 3.1 | 4.4 | 3.7 | 2.7 | 3.4 | 3 |  |
| 4 | 21 | *Oxyethira* | 4.3 | 3.6 | 3.4 | 3.9 | 3.8 | 4 |  |
| 2 | 1 | *Palaeagapetus nearcticus* |  |  |  |  |  |  |  |
| 3 | 87 | *Lepidostoma* | 2.8 | 3.1 | 3.1 | 3.3 | 3.1 | 3 |  |
| 4 | 17 | *Leptoceridae* | 3.8 | 3.9 | 4.3 | 4.3 | 4.0 | 4 |  |
| 4 | 14 | *Mystacides* | 3.4 | 3.6 | 3.0 | 3.9 | 3.5 | 3 |  |
| 4 | 7 | *Mystacides alafimbriata* |  |  |  |  |  |  |  |
| 4 | 13 | *Nectopsyche* | 4.3 | 3.9 | 4.9 | 4.8 | 4.3 | 4 |  |
| 3 | 15 | *Oecetis* | 3.3 | 4.2 | 3.4 | 3.4 | 3.4 | 3 |  |
| 4 | 2 | *Oecetis disjuncta* |  |  |  |  |  |  |  |
| 2 | 1 | *Desmona* |  |  |  |  |  |  |  |
| 3 | 4 | *Dicosmoecus* | 3.1 | 2.6 | 3.5 | 2.7 | 3.0 | 3 |  |
| 3 | 1 | *Dicosmoecus gilvipes* |  |  |  |  |  |  |  |
| 2 | 2 | *Ecclisomyia* | 2.3 | 2.1 | 2.4 | 2.3 | 2.2 | 2 |  |
| 3 | 14 | *Limnephilidae* | 2.4 | 2.4 | 2.3 | 2.6 | 2.5 | 3 |  |
| 4 | 1 | *Limnephilus* |  |  |  |  |  |  |  |
| 3 | 1 | *Onocosmoecus* | 2.7 | 2.8 | 2.7 | 2.9 | 2.7 | 3 |  |
| 3 | 8 | *Psychoglypha* | 2.3 | 2.2 | 3.5 | 2.6 | 2.6 | 3 |  |
| 3 | 2 | *Marilia flexuosa* |  |  |  |  |  |  |  |
| 1 | 1 | *Nerophilus* |  |  |  |  |  |  |  |
| 1 | 2 | *Nerophilus californicus* |  |  |  |  |  |  |  |
| 3 | 5 | *Parthina* | 2.7 | 3.5 | 2.4 | 3.3 | 2.8 | 3 |  |
| 4 | 8 | *Chimarra* | 3.6 | 3.1 | 3.6 | 4.1 | 3.6 | 4 |  |
| 2 | 10 | *Dolophilodes* | 2.1 | 2.1 | 2.6 | 2.3 | 2.3 | 2 |  |
| 3 | 1 | *Dolophilodes\_Sisko* |  |  |  |  |  |  |  |
| 3 | 4 | *Philopotamidae* | 2.9 | 3.4 | 2.9 | 3.3 | 3.2 | 3 |  |
| 3 | 32 | *Wormaldia* | 2.8 | 4.0 | 2.6 | 3.3 | 3.2 | 3 |  |
| 2 | 4 | *Yphria californica* | 2.1 |  | 2.3 | 3.1 | 2.4 | 2 |  |
| 3 | 20 | *Polycentropus* | 2.1 | 3.6 | 2.1 | 2.3 | 2.6 | 3 |  |
| 4 | 21 | *Tinodes* | 3.6 | 4.7 | 3.8 | 3.3 | 3.7 | 4 |  |
| x | 1 | *Himalopsyche* |  |  |  |  |  |  |  |
| 3 | 48 | *Rhyacophila* | 2.3 | 2.6 | 2.5 | 2.6 | 2.7 | 3 |  |
| 2 | 1 | *Rhyacophila alberta group* |  |  |  |  |  |  |  |
| 2 | 1 | *Rhyacophila angelita* | 2.6 | 2.1 | 2.1 | 2.1 | 2.4 | 2 |  |
| 2 | 10 | *Rhyacophila angelita group* |  |  |  |  |  |  |  |
| 3 | 13 | *Rhyacophila arnaudi* | 2.6 | 2.1 | 4.3 | 2.8 | 3.1 | 3 |  |
| 3 | 2 | *Rhyacophila betteni* | 2.3 | 2.9 | 2.4 | 2.6 | 2.6 | 3 |  |
| 3 | 43 | *Rhyacophila betteni group* |  |  |  |  |  |  |  |
| 3 | 36 | *Rhyacophila brunnea group* |  |  |  |  |  |  |  |
| 3 | 2 | *Rhyacophila coloradensis group* | |  |  |  |  |  |  |
| 3 | 1 | *Rhyacophila grandis group* |  |  |  |  |  |  |  |
| 2 | 7 | *Rhyacophila hyalinata group* | |  |  |  |  |  |  |
| 2 | 1 | *Rhyacophila nevadensis group* | |  |  |  |  |  |  |
| 2 | 3 | *Rhyacophila rotunda group* |  |  |  |  |  |  |  |
| 2 | 10 | *Rhyacophila sibirica group* |  |  |  |  |  |  |  |
| 2 | 2 | *Rhyacophila vagrita group* |  |  |  |  |  |  |  |
| 2 | 2 | *Rhyacophila viquaea group* |  |  |  |  |  |  |  |
| x | 2 | *Rhyacophilidae* | 2.4 | 2.8 | 2.5 | 2.7 | 2.7 | 3 |  |
| 3 | 43 | *Gumaga* | 2.5 | 4.1 | 2.6 | 3.3 | 3.1 | 3 |  |
| 3 | 29 | *Neophylax* | 2.1 | 2.3 | 3.4 | 2.6 | 2.6 | 3 |  |
| 3 | 2 | *Neophylax rickeri* |  |  |  |  |  |  |  |
| 3 | 1 | *Neophylax splendens* |  |  |  |  |  |  |  |
| 2 | 1 | *Neothremma* | 2.3 | 2.4 | 2.7 |  | 2.4 | 2 |  |
| 2 | 1 | *Oligophlebodes* | 2.0 | 2.0 |  |  | 2.0 | 2 |  |
| 3 | 3 | *Helichus* | 3.5 | 4.5 | 3.6 | 4.0 | 3.7 | 4 |  |
| 3 | 1 | *Agabinus* | 2.1 |  |  |  | 2.1 |  | FS |
| 3 | 1 | *Agabinus glabrellus* |  |  |  |  |  |  |  |
| 4 | 10 | *Agabus* | 3.8 | 4.8 | 4.3 | 4.2 | 4.2 | 4 |  |
| 4 | 1 | *Agabus seriatus* |  |  |  |  |  |  |  |
| 4 | 17 | *Dytiscidae* | 3.8 | 4.9 | 3.8 | 3.8 | 4.0 | 4 |  |
| 4 | 1 | *Hygrotus* |  |  |  |  |  |  |  |
| 4 | 2 | *Liodessus obscurellus* |  |  |  |  |  |  |  |
| 4 | 1 | *Neoclypeodytes* | 2.9 |  |  |  | 2.8 |  | FS |
| 3 | 8 | *Oreodytes* | 2.4 | 3.2 | 2.6 | 2.3 | 2.7 | 3 |  |
| 3 | 2 | *Oreodytes abbreviatus* |  |  |  |  |  |  |  |
| 3 | 1 | *Oreodytes obesus* |  |  |  |  |  |  |  |
| 3 | 2 | *Oreodytes picturatus* |  |  |  |  |  |  |  |
| 4 | 10 | *Sanfilippodytes* | 3.9 | 4.6 | 3.4 | 4.4 | 3.9 | 4 |  |
| 4 | 6 | *Stictotarsus* | 3.3 | 5.0 | 3.8 | 3.9 | 3.8 | 4 |  |
| 4 | 1 | *Stictotarsus deceptus* |  |  |  |  |  |  |  |
| 4 | 3 | *Stictotarsus griseostriatus* |  |  |  |  |  |  |  |
| 4 | 3 | *Stictotarsus striatellus* |  |  |  |  |  |  |  |
| 3 | 2 | *Uvarus subtilis* | 3.4 |  |  |  | 3.3 |  | FS |
| x | 4 | *Microvelia* |  |  |  |  |  |  |  |
| x | 3 | *Rhagovelia* |  |  |  |  |  |  |  |
| x | 2 | *Veliidae* |  |  |  |  |  |  |  |
| 2 | 21 | *Ampumixis dispar* |  |  |  |  |  |  |  |
| 1 | 1 | *Atractelmis wawona* | 2.1 |  |  |  | 2.1 |  | FS |
| 3 | 14 | *Cleptelmis addenda* |  |  |  |  |  |  |  |
| 4 | 9 | *Dubiraphia* | 4.3 | 4.1 | 4.2 | 4.5 | 4.1 | 4 |  |
| 3 | 14 | *Elmidae* | 3.4 | 3.1 | 3.5 | 3.3 | 3.4 | 3 |  |
| 4 | 1 | *Heterelmis* | 4.3 |  |  |  | 3.8 |  | FS |
| 4 | 1 | *Heterelmis obesa* |  |  |  |  |  |  |  |
| 3 | 14 | *Heterlimnius* | 2.3 | 2.1 | 2.3 | 2.9 | 2.6 | 3 |  |
| 3 | 1 | *Heterlimnius corpulentus* |  |  |  |  |  |  |  |
| 3 | 1 | *Heterlimnius koebelei* |  |  |  |  |  |  |  |
| 3 | 13 | *Lara* | 2.5 | 2.5 | 2.4 | 2.6 | 2.7 | 3 |  |
| 3 | 1 | *Lara avara* |  |  |  |  |  |  |  |
| 3 | 12 | *Microcylloepus* | 3.4 | 4.3 | 3.1 | 2.9 | 3.5 | 3 |  |
| 3 | 2 | *Microcylloepus similis* |  |  |  |  |  |  |  |
| 3 | 13 | *Narpus* | 2.7 | 2.9 | 2.6 | 3.3 | 2.9 | 3 |  |
| 3 | 1 | *Narpus angustus* |  |  |  |  |  |  |  |
| 3 | 3 | *Narpus concolor* |  |  |  |  |  |  |  |
| 4 | 70 | *Optioservus* | 3.1 | 2.9 | 3.8 | 3.8 | 3.4 | 3 |  |
| 4 | 1 | *Optioservus divergens* |  |  |  |  |  |  |  |
| 4 | 6 | *Optioservus quadrimaculatus* | |  |  |  |  |  |  |
| 3 | 33 | *Ordobrevia nubifera* |  |  |  |  |  |  |  |
| 3 | 3 | *Rhizelmis nigra* |  |  |  |  |  |  |  |
| 3 | 48 | *Zaitzevia* | 3.3 | 3.2 | 2.9 | 2.7 | 3.1 | 3 |  |
| 3 | 15 | *Zaitzevia parvula* |  |  |  |  |  |  |  |
| 3 | 2 | *Stenocolus scutellaris* |  |  |  |  |  |  |  |
| 4 | 1 | *Gyrinidae* | 3.8 | 4.8 | 3.9 | 4.1 | 4.0 |  | FS |
| 3 | 2 | *Gyrinus* |  |  |  |  |  |  |  |
| 4 | 1 | *Brychius hornii* |  |  |  |  |  |  |  |
| 4 | 1 | *Haliplidae* | 3.5 | 4.8 | 4.1 | 3.8 | 4.0 | 4 |  |
| 4 | 1 | *Haliplus* |  |  |  |  |  |  |  |
| 4 | 9 | *Peltodytes* |  |  |  |  |  |  |  |
| 3 | 11 | *Hydraena* | 2.7 | 3.7 | 3.3 | 3.6 | 3.3 | 3 |  |
| 4 | 5 | *Ochthebius* | 4.3 | 4.9 | 4.6 | 4.2 | 4.3 | 4 |  |
| 4 | 1 | *Hydrochus* |  |  |  |  |  |  |  |
| 2 | 1 | *Ametor* | 2.6 | 2.2 | 2.4 |  | 2.3 | 2 |  |
| 4 | 1 | *Anacaena* | 4.3 |  |  |  | 4.1 |  | FS |
| 4 | 4 | *Berosus* | 2.9 | 5.0 | 3.9 | 3.1 | 3.5 | 4 |  |
| 4 | 2 | *Cymbiodyta* | 3.7 |  |  |  | 3.5 |  | FS |
| 4 | 1 | *Cymbiodyta punctatostriata* |  |  |  |  |  |  |  |
| 4 | 1 | *Enochrus* | 4.1 | 5.0 | 4.9 |  | 4.4 | 4 |  |
| 4 | 1 | *Helochares normatus* |  |  |  |  |  |  |  |
| 4 | 1 | *Hydrobius* | 4.7 |  |  |  | 3.7 |  | FS |
| 4 | 2 | *Hydrobius fuscipes* |  |  |  |  |  |  |  |
| 4 | 13 | *Hydrophilidae* | 3.7 | 4.8 | 4.5 | 4.3 | 4.3 | 4 |  |
| 4 | 3 | *Laccobius* | 3.4 | 4.8 | 4.6 | 3.9 | 4.0 | 4 |  |
| 4 | 1 | *Tropisternus* | 3.7 | 4.9 | 4.4 | 4.3 | 4.1 | 4 |  |
| 4 | 1 | *Tropisternus ellipticus* |  |  |  |  |  |  |  |
| 2 | 2 | *Acneus* | 2.2 | 3.1 | 2.1 | 2.1 | 2.3 | 2 |  |
| 3 | 40 | *Eubrianax edwardsii* |  |  |  |  |  |  |  |
| 3 | 2 | *Psephenus* | 2.9 | 4.1 | 2.4 | 2.3 | 2.9 | 3 |  |
| 3 | 6 | *Psephenus falli* |  |  |  |  |  |  |  |
| 2 | 1 | *Anchycteis velutina* |  |  |  |  |  |  |  |
| 4 | 1 | *Scirtidae* |  |  |  |  |  |  |  |
| 3 | 1 | *Staphylinidae* | 3.4 | 3.8 | 2.1 |  | 2.9 |  | FS |
| 4 | 1 | *Belostoma* |  |  |  |  |  |  |  |
| 4 | 2 | *Belostomatidae* | 3.3 | 4.9 | 3.7 | 4.7 | 4.0 | 4 |  |
| 4 | 1 | *Lethocerus* |  |  |  |  |  |  |  |
| 5 | 1 | *Callicorixa* |  |  |  |  |  |  |  |
| 5 | 1 | *Corisella* | 5.0 |  |  |  | 4.2 |  | FS |
| 5 | 4 | *Corisella decolor* |  |  |  |  |  |  |  |
| 5 | 47 | *Corixidae* | 4.7 | 4.6 | 4.6 | 4.8 | 4.6 | 5 |  |
| 4 | 2 | *Graptocorixa* | 2.7 |  |  |  | 2.8 |  | FS |
| 4 | 1 | *Hesperocorixa laevigata* |  |  |  |  |  |  |  |
| 4 | 15 | *Sigara* | 3.8 | 4.1 | 3.3 | 4.1 | 3.8 | 4 |  |
| 4 | 1 | *Sigara mckinstryi* |  |  |  |  |  |  |  |
| 4 | 2 | *Sigara washingtonensis* |  |  |  |  |  |  |  |
| 5 | 3 | *Trichocorixa* | 5.0 |  |  |  | 4.5 | 5 |  |
| 5 | 6 | *Trichocorixa calva* |  |  |  |  |  |  |  |
| x | 1 | *Gelastocoris oculatus* |  |  |  |  |  |  |  |
| x | 1 | *Aquarius* |  |  |  |  |  |  |  |
| x | 4 | *Gerridae* |  |  |  |  |  |  |  |
| x | 1 | *Gerris* |  |  |  |  |  |  |  |
| 4 | 11 | *Ambrysus* | 3.5 | 4.9 | 4.0 | 3.7 | 3.9 | 4 |  |
| 4 | 1 | *Ambrysus mormon* |  |  |  |  |  |  |  |
| 4 | 1 | *Naucoridae* | 3.5 | 4.9 | 4.0 | 3.7 | 3.9 | 4 |  |
| x | 1 | *Parapoynx* |  |  |  |  |  |  |  |
| 4 | 14 | *Petrophila* | 4.3 | 3.3 | 4.0 | 4.3 | 3.9 | 4 |  |
| 4 | 1 | *Pyralidae* | 4.3 | 3.3 | 4.0 | 4.3 | 3.9 | 4 |  |
| 3 | 9 | *Corydalidae* | 2.5 | 3.1 | 3.1 | 2.1 | 2.6 | 3 |  |
| 3 | 5 | *Neohermes* | 3.0 | 4.5 | 3.4 | 2.9 | 3.4 | 3 |  |
| 2 | 14 | *Orohermes crepusculus* |  |  |  |  |  |  |  |
| 4 | 28 | *Sialis* | 2.8 | 3.9 | 2.8 | 3.6 | 3.2 | 3 |  |
| 4 | 5 | *Aeshna* |  |  |  |  |  |  |  |
| 4 | 9 | *Aeshnidae* | 4.4 | 4.4 | 3.4 | 4.1 | 4.1 | 4 |  |
| 4 | 8 | *Hetaerina americana* |  |  |  |  |  |  |  |
| 4 | 48 | *Argia* | 4.4 | 4.9 | 4.6 | 5.0 | 4.6 | 5 |  |
| 4 | 1 | *Argia vivida* |  |  |  |  |  |  |  |
| 5 | 34 | *Coenagrionidae* | 4.4 | 4.9 | 4.4 | 4.9 | 4.6 | 5 |  |
| 4 | 4 | *Ischnura* | 4.6 |  |  |  | 4.4 |  | FS |
| 3 | 8 | *Cordulegaster dorsalis* |  |  |  |  |  |  |  |
| 5 | 1 | *Corduliidae* | 4.7 |  |  |  | 4.8 |  | FS |
| 4 | 2 | *Erpetogomphus* |  |  |  |  |  |  |  |
| 4 | 13 | *Gomphidae* | 3.8 | 3.6 | 3.6 | 3.8 | 3.7 | 4 |  |
| 3 | 1 | *Gomphus* |  |  |  |  |  |  |  |
| 3 | 20 | *Octogomphus specularis* |  |  |  |  |  |  |  |
| 4 | 5 | *Ophiogomphus* | 3.6 | 3.4 | 4.3 | 4.0 | 3.9 | 4 |  |
| 4 | 2 | *Progomphus* | 4.7 |  |  |  | 4.1 |  | FS |
| 4 | 5 | *Archilestes* |  |  |  |  |  |  |  |
| 3 | 1 | *Lestidae* | 3.6 | 4.8 | 3.3 | 2.9 | 3.4 | 3 |  |
| 4 | 4 | *Brechmorhoga mendax* |  |  |  |  |  |  |  |
| 4 | 1 | *Libellula* |  |  |  |  |  |  |  |
| 4 | 1 | *Libellula saturata* |  |  |  |  |  |  |  |
| 4 | 12 | *Libellulidae* | 4.5 | 4.9 | 4.3 | 4.6 | 4.3 | 4 |  |
| x | 1 | *Perithemis intensa* |  |  |  |  |  |  |  |
| 4 | 3 | *Sympetrum* |  |  |  |  |  |  |  |
| 4 | 46 | *Ablabesmyia* | 4.6 | 4.1 | 3.9 | 4.9 | 4.4 | 4 |  |
| 4 | 15 | *Alotanypus* | 4.5 | 5.0 | 3.9 | 4.3 | 4.1 | 4 |  |
| 5 | 55 | *Apedilum* | 4.5 | 5.0 | 4.5 | 4.4 | 4.4 | 4 |  |
| 3 | 2 | *Apsectrotanypus* | 3.1 |  | 2.7 | 3.3 | 2.8 | 3 |  |
| 3 | 2 | *Boreoheptagyia* | 2.4 |  |  |  | 2.5 |  | FS |
| 4 | 74 | *Brillia* | 3.7 | 3.6 | 3.2 | 3.6 | 3.5 | 4 |  |
| 4 | 4 | *Brundiniella* | 3.7 | 3.8 | 3.0 | 3.8 | 3.6 | 4 |  |
| 3 | 7 | *Cardiocladius* | 2.3 | 3.3 | 3.8 | 2.8 | 3.0 | 3 |  |
| 4 | 8 | *Chironomidae* | 4.4 | 4.5 | 4.7 | 4.6 | 4.4 | 4 |  |
| 4 | 16 | *Chironominae* | 3.6 | 5.0 | 4.3 | 4.8 | 4.2 | 4 |  |
| 5 | 74 | *Chironomini* | 4.4 | 4.8 | 4.5 | 4.9 | 4.6 | 5 |  |
| 5 | 55 | *Chironomus* | 4.9 | 4.8 | 5.0 | 4.9 | 4.7 | 5 |  |
| 4 | 2 | *Cladopelma* |  |  |  |  |  |  |  |
| 4 | 33 | *Cladotanytarsus* | 4.3 | 3.4 | 4.8 | 4.6 | 4.2 | 4 |  |
| x | 2 | *Clinotanypus* |  |  |  |  |  |  |  |
| 4 | 6 | *Conchapelopia* |  |  |  |  |  |  |  |
| 4 | 1 | *Constempellina* | 4.3 |  |  |  | 3.9 |  | FS |
| 4 | 64 | *Corynoneura* | 3.7 | 4.0 | 4.1 | 4.2 | 4.0 | 4 |  |
| 4 | 118 | *Cricotopus* | 4.5 | 4.1 | 4.6 | 4.7 | 4.4 | 4 |  |
| 4 | 1 | *Cricotopus bicinctus* | 4.8 | 4.8 | 4.9 | 4.8 | 4.7 | 5 |  |
| 4 | 27 | *Cricotopus bicinctus group* |  |  |  |  |  |  |  |
| 3 | 32 | *Cricotopus nostocicola* | 2.4 | 2.8 | 2.9 | 2.7 | 2.7 | 3 |  |
| 4 | 1 | *Cricotopus trifascia* | 4.1 | 4.4 | 4.6 | 4.8 | 4.3 | 4 |  |
| 4 | 16 | *Cricotopus trifascia group* |  |  |  |  |  |  |  |
| 5 | 37 | *Cryptochironomus* | 4.9 | 4.7 | 4.8 | 5.0 | 4.7 | 5 |  |
| 4 | 12 | *Cryptotendipes* | 4.6 | 4.2 | 4.0 | 4.9 | 4.4 | 4 |  |
| 4 | 3 | *Demicryptochironomus* | 3.5 | 4.1 | 3.6 | 4.3 | 3.8 | 4 |  |
| 3 | 8 | *Diamesa* | 2.6 | 2.0 | 2.1 | 2.9 | 2.4 | 2 |  |
| x | 1 | *Diamesinae* | 3.3 |  |  |  | 3.1 |  | FS |
| 5 | 86 | *Dicrotendipes* | 5.0 | 4.8 | 4.9 | 4.8 | 4.7 | 5 |  |
| 4 | 3 | *Endochironomus* |  |  |  |  |  |  |  |
| 4 | 103 | *Eukiefferiella* | 3.9 | 3.8 | 4.3 | 3.9 | 4.0 | 4 |  |
| 4 | 4 | *Eukiefferiella brehmi group* |  |  |  |  |  |  |  |
| 4 | 2 | *Eukiefferiella brevicalcar group* | |  |  |  |  |  |  |
| 5 | 3 | *Eukiefferiella claripennis* |  |  |  |  |  |  |  |
| 5 | 1 | *Eukiefferiella claripennis group* | |  |  |  |  |  |  |
| 3 | 4 | *Eukiefferiella devonica* |  |  |  |  |  |  |  |
| 3 | 4 | *Eukiefferiella gracei group* |  |  |  |  |  |  |  |
| 4 | 1 | *Euryhapsis* | 3.0 | 2.0 |  |  | 2.7 | 3 |  |
| 4 | 2 | *Glyptotendipes* |  |  |  |  |  |  |  |
| x | 1 | *Gymnometriocnemus* |  |  |  |  |  |  |  |
| x | 1 | *Harnischia* |  |  |  |  |  |  |  |
| 3 | 7 | *Heleniella* | 2.0 | 3.4 | 2.7 | 2.6 | 2.6 | 3 |  |
| 5 | 1 | *Heterotanytarsus* |  |  |  |  |  |  |  |
| 3 | 16 | *Heterotrissocladius* | 2.7 | 2.8 | 2.7 | 3.9 | 2.9 | 3 |  |
| 3 | 3 | *Heterotrissocladius marcidus group* | |  |  |  |  |  |  |
| 3 | 2 | *Hydrobaenus* | 4.0 | 2.6 | 3.3 | 2.6 | 2.9 | 3 |  |
| 4 | 5 | *Krenosmittia* | 3.0 | 2.2 | 2.1 | 2.9 | 2.7 | 3 |  |
| 4 | 19 | *Labrundinia* |  |  |  |  |  |  |  |
| 4 | 2 | *Labrundinia\_Nilotanypus* |  |  |  |  |  |  |  |
| 4 | 7 | *Larsia* | 3.3 | 4.0 | 3.1 | 3.3 | 3.4 | 3 |  |
| 3 | 9 | *Lauterborniella* | 2.3 | 4.3 | 2.5 | 3.0 | 2.9 | 3 |  |
| 5 | 24 | *Limnophyes* | 4.9 | 4.9 | 4.9 | 4.9 | 4.8 | 5 |  |
| 4 | 5 | *Lopescladius* | 2.7 | 2.8 | 4.6 | 2.1 | 3.0 | 3 |  |
| 3 | 7 | *Macropelopia* | 3.4 | 3.7 | 2.8 | 3.4 | 3.4 | 3 |  |
| 4 | 10 | *Macropelopiini* | 3.6 |  |  |  | 3.5 | 4 |  |
| x | 1 | *Microchironomus* |  |  |  |  |  |  |  |
| 4 | 114 | *Micropsectra* | 4.1 | 4.0 | 4.5 | 4.0 | 4.1 | 4 |  |
| x | 50 | *Micropsectra\_Tanytarsus* |  |  |  |  |  |  |  |
| 4 | 4 | *Microtendipes* | 3.2 | 4.0 | 3.2 | 3.5 | 3.5 | 3 |  |
| 4 | 43 | *Microtendipes pedellus group* | |  |  |  |  |  |  |
| 4 | 43 | *Microtendipes rydalensis group* | |  |  |  |  |  |  |
| 4 | 2 | *Monodiamesa* | 2.8 | 2.4 | 2.3 | 3.9 | 2.9 | 3 |  |
| 4 | 28 | *Nanocladius* | 4.1 | 3.5 | 4.3 | 4.3 | 3.9 | 4 |  |
| 4 | 7 | *Nilotanypus* |  |  |  |  |  |  |  |
| 4 | 4 | *Nilothauma* | 4.3 | 3.9 | 3.8 | 3.3 | 3.7 | 4 |  |
| 4 | 3 | *Odontomesa* | 2.9 | 2.3 | 2.1 | 3.3 | 2.9 | 3 |  |
| 4 | 86 | *Orthocladiinae* | 3.9 | 4.4 | 4.0 | 4.9 | 4.3 | 4 |  |
| 4 | 3 | *Orthocladius* | 4.0 | 3.9 | 4.5 | 4.3 | 4.1 | 4 |  |
| 4 | 1 | *Orthocladius (Euorthocladius)* | |  |  |  |  |  |  |
| 2 | 1 | *Orthocladius (Symposiocladius)* | |  |  |  |  |  |  |
| 4 | 111 | *Orthocladius complex* |  |  |  |  |  |  |  |
| 2 | 10 | *Orthocladius lignicola* |  |  |  |  |  |  |  |
| 3 | 32 | *Pagastia* | 2.9 | 2.4 | 3.0 | 2.8 | 2.9 | 3 |  |
| 3 | 4 | *Parachaetocladius* | 2.6 | 3.5 | 2.1 | 2.9 | 2.8 | 3 |  |
| 4 | 26 | *Paracladopelma* | 4.3 | 4.4 | 4.3 | 4.2 | 4.4 | 4 |  |
| x | 1 | *Paracricotopus* |  |  |  |  |  |  |  |
| 4 | 23 | *Parakiefferiella* | 3.7 | 2.9 | 3.5 | 3.9 | 3.5 | 3 |  |
| 4 | 98 | *Parametriocnemus* | 3.6 | 4.4 | 4.3 | 4.3 | 4.0 | 4 |  |
| 4 | 9 | *Paraphaenocladius* | 4.3 | 3.9 | 4.7 | 4.1 | 4.2 | 4 |  |
| 4 | 38 | *Paratanytarsus* | 4.5 | 3.9 | 4.4 | 4.6 | 4.3 | 4 |  |
| 4 | 24 | *Paratendipes* | 4.2 | 4.6 | 3.6 | 4.8 | 4.2 | 4 |  |
| 5 | 86 | *Pentaneura* | 4.6 | 5.0 | 5.0 | 4.9 | 4.7 | 5 |  |
| 4 | 70 | *Phaenopsectra* | 3.8 | 4.1 | 3.6 | 4.7 | 4.0 | 4 |  |
| 4 | 119 | *Polypedilum* | 4.3 | 4.3 | 4.4 | 4.4 | 4.3 | 4 |  |
| 3 | 2 | *Polypedilum aviceps* |  |  |  |  |  |  |  |
| 4 | 2 | *Polypedilum scalaenum* |  |  |  |  |  |  |  |
| 3 | 1 | *Potthastia* | 2.8 | 2.4 | 3.5 | 2.6 | 2.8 | 3 |  |
| 3 | 13 | *Potthastia gaedii group* |  |  |  |  |  |  |  |
| 3 | 2 | *Potthastia longimana group* |  |  |  |  |  |  |  |
| 5 | 34 | *Procladius* | 4.8 | 4.8 | 4.8 | 4.8 | 4.7 | 5 |  |
| 3 | 26 | *Psectrocladius* | 2.8 | 3.3 | 2.9 | 2.8 | 3.0 | 3 |  |
| x | 2 | *Psectrotanypus* |  |  |  |  |  |  |  |
| 4 | 43 | *Pseudochironomus* | 4.6 | 4.9 | 4.3 | 3.9 | 4.1 | 4 |  |
| 2 | 4 | *Pseudodiamesa* | 2.5 | 2.9 | 2.2 |  | 2.5 | 2 |  |
| 4 | 5 | *Pseudosmittia* | 4.8 | 4.7 | 4.7 | 4.0 | 4.5 | 5 |  |
| 4 | 1 | *Psilometriocnemus* |  |  |  |  |  |  |  |
| 4 | 4 | *Radotanypus* | 4.3 | 4.9 | 3.8 |  | 4.1 |  | FS |
| 4 | 6 | *Reomyia* | 2.0 |  |  |  | 2.2 | 2 |  |
| 4 | 66 | *Rheocricotopus* | 4.6 | 4.6 | 4.8 | 4.8 | 4.5 | 4 |  |
| 4 | 121 | *Rheotanytarsus* | 3.6 | 4.4 | 4.2 | 4.1 | 4.0 | 4 |  |
| 4 | 1 | *Robackia* | 4.6 | 2.4 |  | 3.5 | 3.7 | 4 |  |
| 4 | 3 | *Robackia demeijerei* |  |  |  |  |  |  |  |
| 3 | 19 | *Stempellina* | 3.4 | 2.6 | 2.5 | 3.0 | 2.9 | 3 |  |
| 3 | 64 | *Stempellinella* | 2.7 | 2.9 | 2.7 | 3.1 | 2.9 | 3 |  |
| 4 | 9 | *Stenochironomus* | 3.9 | 3.9 | 3.4 | 3.4 | 3.7 | 4 |  |
| 4 | 3 | *Stictochironomus* |  |  |  |  |  |  |  |
| 4 | 1 | *Sublettea* | 3.7 | 2.1 | 2.2 | 3.5 | 2.9 | 3 |  |
| 3 | 33 | *Synorthocladius* | 3.3 | 2.7 | 3.4 | 3.0 | 3.2 | 3 |  |
| 4 | 76 | *Tanypodinae* | 3.8 | 4.9 | 4.0 | 5.0 | 4.4 | 4 |  |
| 5 | 10 | *Tanypus* |  |  |  |  |  |  |  |
| 4 | 75 | *Tanytarsini* | 4.1 | 4.4 | 4.2 | 4.8 | 4.3 | 4 |  |
| 4 | 123 | *Tanytarsus* | 4.6 | 4.5 | 3.9 | 4.1 | 4.2 | 4 |  |
| 4 | 67 | *Thienemanniella* | 3.7 | 3.9 | 3.8 | 4.0 | 3.9 | 4 |  |
| 4 | 6 | *Thienemannimyia* | 3.8 | 4.1 | 3.7 | 3.9 | 3.8 | 4 |  |
| 4 | 91 | *Thienemannimyia group* |  |  |  |  |  |  |  |
| 4 | 3 | *Tribelos* | 4.5 |  |  |  | 4.4 |  | FS |
| 3 | 25 | *Tvetenia* | 3.2 | 2.8 | 3.1 | 2.8 | 3.1 | 3 |  |
| 3 | 51 | *Tvetenia bavarica group* |  |  |  |  |  |  |  |
| 3 | 3 | *Tvetenia discoloripes group* |  |  |  |  |  |  |  |
| 4 | 5 | *Zavrelimyia* |  |  |  |  |  |  |  |
| 4 | 53 | *Zavrelimyia\_Paramerina* |  |  |  |  |  |  |  |
| 5 | 1 | *Zoniagrion exclamationis* |  |  |  |  |  |  |  |
| x | 1 | *Brachycera* |  |  |  |  |  |  |  |
| 3 | 6 | *Atherix pachypus* |  |  |  |  |  |  |  |
| 3 | 4 | *Blepharicera* |  |  |  |  |  |  |  |
| 3 | 2 | *Blephariceridae* | 3.3 | 3.1 | 3.2 | 3.3 | 3.2 | 3 |  |
| 4 | 8 | *Atrichopogon* | 3.7 | 3.9 | 3.1 | 3.9 | 3.6 | 4 |  |
| 4 | 101 | *Bezzia\_Palpomyia* |  |  |  |  |  |  |  |
| 4 | 3 | *Ceratopogon* | 4.1 | 3.9 | 4.3 |  | 4.1 |  | FS |
| 4 | 28 | *Ceratopogonidae* | 4.3 | 4.6 | 4.4 | 3.8 | 4.2 | 4 |  |
| 4 | 14 | *Culicoides* | 4.3 | 4.8 | 4.8 | 4.6 | 4.5 | 4 |  |
| 5 | 36 | *Dasyhelea* | 4.3 | 5.0 | 4.9 | 4.4 | 4.6 | 5 |  |
| 3 | 1 | *Forcipomyia* | 3.4 |  |  |  | 3.2 | 3 |  |
| 4 | 28 | *Probezzia* | 3.9 | 4.1 | 3.8 | 4.8 | 4.0 | 4 |  |
| 4 | 1 | *Sphaeromias* | 3.9 | 2.8 | 3.9 |  | 3.6 | 4 |  |
| 3 | 7 | *Stilobezzia* | 3.0 | 4.1 | 2.4 | 2.9 | 3.1 | 3 |  |
| 5 | 1 | *Eucorethra underwoodi* |  |  |  |  |  |  |  |
| 4 | 1 | *Anopheles* |  |  |  |  |  |  |  |
| 2 | 2 | *Deuterophlebia* | 2.1 | 2.1 | 2.3 | 2.4 | 2.2 |  | FS |
| 3 | 17 | *Dixa* | 3.6 | 3.8 | 3.1 | 2.8 | 3.4 | 3 |  |
| 4 | 5 | *Dixella* | 2.8 | 4.9 | 4.8 | 4.5 | 3.9 | 4 |  |
| 4 | 3 | *Dixidae* | 3.7 | 4.1 | 3.2 | 3.1 | 3.6 | 4 |  |
| 3 | 11 | *Meringodixa chalonensis* |  |  |  |  |  |  |  |
| 5 | 10 | *Dolichopodidae* | 4.9 | 5.0 | 4.9 | 4.6 | 4.6 | 5 |  |
| 4 | 1 | *Chelifera* |  |  |  |  |  |  |  |
| 4 | 12 | *Chelifera\_Metachela* |  |  |  |  |  |  |  |
| 3 | 17 | *Clinocera* | 3.0 | 2.8 | 3.1 | 3.8 | 3.2 | 3 |  |
| 4 | 18 | *Empididae* | 3.6 | 3.8 | 3.9 | 4.3 | 3.9 | 4 |  |
| 4 | 25 | *Hemerodromia* | 4.2 | 4.6 | 4.8 | 4.7 | 4.4 | 4 |  |
| 4 | 35 | *Neoplasta* | 3.5 | 3.9 | 2.8 | 4.3 | 3.7 | 4 |  |
| 2 | 4 | *Oreogeton* | 2.3 | 2.1 | 2.1 | 2.1 | 2.2 | 2 |  |
| 4 | 3 | *Trichoclinocera* | 3.8 |  |  |  | 3.6 | 4 |  |
| 3 | 4 | *Wiedemannia* | 3.7 | 2.3 | 2.1 | 2.1 | 2.7 | 3 |  |
| 5 | 2 | *Ephydra* |  |  |  |  |  |  |  |
| 5 | 15 | *Ephydridae* | 4.6 | 4.9 | 4.9 | 4.9 | 4.6 | 5 |  |
| 4 | 2 | *Hydrellia* |  |  |  |  |  |  |  |
| 4 | 1 | *Scatella* |  |  |  |  |  |  |  |
| 5 | 14 | *Muscidae* | 4.5 | 4.8 | 4.8 | 4.8 | 4.5 | 5 |  |
| 3 | 9 | *Maruina lanceolata* |  |  |  |  |  |  |  |
| 3 | 3 | *Pericoma* |  |  |  |  |  |  |  |
| 4 | 28 | *Pericoma\_Telmatoscopus* |  |  |  |  |  |  |  |
| 4 | 3 | *Psychoda* | 4.4 | 4.8 | 4.9 | 4.6 | 4.4 | 4 |  |
| 4 | 5 | *Psychodidae* | 4.1 | 3.9 | 4.5 | 3.7 | 4.0 | 4 |  |
| 4 | 2 | *Ptychoptera* | 3.1 | 2.6 | 2.2 | 4.1 | 2.9 | 3 |  |
| x | 2 | *Scathophagidae* |  |  |  |  |  |  |  |
| 4 | 2 | *Sciomyzidae* |  |  |  |  |  |  |  |
| 4 | 2 | *Helodon* |  |  |  |  |  |  |  |
| 3 | 5 | *Prosimulium* | 2.4 | 2.3 | 2.8 | 2.6 | 2.6 | 3 |  |
| 4 | 5 | *Simuliidae* | 4.3 | 4.4 | 4.6 | 4.3 | 4.3 | 4 |  |
| 4 | 124 | *Simulium* | 4.3 | 4.5 | 4.8 | 4.4 | 4.4 | 4 |  |
| 4 | 1 | *Simulium argus* |  |  |  |  |  |  |  |
| 4 | 6 | *Simulium canadense* |  |  |  |  |  |  |  |
| 4 | 1 | *Simulium donovani* |  |  |  |  |  |  |  |
| 4 | 2 | *Simulium hippovorum* |  |  |  |  |  |  |  |
| 4 | 2 | *Simulium piperi* |  |  |  |  |  |  |  |
| 4 | 3 | *Simulium vittatum* |  |  |  |  |  |  |  |
| 4 | 1 | *Caloparyphus* |  |  |  |  |  |  |  |
| 5 | 40 | *Caloparyphus\_Euparyphus* |  |  |  |  |  |  |  |
| 4 | 17 | *Euparyphus* | 4.5 | 4.6 | 4.8 | 4.9 | 4.4 | 4 |  |
| 4 | 4 | *Nemotelus* | 4.7 |  |  |  | 4.5 |  | FS |
| 4 | 2 | *Odontomyia* |  |  |  |  |  |  |  |
| 4 | 13 | *Odontomyia\_Hedriodiscus* |  |  |  |  |  |  |  |
| 4 | 5 | *Stratiomyidae* | 4.6 | 4.8 | 4.8 | 4.5 | 4.4 | 4 |  |
| 5 | 1 | *Syrphidae* |  |  |  |  |  |  |  |
| 4 | 2 | *Chrysops* |  |  |  |  |  |  |  |
| 3 | 3 | *Tabanidae* | 3.2 | 3.8 | 3.8 | 2.6 | 3.4 | 3 |  |
| 4 | 2 | *Tabanus\_Atylotus* |  |  |  |  |  |  |  |
| 3 | 1 | *Thaumalea* |  |  |  |  |  |  |  |
| 3 | 12 | *Antocha* | 2.8 | 2.9 | 2.9 | 2.6 | 2.8 | 3 |  |
| 3 | 26 | *Antocha monticola* |  |  |  |  |  |  |  |
| 3 | 5 | *Cryptolabis* | 2.1 | 2.5 | 2.9 |  | 2.4 | 2 |  |
| 3 | 37 | *Dicranota* | 2.9 | 2.9 | 3.1 | 3.4 | 3.0 | 3 |  |
| 4 | 3 | *Erioptera* | 4.7 |  |  |  | 4.0 |  | FS |
| 2 | 3 | *Hesperoconopa* | 2.4 | 2.1 | 2.9 | 2.6 | 2.5 | 2 |  |
| 3 | 37 | *Hexatoma* | 2.9 | 3.3 | 3.1 | 2.5 | 3.0 | 3 |  |
| 3 | 11 | *Limnophila* | 2.6 | 3.9 | 2.1 | 2.5 | 2.8 | 3 |  |
| 4 | 5 | *Limonia* | 4.1 | 4.8 | 4.3 | 4.6 | 4.4 | 4 |  |
| 4 | 1 | *Molophilus* |  |  |  |  |  |  |  |
| 4 | 2 | *Ormosia* | 4.6 |  |  |  | 4.4 | 4 |  |
| 3 | 1 | *Pedicia* |  |  |  |  |  |  |  |
| x | 1 | *Pseudolimnophila* |  |  |  |  |  |  |  |
| 4 | 18 | *Tipula* | 4.5 | 4.9 | 4.8 | 4.6 | 4.7 | 5 |  |
| 4 | 19 | *Tipulidae* | 3.7 | 3.4 | 3.9 | 3.4 | 3.6 | 4 |  |