ECOLOGICAL CONDITION OF WATERSHEDS IN COASTAL SOUTHERN CALIFORNIA: SUMMARY OF THE STORMWATER MONITORING COALITION'S STREAM MONITORING PROGRAM FIRST YEAR (2009)

Prepared for the Stormwater Monitoring Coalition
Bioassessment Workgroup

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Southern California Coastal Water Research Project
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Cover photo: View of the upper portions of the Los Angeles River watershed, with the snowy peaks of the San Gabriel Mountains visible in the background.

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Executive Summary

In 2009, the Stormwater Monitoring Coalition initiated a program to assess the condition of streams in southern California watersheds by sampling water chemistry, toxicity, physical habitat, and benthic macroinvertebrates. This program was designed to address three primary questions over a 5-year sampling cycle:

1. What is the condition of streams in southern California (across the region and in agricultural, open, or urban land use classes)?
2. What are the stressors that affect stream condition?
3. Are stream conditions getting better or worse over time?

In the first year of the program, a total of 134 sites were sampled in 15 watersheds in the coastal southern California region. This report summarizes the results of this sampling and represents the first time that the first two questions have been answered in a scientifically robust way for the entire region. The third question is based on temporal trends and requires multiple years of data before it can be fully addressed.

The sampling survey was designed to assess the condition of perennial, wadeable streams that are second-order or higher. First order streams and nonperennial streams were excluded to improve sampling success and because bioassessment tools have not yet been validated in nonperennial streams. Of more than 7,000 stream-km in the region, about 2,000 km were perennial, wadeable streams. Nonperennial streams were unevenly distributed among land-use classes, with perennial streams being more common in urban than in agricultural or undeveloped (open) streams.

Question 1: What is the condition of streams in Southern California?

Different indicators provided different insights into the health of streams in Southern California, but several indicators showed large differences in condition among the three land use classes (**Figure E1**). Biological indicators, which integrate other indicators of ecological health over time, showed that the majority of streams in the region had non-reference biological condition. The median Index of Biotic Integrity (IBI) score was 33 out of 100 maximum and 53% of stream-miles region-wide had scores ≤39, indicating widespread non-reference condition. In undeveloped watersheds, 90% of stream-miles were in reference condition. In contrast, only 35% of agricultural stream-miles were in reference condition. Urban streams were almost exclusively (98%) in non-reference condition (**Figures E1, E2**).

Water chemistry was evaluated by comparing chemical concentrations to numeric thresholds using numbers reported in scientific literature or in regulations. Many pollutants typically associated with stormwater (e.g., metals, pesticides) were rarely above thresholds. For example, copper was below threshold in 96% of stream-miles, and several metals (e.g., zinc) never exceeded thresholds. Pyrethroid pesticides were detected in 28% of stream-miles regionally, and these detections were more frequent in agricultural and urban streams (39% and 38%, respectively) than undeveloped streams (16%). In contrast, nutrients were widespread; more than two-thirds of stream-miles had concentrations of nitrogen over 1 mg/L, and 42% had concentrations of phosphorus over 0.1 mg/L.

Furthermore, concentrations of nitrogen greater than 1.0 mg/L were observed in a large extent (i.e., 37%) of undeveloped stream-miles. Future reports will investigate the relationship between nutrient concentrations and biological impacts using algae indicators (**Figure E1**).

Toxicity to *Ceriodaphnia dubia* reproduction was observed in 47% of stream-miles in the region, although the distribution of sites with toxicity did not correspond with patterns observed for water chemistry or biological indicators. Undeveloped streams showed more pervasive toxicity (i.e., 63%) than agricultural (37%) or urban streams (32%). Toxicity to survival was observed in only 2% of stream-miles across the region, but was also more common in undeveloped streams than agricultural or urban streams (**Figure E1**).

Question 2: What are the stressors affecting stream condition?

Stressors related to biological condition were evaluated using two different analyses; relative risk and correlation. Although neither analysis proves causality, both identified a similar suite of water chemistry and physical habitat stressors associated with non-reference IBI scores. Three of the four highest risk stressors were related to physical habitat. For example, sandy substrate, low habitat complexity, and high human disturbance near the stream banks more than tripled the risk of observing non-reference biology, and low levels of riparian vegetation doubled the risk. Physical habitat assessments revealed that stressors were typically greater in urban and agricultural streams than those in open space. For example, metrics related to substrate size, riparian vegetation, primary productivity, habitat availability, and human disturbance all showed that stressors were higher in urban streams than open streams, and that agricultural streams were intermediate between the other two land-use classes. However, thresholds for physical habitat impairment have not been established, and the extent of streams with high quality habitat was not assessed. Among water chemistry constituents, nutrient concentrations (particularly total phosphorus) and major ions (e.g., chloride and sulfate) had relative risks ranging from 2 to 4. In contrast, metals and pyrethroids typically showed no or small increased risks.

Correlation analysis showed that several physical habitat and water chemistry stressors had wedge- or step-shaped relationships with IBI scores, suggesting that multiple stressors interact to limit biological condition. Many toxic pollutants (e.g., metals) showed weak associations with biological integrity, and sites that were toxic to *Ceriodaphnia* were no less likely to have reference biology than non-toxic sites.

Key Findings and Recommendations

- The first year of the SMC program was an effective collaboration that has begun to provide answers to two of three management questions.

  Recommendation: Continue the program to answer key questions, and modifying the design to improve statistical power.

- More than half of the streams in southern California are nonperennial, and therefore excluded from standard bioassessment protocols.

  Recommendation: Develop assessment tools (e.g., IBIs, maps) to include nonperennial streams in future surveys.

- Each indicator showed a different extent of streams in reference condition, but most showed that reference conditions were most widespread in undeveloped watersheds.

  Recommendation: Develop a framework for interpreting multiple indicators.

  - For biological indicators, reference conditions were rare (35%) in agricultural streams, and nearly absent (2%) from urban streams. High nutrient concentrations were widespread in urban (N: 83%; P: 82%) and agricultural streams (N: 78%, P: 54%) compared to open streams (N: 37%; P: 7%).

    Recommendation: Help the State Water Resources Control Board identify appropriate management goals for non-reference streams.

- Physical habitat, nutrient concentrations, and major ions appeared to be important stressors for biological condition, but cause-and-effect relationships were not examined. Major stressors for toxicity were not as clear, and need further investigation.

  Recommendation: Conduct site-specific stressor analyses at sites of interest.

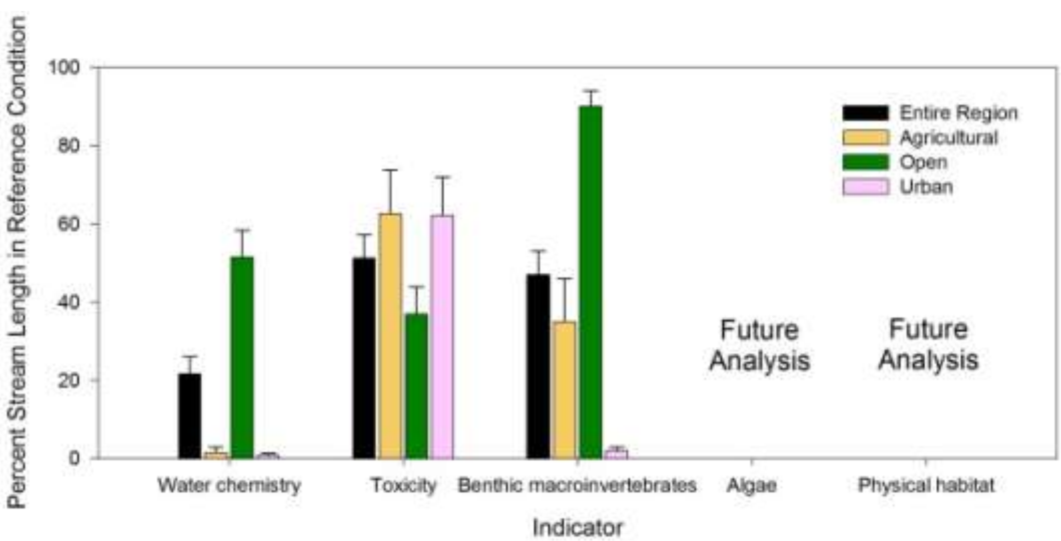

Figure E1. Percent of stream-length in reference condition by land use class and indicator. Reference was defined for each indicator as follows: No water chemistry analyte exceeding threshold; no evidence of toxicity to reproductive or survival endpoints; and index of biotic integrity scores over 39. Algae and physical habitat indicators were not assessed in this report.

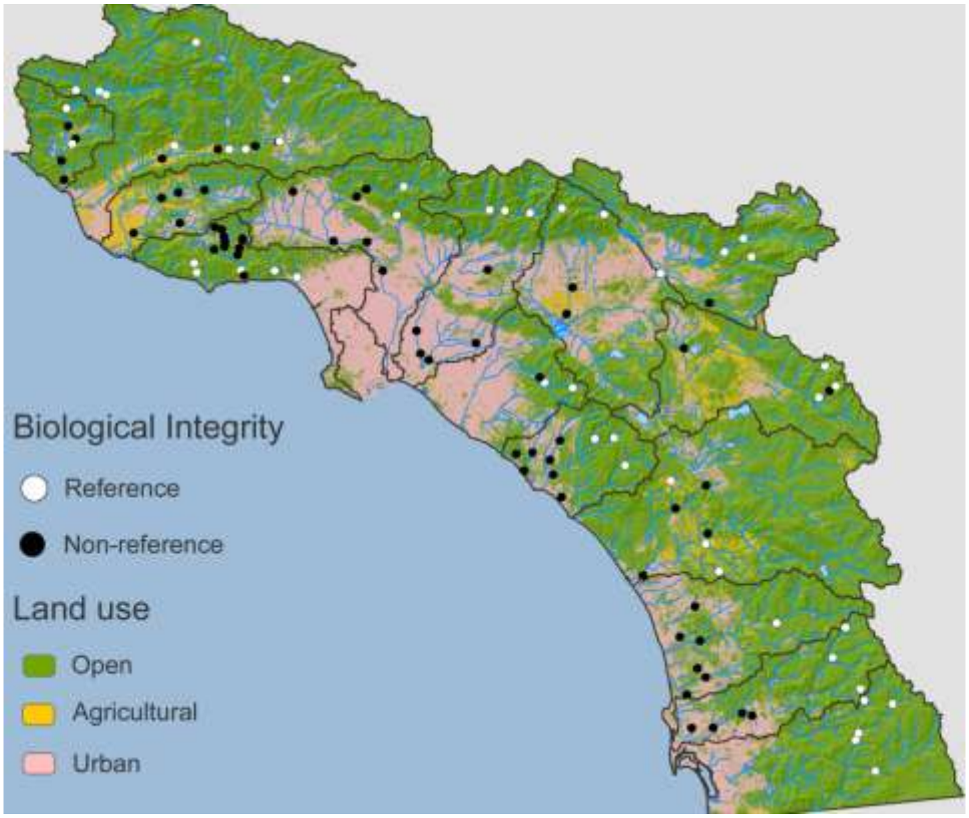

Figure E2. Biological integrity at sampled sites across the region. Sites in reference condition had Index of Biotic Integrity (IBI) scores ≥ 39.

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Introduction

Southern California's coastal watersheds contain important aquatic resources that support a variety of ecological functions and environmental values. However, the ecological health of streams in these watersheds has never been assessed in a comprehensive and statistically unbiased manner. Comprising over 7,000 stream-kilometers, both humans and wildlife depend on these watersheds for habitat, drinking water, agriculture, and industrial uses. In order to assess the health of streams in these watersheds, the Stormwater Monitoring Coalition (SMC), a coalition of multiple state, federal, and local agencies, initiated a regional monitoring program in 2009. Using multiple indicators of ecological health, including benthic macroinvertebrates, benthic algae, riparian wetland condition, water chemistry, water column toxicity, and physical habitat, the SMC is conducting the first comprehensive assessment Southern California's watersheds based on a probabilistic survey design. Through the re-allocation of permit-required monitoring efforts, the SMC has developed a cooperative sampling program that is efficient and cost-effective for participants.

The SMC monitoring program was designed to address three main questions: 1) What is the condition of streams in southern California? 2) What are the stressors that affect stream condition? and 3) Are conditions getting better or worse over time? The first question is addressed through an analysis of the magnitude and extent of stream length in non-reference condition. The second question is addressed through correlation analyses, as well as relative risk calculations (Van Sickle et al. 2006). The third question is addressed through temporal trends analyses. The first two questions are addressed in this report, and the third will be addressed after additional years of data have been collected. (SMC 2007)

Regional assessments provide critical information to complement site-specific monitoring at sites of interest. Regional surveys that use a probabilistic design provide statistically valid and unbiased assessments of large geographic areas (Gibson et al. 1996). Crucially, regional assessments provide context to site-specific problems and allow sites to be prioritized for protection or restoration (Barbour et al. 1996). Furthermore, regional assessments provide a comprehensive perspective on reference conditions (Reynoldson et al. 1997). Although regional programs do not replace the need for monitoring at sites of interest (such as below discharges or within sensitive wildlife areas), the context provided by a regional assessment is essential for effective watershed management (Barbour et al. 1996, Gibson et al. 1996).

Methods

Study Area

Coastal Southern California is a semi-arid region with a Mediterranean climate. Lower elevations are characterized by chaparral, oak woodlands, and sage scrub. The region is bordered by the Transverse Ranges to the North, and the Peninsular Ranges to the East, and continues to the Mexican border to the South. Both Transverse and Peninsular ranges contain peaks that exceed 10,000 feet, and are characterized by pine forests. The mountains receive a large portion of their precipitation as snow, which typically contributes water to streams until mid- to late-summer. Much of the higher elevations are undeveloped and remain protected in national forests and a network of national, state, and county parks. The lower elevations have been pervasively altered by urbanization or conversion to agriculture. Wildfires and drought are frequent in the region, with extensive fires occurring in 2007 throughout much of the area. By area, the overall region is 59% undeveloped open space, 28% urban, and 13% agricultural (National Oceanic and Atmospheric Administration, NOAA 2001). **Figure 1** shows the distribution of land uses in the region.

Description of Survey Design

Sample Frame

The study area was divided into fifteen management units (hereafter referred to as watersheds) based on a combination of hydrologic and political boundaries (**Table 1**; **Figure 2**). The National Hydrography Dataset Plus stream network (NHD Plus, US Geological Survey and US Environmental Protection Agency 2005) was used as the sample frame. In order to assign land use to each segment of the NHD Plus frame, a 500-m buffer was drawn around each stream segment and overlain in a GIS onto a landcover layer (NOAA 2001). If the buffer was more than 75% natural or open land, the segment was considered open space; if not, it was considered urban or agricultural, depending on which land use was relatively more dominant. Very short segments were occasionally hand corrected if the buffers were too small to adequately capture the adjacent land use; these corrections were most typically used for segments representing individual channels in complex braided systems, such as the mainstem of the Santa Clara River.

Determination of Sampling Locations

The study employed the “master list” approach to integrate sampling efforts by multiple agencies and to facilitate collaboration with other monitoring programs (Larsen et al. 2008). A master list was generated, containing over 50,000 sites randomly distributed across the entire stream network using a spatially balanced generalized random-tessellation design (Stevens and Olsen, 2004). Sites were then assigned to a watershed using a geographic information system. Sites were attributed with Strahler stream order from the NHD Plus dataset, and with land use based on the designation of the stream segment, as described above. First order streams were excluded from the survey, because these sites typically have a higher rejection rate based on nonperenniality or inaccessibility in mountainous regions.

Strata were identified based on watershed, stream order, and land use. The design of the program was to collect data in each watershed at 30 sites (450 total) with 6 sites sampled in each watershed in the first year. The number of sites per watershed was chosen in order to estimate the extent of non-reference condition within the desired precision of 20% based on preliminary investigations (data not shown). The resulting sample was designed to reflect the regional representation of stream order and land use, as opposed to reflecting each watershed. Furthermore, uncommon strata (e.g., agricultural land, or high-order streams) were deliberately over-represented in the sample design. Sites were then selected from the “master” list of 50,000 sites, with an oversample ranging from 500% to 2000% for each watershed. Sampling effort was distributed over five years to integrate temporal fluctuations in condition; to maintain consistent budgets for sampling agencies; to uphold technical capacity among analytical labs; and to coincide with stormwater permit renewal cycles.

Site Evaluation and Reconnaissance

Sites were evaluated for sampling using both a desktop and field phase. Sites were evaluated for suitability for sampling, such as perenniality (defined as flow that persists through the water-year, which ends September 30) and accessibility (defined as sites that can be safely reached and sampled within one day).

Sampling

Sampling occurred in a single event between May 15 and July 15, more than 4 weeks after the previous major rainfall. This snapshot approach allows evaluation of baseline conditions at each site, but does not detect storm-related impacts to water chemistry or toxicity, and does not allow assessment of nutrient impacts from peak growth of algae communities, which typically occur in late summer or fall.

Landscape Variables

Using a geographic information system (GIS), watersheds were delineated for each site from 30-m digital elevation models (USGS 1999), and visually corrected to reflect local conditions. For sites draining ambiguous watersheds with minimal topography, delineations were modified using CALWATER boundaries (California Department of Forestry and Fire Protection 2004) or by consulting local experts. Watersheds were clipped at 5 km and 1 km to evaluate local conditions, creating a total of three scales (abbreviated as WS, 5k, and 1k). A fourth scale (i.e., point), based only on the site location, was used to calculate distance-based metrics. These delineations were then used to calculate metrics from source layers relating to landcover (NOAA 2001), human population (US Census 2000), transportation (CDFG custom roads layer, P. Ode, unpublished data), grazing (federal grazing allotments, USDA 2008), geology (J. Olson and C. Hawkins, unpublished data), hydrology (National Inventory of Dams and NHD Plus), and mining (Mineral Resource Data System, USGS 2005). The full suite of landscape metrics is summarized in **Table 2**.

Water Chemistry

Field crews measured pH, specific conductance, dissolved oxygen, salinity, and alkalinity at each site visit using digital field sensors (or by collecting samples for lab analyses, where appropriate). In addition, samples of stream water were collected for measurements of 36 different analytes, including: total suspended solids, total hardness (as $CaCO_3$), silica, major ions, nutrients, dissolved and total metals, and pyrethroid pesticides. A full list of analytes is provided in **Table 3**. Analytical methods and quality assurance protocols are described in SWAMP QAT 2008 and the SMC Workplan (SMC 2007).

Toxicity

At each site, ~4 L of water were collected for toxicity assays, primarily using the daphnia species *Ceriodaphnia dubia*. Seven or eight day exposures to undiluted field-collected stream water were conducted, and both survival (acute toxicity as percent mortality) and reproduction (chronic toxicity as young per female) endpoints were recorded. In samples with specific conductivity ≥2500 uS/cm, a 10-day survival assay using the amphipod *Hyalella azteca* was used instead, with no reproductive endpoint (USEPA 2002, SWAMP QAT 2008).

Physical Habitat

At each site, physical habitat was assessed as specified in Ode (2007) and Fetscher et al. (2009), which were modified from the USEPA's Environmental Monitoring and Assessment Program (EMAP, Peck et al. 2006). Briefly, a 150-m reach (250-m for streams over 10 m wide) was divided into 11 equidistant transects, with 10 inter-transects located halfway between them. At each transect, the following parameters were measured: bank dimensions, wetted width, water depth in 5 locations, substrate size, cobble embeddedness, bank stability, microalgae thickness, presence of coarse particular organic matter, presence of attached or unattached macroalgae, presence of macrophytes, riparian vegetation, instream habitat complexity, canopy cover using a densiometer, human influence, and flow habitats. A subset of variables were measured at each inter-transect as well. The slope of the water surface was measured across the entire reach at each site.

Benthic Macroinvertebrates

Benthic macroinvertebrates were collected using protocols described by Ode (2007). At each transect established for physical habitat sampling, a sample was collected using a D-frame kicknet at 25, 50, or 75% of the stream width. A total of 11 ft^2 of streambed was sampled. This method was identical to the Reach-Wide Benthos method used by EMAP (Peck et al. 2006). However, in low-gradient streams (i.e., gradient <1%), sampling locations were adjusted to 0, 50, and 100% of the stream width, because traditional sampling methods fail to capture sufficient organisms for bioassessment indices in these types of streams (Mazor et al. 2010). Benthic macroinvertebrates were collected and preserved in 70% ethanol, and sent to one of five labs for identification. At all labs, a target number of at least 600 organisms were removed from each sample and identified to the highest taxonomic resolution that can be consistently achieved (i.e., SAFIT Level 2 in Richards and Rogers 2006); in general, most taxa were identified to species and chironomids were identified to genus.

Other Indicators

Algae biomass and community composition was assessed using the methods of Fetscher et al. (2009), and riparian wetland condition were assessed using the California Rapid Assessment Method, Collins et al. 2008). However, these data have not yet been fully analyzed. They will be included in future SMC data reports.

Quality Assurance

Water Chemistry

Water chemistry data quality was assessed using the SWAMP Quality Assurance Program Plan (QAPrP; SWAMP QAT 2008). Accuracy was assessed by examining matrix spike recovery (not available for pyrethroids). Precision was assessed by examining relative percent differences of lab duplicates and matrix spike duplicates. Sensitivity was assessed by evaluating lab blanks. Batches that failed to meet measurement quality objectives specified in the QAPrP were rejected from analysis. Overall, 0.3% of records were excluded due to QA failures, though most of these were limited to analyses of total phosphorus, chloride, or sulfate. These rejections resulted from failures to meet accuracy objectives; in contrast, sensitivity and precision objectives were almost always met.

Assessment of water chemistry data quality was constrained because of incomplete QA data submission from all participating laboratories. Partial or complete evaluations were possible for 88% of the water chemistry data; incomplete QA data prevented full evaluation of 33% of submitted data. Batches with incomplete QA were retained in the analysis.

Toxicity

Data quality of toxicity assays was tested by evaluating test acceptability criteria specified in by SWAMP (SWAMP QAT 2008). Nine toxicity batches (containing samples from 12 sites) had specific conductivity ≥ 2500 us/cm, and *Hyalella azteca* was substituted for *Ceriodaphnia dubia* as a test organism for all but one; however, in the one high-conductivity assay where *C. dubia* was used, no toxicity was observed. Results from all assays were used in analyses.

Assessment of toxicity data quality was constrained because of incomplete QA data submission from all participating laboratories. Complete reference toxicant data was submitted for 28 of 89 batches, and none showed indications of increased tolerance of lab broods. Batches with incomplete QA were retained in the analysis.

Physical Habitat and Field Sampling

Because physical habitat assessments do not currently have measurement quality objectives, data quality was assessed by auditing field crews during sampling. Every field crew was audited at a single site, and auditors provided oral feedback to crews on site as well as a written report. All deviations were corrected on site, and sites were resampled, if necessary.

Biology

Sorting and identification of benthic macroinvertebrates were assessed as described in the SMC Quality Assurance Project Plan (2009). A subset of samples (10%) was sent to a reference lab for verification of identifications. For each re-identification, error rates were calculated. Labs that failed to meet measurement quality objectives were required to correct identifications, and submit a second subset of 10% of samples for another round of quality assurance. Because all errors could be corrected, only the error rates from the final round of re-identification were used in analysis.

A total of five labs submitted samples for re-identification, and two were required to submit a second batch. In general, the Taxa ID Error Rate was higher than the other error rates. This metric is particularly sensitive to misidentifications in samples with few taxa, although it was below the objective (i.e., 10%) for all samples ultimately submitted for re-identification. The results of the final round of QA are presented in **Table 4**.

Data Analysis

Area Weights

Because the survey used an unequal-probability sampling design, weights for each site had to be calculated based on reconnaissance information and *a priori* estimates of stream lengths from the NHD Plus stream network. For sites where flow status (i.e., perennial vs. nonperennial) could not be determined (e.g., because of physical inaccessibility or land owner denial), flow status from NHD Plus attribute data was used instead. Adjusted weights were calculated for each watershed-stream order-land use class combination by dividing the total *a priori* stream length by the number of sites evaluated during reconnaissance. Estimates of stream condition (e.g., the percent of stream miles below a threshold) were calculated using the Horvitz-Thompson estimator (1952), which is a weighted average of sample values where weights are adjusted according to design implementation. Confidence intervals were based on local neighborhood variance estimators (Stevens and Olsen 2003), which assumes that samples located close together tend to be more alike than samples that are far apart. All weight calculations were conducted using the *spsurvey* package in R version 2.11.1 (Kincaid and Olsen 2009, The R Foundation for Statistical Computing 2010).

Extent and Magnitude Estimates

To determine the health of streams in the study area, weighted medians were calculated for each indicator, as well as the proportion of stream length exceeding numeric thresholds. Where possible, thresholds were determined using numbers from established regulatory standards. However, many indicators lack such thresholds; instead thresholds derived from published studies, previous surveys, or best professional judgment were applied, as described below. Although these thresholds were applied to all sites within the region, exceedance of a threshold may not necessarily signify impairment at a specific site.

Where possible, thresholds were determined using numbers from established regulatory standards. Although these thresholds were applied to all sites within the region, exceedance of a threshold may not necessarily signify impairment at a specific site.

Landscape Variables

Weighted statistical distributions for all GIS metrics were calculated using adjusted weights, as described above. No thresholds were used for comparison of landscape variables.

Water Chemistry

Weighted statistical distributions for each water chemistry analyte were calculated using adjusted weights, as described above. Published thresholds based on observed biological responses were used to assess the potential impacts of the different constituents on the aquatic life of Southern California's streams (**Table 5**). Although thresholds for some analytes (e.g., total nitrogen) were developed for specific streams, the numbers in this report were applied across the region to provide consistency in assessments.

With the exception of pyrethroids, data reported as "not detected" were given a value equal to one-half of the method detection limit for that compound and analytical batch, whereas data reported as "detected-not quantified" were given a value equal to one-half of the reporting limit for that compound and analytical batch. A different approach was used for pyrethroids, because numeric thresholds were in some cases lower than the method detection limits. Pyrethroids reported as ND were given a value of 0 and values reported as DNQ were given a value equal to one-half of the reporting limit.

Toxicity

Extent and magnitude of survival and reproductive responses were evaluated using control-normalized endpoints by expressing the endpoint as percent of control (**Table 5**). Identification of toxicity for survival endpoints were compared to control treatments using traditional t-tests (USEPA 2002). For reproductive endpoints the US Environmental Protection Agency Test of Significant Toxicity (TST) method (USEPA 2010a) was used to compare samples with controls. The TST method represents a recent modification in the way continuous toxicity data (e.g., # young per female) are evaluated, adjusting the statistical test to better account for variability in control treatments. However, because this approach is relatively new, traditional t-tests were also used to evaluate reproductive endpoints, and the results were compared using the Mantel-Haenszel chi-square analysis of toxicity using SAS v9.2 (Stokes et al. 2000).

Benthic Macroinvertebrates

Benthic macroinvertebrate data was analyzed by calculating the multimetric Southern California Index of Biotic Integrity (IBI, Ode et al. 2005). In order to calculate the IBI, samples were converted to SAFIT Level 1 standard taxonomic effort (i.e., most taxa to genus, with chironomids left at family, Richards and Rogers 2006). For samples with more than 500 individuals, a Monte Carlo simulation was used to reduce the samples to 500 organisms. Seven samples with fewer than 450 individuals were excluded from analysis. The constituent metrics of the IBI were then calculated (see **Table 6**), scored, summed, and rescaled to 100 points. Because reach-wide multi-habitat sampling was used, 7.8 points were added to each score to remove the bias introduced by this sampling method (Rehn et al. 2007). Samples with IBI scores ≤ 39 were considered non-reference. Samples with scores > 40 were considered to be in or near reference condition, as these sites had IBI scores within two standard deviations of the mean of reference sites (Ode et al. 2005).

Weighted statistical distributions for the IBI and its component metrics were calculated using adjusted weights, as described above. IBI scores were compared to the threshold for reference condition reported in Ode et al. (2005), which is two standard deviations below the mean of reference sites (i.e., ≤ 39, **Table 5**).

Stressor Relationships

For both benthic macroinvertebrate community structure and for toxicity endpoints, relative risks were calculated (Van Sickle et al. 2006). This approach allows quantification of risks in a meaningful way and can rank stressors in terms of their relative importance. However, relative risk analysis requires thresholds for both stressors and indicators, and is insensitive to the continuous nature of stressor data. Furthermore, if data do not meet distribution requirements (described below), relative risk calculations may be invalid or impossible. Therefore, multiple regression (for toxicity) and correlation analyses (for benthic macroinvertebrate community structure) were also used to analyze stressor relationships. In addition, stressor relationships were examined graphically by creating bivariate scatterplots of stressors and select stressors.

Relative risk analysis (Van Sickle et al. 2006) calculates the risk for each stressor by dividing the likelihood of observing an impact when a stressor is present by the likelihood of observing it when the stressor is absent. To determine if risks were significantly greater than 1 (i.e., equal risk of impact regardless of whether a stressor is present), and to compare stressors with each other, the upper and lower 95% confidence interval was calculated for each relative risk. Because relative risk analysis requires classification of continuous stressor and indicator variables into condition classes (e.g., reference or non-reference), thresholds for classification were based on numbers reported in regulations or scientific literature for water chemistry and toxicity (**Table 5**). Thresholds for IBI scores were based on the reference distribution as reported in Ode et al. (2005). Because no thresholds are available for physical habitat or GIS data, survey medians and best professional judgment were applied instead.

Data must meet distributional requirements in order for relative risk calculations to be valid (Van Sickle et al. 2006). Calculations are based on a two-by-two table expressing the total stream-length in each category: stressed and non-reference condition, unstressed and non-reference condition, stressed and reference condition, and unstressed and reference condition. Results were flagged if a cell in the table was based on a small number of samples (i.e., <6). Because the category of "unstressed and non-reference condition" appears in the formula denominator, relative risks may be implausibly high when this number is low, and these values were also flagged. This situation arose most often for the most widespread stressors, where unstressed samples were rare. Stressors that were always below threshold were only analyzed using regression or correlation analysis.

The relationship between toxicity and chemical stressors was further assessed using a series of logistic (toxic versus non-toxic) and continuous (% survival and young per female) regressions that were constructed between toxicity measures and measured chemical constituents in SAS v 9.2 (Stokes et al. 2000). The best fitting regression models were evaluated using Akaike's Information Criteria corrected (AICc; Burnham and Aderson 2002).

The relationships between stressors and benthic macroinvertebrate community structure were further examined by calculating Spearman rank correlations between IBI scores and potential water chemistry and physical habitat stressors. Relationships with landscape variables were also calculated. Because the large number of relationships evaluated may lead to spurious results, formal statistical tests were not conducted. Instead, important stressors were identified by overall strength (e.g., relative risks ≥ 2, or rank correlation $Rho^2 \geq 0.15$). Confidence intervals and p-values are included in tables as supplementary information.

Results

Sampling Effort and Reconnaissance

Survey design planned for 90 sites to be sampled in 2009 (SMC 2007); however, 134 sites were sampled due to collaborations with other monitoring programs (such as the San Gabriel River Regional Monitoring Program, and the Santa Ana River monitoring program) and intensifications by individual member agencies of the SMC. At least 6 sites were sampled in each watershed, with the exception of the Lower Santa Ana watershed, where only 3 sites were sampled. To obtain this sample size, 550 sites were evaluated for sampling. At 21%, the sampling success rate was low overall, but ranged from a high of 82% in the Los Angeles watershed to a low of 5% in the San Jacinto watershed. By a wide margin, the most frequent cause of site rejection was nonperenniality (78%), followed by physical inaccessibility (10%), and frame errors in the NHD Plus (9%). Frame errors were often the result of recent impoundments, culverting, or redirecting of streams caused by urbanization. Other causes of failure (e.g., landowner denial, or non-wadeability) were rare (≤3%).

Based on this reconnaissance, 43.7% (±2.5 standard error) of the 7,268 stream-km in the region were determined to be part of the target population of perennial, wadeable streams. Rejection of nontarget sites altered the distribution of land uses of the study area, because target streams were disproportionately more urban than nontarget streams (**Table 7**; **Figure 3**). Similarly, rejection of nontarget streams disproportionately affected 2nd order streams relative to higher order streams.

Landscape Variables

Extent and Magnitude Estimates

Undeveloped watersheds were smaller, colder, wetter, and at higher elevations urban and agricultural watersheds. These watersheds also had the lowest % sedimentary, % Cenozoic, % nitrogenous, and % Sulfur-bearing geologies. These patterns are consistent with the mountainous terrain where most open streams are located, in contrast to the marine sediments that underlie the agricultural and urban portions of the region.

Unsurprisingly, metrics related to urban and agricultural landcover were higher in their respective land use classes than in open sites, and these trends were consistent across all of the spatial scales analyzed. For example, streams in the urban class had the highest % urban metric, and streams in the agricultural class had the highest % agricultural metric. This result confirms the usefulness of using a 500-m buffer to designate stream segments during the sample draw process. Imperviousness was much higher in urban watersheds, although agricultural watersheds were slightly more impervious than open watersheds. Code 21, a land use classification that corresponds to areas with extensive vegetation management (such as low-density residential, highway medians, parks, and golf courses, NOAA 2001) was highest in the urban watersheds. Transportation metrics, such as road density and road crossing density, were also highest in urban watersheds and lowest in open watersheds.

Water Chemistry

Extent and Magnitude Estimates

Most conventional analytes, nutrients, and metals were detected at concentrations above reporting limits in nearly every sample (**Table 3**). However, concentrations of toxic pollutants were generally low across the region, with concentrations above thresholds being observed in a small percentage of streams. Conversely, elevated concentrations of several nutrients (i.e., total nitrogen and total phosphorus, but not ammonia) were more broadly distributed (**Table 3**). Nearly all constituents had a similar distribution among the different land uses across the region: the lowest median concentrations were typically found in streams from open watersheds, while the greater concentrations were typically observed in the urban and agricultural streams (**Figure 4**). In general, median concentrations of nutrients and metals were greatest in urban streams, although selenium was higher in agricultural streams. For example, the median concentration of dissolved copper was 0.7 µg/L in open streams, 1.7 µg/L in agricultural streams, and 2.6 µg/L in urban streams (**Table 3**; **Figure 3**). Pyrethroid pesticides were rarely detected. Bifenthrin, the most widespread pyrethroid, was detected in 15% (±6 standard error) of streams in the region. One pyrethroid (i.e., deltamethrin) was never detected in any sample. Most pyrethroid detections occurred in agricultural or urban streams.

Field water quality measurements also indicated large differences among the three land use classes. For example, turbidity was elevated in agricultural streams (median 3.6 NTUs), and even more so urban streams (10.3), relative to open streams (0.8; **Table 3**). Specific conductivity was similarly high in both agricultural (median 1220 uS/cm) and urban (1382) relative to open streams (435). In contrast, pH, dissolved oxygen, and alkalinity were similar among the three land uses.

At least one constituent exceeded thresholds in 83% (± 4 standard error) of streams across the region, and nearly 100% of streams from agricultural (± 1) and urban (± 0) watersheds had at least one constituent above threshold (**Figures 5, 6**). Furthermore, urban and agricultural streams typically exceeded multiple thresholds. For example, 88% (± 5) of agricultural had 3 or more exceedances and 22% (± 10) of urban streams had 6 or more exceedances, compared to open watershed streams, which typically only exceeded 1 or 2 thresholds (**Figures 5, 6**).

Nutrient concentrations commonly exceeded thresholds throughout the region. Total nitrogen exceeded 1 mg/L in 63% (±6 standard error) of all streams, and exceedances were observed in all land use classes (agricultural: 78% ± 9, open: 37% ± 8, and urban: 83% ± 6). Similarly, total P was observed above the threshold of 0.1 mg/L in most developed streams (agricultural: 54% ± 12, urban: 82% ± 6). But unlike total N, total P was below the threshold in almost all (93% ± 3) undeveloped streams (**Table 8**).

Other analytes (e.g., metals, pyrethroids, major ions, and conventional analytes) displayed similar patterns observed in the nutrients: agricultural and urban streams had the largest percentage of stream length in exceedance of thresholds compared to those from open watersheds, though the majority of constituents were below their threshold value. Selenium (13% ± 3) and copper (4% ± 2%) were the most common metals in exceedance of their threshold, while bifenthrin (15% ± 6%), cyfluthrin

(4% ± 2%) and cyhalothrin-lambda (2% ± 1%) were the pyrethroids most frequently observed in exceedance of threshold values. Sulfate (41% ± 6%) and Chloride (26% ± 5%) were the most common ions in exceedance of threshold values (**Table 8**). Typically, multiple exceedances of nutrients or major ions were observed together, whereas only a single metal or pyrethroid typically exceeded a threshold at one site. Across the region, very few streams (1.2% ± 0.3) were observed to exceed multiple thresholds for metals (**Figures 5, 6**).

Water Toxicity

Extent and Magnitude Estimates

Toxic responses were larger and more widespread among undeveloped streams than among urban or agricultural streams. For example, both median survival and reproduction were lower in open streams than in the other land-use classes (**Figure 7**). Across all of streams of Southern California, 51% (± 6 standard error) had evidence of toxicity to reproduction, and 2% (±1) had evidence of toxicity to survival (**Table 9**). Streams from open watersheds had the greatest incidence of toxicity (reproduction: 63% ± 7; survival: 2% ±1), followed by agricultural (reproduction: 37% ± 11; survival: 9% ± 7) and urban streams (reproduction: 41% ± 11; survival: 2% ± 1; **Figure 8**). However, differences among the land uses were not significant at the 95% confidence level. The spatial distribution of toxicity revealed unusual patterns. Many of the sites in lower portions of the watersheds showed no evidence of toxicity, whereas toxic sites were observed in many high-elevation undeveloped regions (**Figure 9**).

The two toxicity testing methods (TST and traditional t-tests) resulted in identical findings of toxicity at 88 sites and disagreed at 12. This difference was not significant across the region, or within each of the three land-use classes ($p < 0.05$). All disagreements were identified as toxic by the TST test and non-toxic by the traditional t-test.

Stressor Relationships

Relative Risk Analysis - Relative risks to reproductive and survival endpoints were calculated for chloride, sulfate, selenium, phosphate, and total nitrogen, as well as copper (reproductive only), because these were the only stressors that met the data distribution requirements for analysis. Apart from selenium, no chemical constituent posed a risk greater than 1 to reproduction. Conversely, total nitrogen, selenium, and sulfate all showed a potential relationship with survival, with total nitrogen having the greatest risk (3.5) of creating a toxic response (**Table 10**; **Figure 10**).

Regression Analysis - In contrast to relative risk assessments, regression models found that arsenic, chromium, and alkalinity had stronger relationships than nutrients to toxicity, suggesting that these constituents may have be responsible for the observed toxicity, despite being found in concentrations below threshold. The best fitting regression model for reproduction indicated that alkalinity and arsenic had a negative effect on the number of young per female, while chloride had a positive effect, although the r^2 for this equation was low (0.23). The best fitting logistic regression model for reproduction indicated that alkalinity and chromium decreased the likelihood of a stream being non-toxic, while total nitrogen increased that likelihood. For the survival endpoint, the best fit regression model was a positive linear relationship with arsenic. However, this relationship was weak ($r^2 = 0.05$), and lacks a plausible physiological mechanism to explain this relationship; therefore, the statistical significance may be spurious, or correlated with other sources of toxicity. The best fitting logistic model for survival indicated that increasing alkalinity in a stream decreased the likelihood of a non-toxic result.

Physical Habitat

Extent and Magnitude Estimates

Many physical habitat metrics showed strong differences among the land uses, with urban streams being in a more degraded state and open streams in a less degraded state. For example, W1_Hall, a proximity-weighted human disturbance index developed for EMAP (Stoddard et al. 2005), had a median value of 0.7 in open streams and a value of 5.2 in urban streams (**Figure 11**). This pattern was repeated for metrics related to instream habitat complexity (e.g., XFC_NAT, an area-weighted index of natural instream habitat developed for EMAP, Stoddard et al. 2005), riparian vegetation (e.g., average number of layers), and substrate (e.g., % sands and fines). The condition of agricultural streams was similar to open streams for some metrics (e.g., W1_Hall), and similar to urban streams for others (e.g., XFC_NAT). For a small number of metrics, agricultural streams were in the most degraded condition; these metrics include those related to bank stability (e.g., % eroded or vulnerable banks), productivity (e.g., % cover of visible microalgae), and substrate (e.g., % sands and fines). Aggregate metrics (like W1_Hall and XFC_NAT) were typically better able to distinguish among the different land uses than their individual constituents (e.g., trash or live tree roots), suggesting that the land uses affect stream habitat in terms of overall severity, rather than particular habitat components. Distributions of physical habitat metrics are presented in **Table 11**.

Benthic Macroinvertebrates

Extent and Magnitude Estimates

The majority of streams in the region were in non-reference condition, with a median score of 33, and 47% (± 6 standard error) of stream-length was estimated to be in or near reference condition (**Table 12**; **Figure 12**). These sites were restricted to the higher elevation portions of the Transverse and Peninsular Ranges (**Figure 13**). Differences among the three land use classes were dramatic, with median IBI scores of 27, 57, and 16 in agricultural, open, and urban streams respectively. Moreover, only 2% (± 1%) of urban streams and 35 (± 11%) of agricultural streams were estimated to be in reference condition. In contrast, 90% (± 4%) of open streams were in reference condition.

IBI sub-metrics (e.g., richness of predator taxa) showed similar patterns, with metric values indicating the least degradation in open streams and the most among urban (**Table 6**). In fact, several metrics suggested a near absence of sensitive taxa from urban and agricultural streams, which had median values at or near zero for coleopteran richness, EPT richness, and % intolerant individuals. Only the predator richness metric suggested that one of these classes (agricultural streams) was similar to the open streams.

Stressor Relationships

Relative Risk Analysis - Relative risk analysis showed that many physical habitat variables pose high risk to biological condition (**Tables 13**, **14**; **Figure 14**). For example, one of the higher relative risks observed was for the % sands and fine: sites where this metric was above the survey median (34%) were 4.3 times more likely to have a non-reference IBI score than sites with coarser substrates. Other major stressors (i.e., relative risk ≥ 2) include channel alteration, several human disturbance metrics (e.g., W1_Hall), substrate (e.g., % sands and fines), low instream habitat cover (e.g., XFC_NAT), and degraded riparian vegetation (e.g., number of vegetated layers). The highest risk physical habitat metric was epifaunal substrate, which had a relative risk of 8.4; however, because only 4 sites were in the "unstressed and non-reference condition" category, this validity of this result is uncertain.

In contrast to physical habitat, only a few water chemistry variables had high relative risks, although many could not be analyzed because they were never detected above thresholds (e.g., Arsenic). However, a few analytes had high risks, and one (total phosphorous) had one of the highest risks observed in the study (i.e., 4.0). Among constituents that were not flagged for small cell size, only total nitrogen and sulfate had relative risks greater than 2.

Many landscape metrics generally had very high relative risks for biology, compared to locally measured stressors (**Table 15**; **Figure 14**). For example, if % imperviousness within 1 km of the sample site exceeded the survey median of 2.9%, the relative risk was 7.9. Several landscape metrics had relative risks greater than 4 at one or more spatial scales, including % development, % urban land, road density, population density, and housing density. Slightly smaller relative risks (i.e., 2 to 4) were observed for metrics relating to hydrologic alteration, such as the presence of dams or modified channels in the watershed. Grazing and mining did not have relative risks that were significantly different from 1 (i.e., no increased risk when the stressor is present). The finding that landscape metrics generally had higher relative risks than locally measured stressors suggest that landscape-scale alterations may degrade a stream through multiple stressors, which may not be detected in any individual stressor.

Landscape metrics calculated at smaller spatial scales often had higher relative risks than those calculated at watershed scales, suggesting that distance from the disturbance may mediate some of the stresses of watershed alteration. For example, the relative risk for having road density above the median at the 1-km scale was 5.0, but only 3.7 at the watershed scale. This pattern was consistent for many landcover and transportation metrics, but not for census metrics. For example, both human and population density had the lowest relative risk at the 5-km scale.

Correlation Analysis - Many of the same stressors identified by relative risk analysis showed strong correlations with IBI scores (**Tables 16, 17, 18; Figure 15**). In general, more physical habitat metrics showed stronger relationships with IBI scores than water chemistry analytes, but the strongest relationships were observed for landscape metrics. For example, several landscape stressor metrics (e.g., % impervious or road density at the 5k scale) had |Rho|>0.70, whereas all physical habitat and water chemistry stressors had |Rho|<0.65. However, stressors with strong relationships with biological condition were observed for every class of stressor.

Among water chemistry constituents, nutrient concentrations (e.g., total N and total P) and conventional analytes (e.g., sulfate, TSS, specific conductance, and chloride) had the strongest relationships with IBI scores, and metals and pyrethroids had weaker relationships (**Table 16**). However, several analytes had stronger correlations than might be expected from relative risk analysis. For example, among water chemistry analytes, both chloride and total N had stronger correlations (Rho = -0.65 and -0.58, respectively) but lower relative risks (2.5 and 2.2, respectively) than total P (Relative risk = 4.0, Rho = -0.54). Arsenic and copper, which exceeded thresholds too rarely to conduct relative risk analysis, also had strong relationships with the IBI (Rho = -0.44 and -0.40, respectively). Furthermore, stressors for which no thresholds were applicable (e.g., TSS, orthophosphate) also showed strong correlations with the IBI. Therefore, the thresholds used in relative risk analysis may obscure the importance of several stressors.

Among physical habitat variables, the strongest relationships (i.e., |Rho| > 0.5) were observed for visual habitat characterizations (e.g., channel alteration), human influence (e.g., W1_Hall), instream habitat complexity (e.g., % boulder cover), and substrate (e.g., % boulders; **Table 17**). Many riparian vegetation metrics showed somewhat weaker relationships (i.e., |Rho| between 0.2 and 0.4). However, only one productivity metric (i.e., % macroalgae cover) had |Rho| > 0.2.

Graphical analysis of stressor relationships revealed that many variables had a triangular or wedge-shaped relationship with the IBI (e.g., channel alteration, % macroalgae cover, number of riparian layers; **Figure 15**). These stressors may limit biological condition in a continuous and linear manner, and that other stressors may explain residual variability from this limit. The relationship with number of riparian vegetation layers is unusual because the wedge-shaped pattern was also evident within the subset of developed sites; therefore, this metric may be particularly important in explaining biological variability at urban and agricultural sites.

In contrast, to wedge-shaped relationships, step-shaped relationships were observed for other stressors (e.g., total N, chloride, and sulfate), suggesting a threshold limit to biological condition (**Figure 15**). When these stressors were present above a certain level, IBI scores were uniformly low. Thresholds were particularly strong for GIS metrics. For example, sites were predominantly in non-reference condition when % development was greater than 10% regardless of the spatial scale analyzed (**Figure 15**).

Discussion

Different indicators sampled in the first year of the SMC stream monitoring program provided different views of the ecological health of these streams, although most showed large differences among the three land use classes. Differences were most strongly evident for benthic macroinvertebrates. The most dramatic difference in extent of streams with reference IBI scores was between open and urban land uses (90% vs. 2%); the magnitude of this difference was unmatched by other indicators.

Biological condition was non-reference at the majority of streams in the region, and nearly all streams exceeded at least one water chemistry threshold, particularly for nutrient concentrations. Stressors known to be associated with biological degradation, such as metals (e.g., Buchwalter et al. 2008, Cuffney et al. 2010), pesticides (e.g., Cuffney et al. 2010), major ions (Sandin and Johnson 2004), high nutrient concentrations (Yuan 2010), and altered physical habitat (Mazor et al. 2006, Cuffney et al. 2010), were greater in developed streams than in open spaces. However, reproductive toxicity was also widespread, even in open streams with high IBI scores, but the spatial distribution and correlations with likely stressors do not suggest an obvious source.

Although stressors for benthic macroinvertebrates were generally low in open streams, nitrogen concentrations were an exception, as over one-third of these streams exceeded a threshold of 1 mg/L. High nitrogen concentrations were a regional phenomenon, present in all land use classes and above thresholds in two-thirds of all streams in southern California. In contrast, phosphorous concentrations over 0.1 mg/L were almost exclusively observed in developed areas. This difference suggests that the two classes of nutrients have different sources. Possible reasons that nitrogen concentrations were elevated in undeveloped watersheds include aerial deposition (Fenn et al. 2003), persistent effects of wildfire (e.g., Viera et al. 2004, Koetsier et al. 2010), grazing (del Rosario et al. 2002) Ellison et al.2009) and recreational impacts from hikers and pack animals (Farag et al. 2001). Aerial transport and deposition of nitrogen has been documented in southern California watersheds (Fenn et al. 2008), and is known to be a major source of nutrients in certain streams (Fenn and Poth 1999). High nutrient concentrations can affect stream biology by stimulating growth of algae and macrophytes, which in turn may limit microhabitat diversity, alter food sources, deplete dissolved oxygen (e.g., Yuan 2010), or introduce toxic metabolites to the water (e.g., Codd et al. 2005, Izaguirrea et al. 2007). Because the SMC program collects extensive data on algae communities, the impacts of nutrients on biological communities can be investigated in future reports.

Stressor analyses consistently identified nutrient concentrations, major ions, and physical habitat metrics related to instream and riparian condition as having strong associations with biological condition. In contrast, IBI scores had weak associations with most metals, pesticides, and toxicity. However, natural variability cannot be ruled out as a cause of low IBI scores at some sites. For example, although all sites were evaluated for perenniality of flow (defined as flow through the end of the hydrologic year), these evaluations are necessarily imperfect, and they do not consistently capture long-term variability in flow conditions. Therefore, it is possible that several nonperennial streams were erroneously sampled. Several studies have shown that nonperennial streams have distinct biological assemblages (e.g., Bêche et al. 2006, Williams 2006), and these differences affect bioassessment metrics (e.g., Morais et al. 2004, Mazor et al. 2009, Lawrence et al. 2010). Secondly, low-gradient streams (e.g., slope <1%), which were poorly represented in IBI calibration data (Ode et al. 2005), may have naturally high stressors, and therefore may have naturally low IBI scores (Mazor et al. 2010), potentially inflating the number of low-gradient sites identified as non-reference.

The counter-intuitive geographic distribution of reproductive toxicity was not fully explained by our data. The causes of toxicity in open streams were not clear, because most stressors were low in these watersheds. For example, alkalinity was identified as a possible stressor for toxicity tests, although alkalinity never approached the threshold of 20,000 mg/L, and concentrations were similar in all three land-use classes. Constituents like total nitrogen are not known to be toxic, and may have indirect relationships with toxicity by stimulating the growth of toxic algae (e.g., Codd et al. 2005). Examination of the spatial distribution of toxic sites suggests a number of potential explanations for this distribution, which may be tested with additional data (**Figure 9**). Within the Peninsular Ranges, which include the Santa Ana Mountains in Orange County, Mt. San Jacinto in Riverside, and the eastern backbone of San Diego County, toxic sites roughly corresponded to the perimeters of wildfires that occurred within 5 years of the sample date. In 2007, wildfires burned large portions of this area. However, this pattern did not persist within the Transverse Ranges in the northern portions of the region, which also experienced large wildfires in the same time period. In the eastern portions of the Transverse Range, including the San Bernardino and the eastern San Gabriel Mountains, toxicity was nearly absent, but in the western portions, which include the Santa Monica Mountains, the Topatopa Mountains, Pine Mountain Ridge, and Frazier Mountain, toxicity was observed at nearly every open site. The dividing line between these two regions corresponded to the mainstem of the San Gabriel River, as the two samples from the East Fork were non-toxic, and the one sample from the West Fork exhibited chronic toxicity. This pattern may be explained by geological differences in the eastern and western portions of the Transverse Range, or by elevation differences, as the eastern portions are higher and therefore may be less exposed to atmospheric inputs of pollutants. Additional analyses, such as toxicity identification evaluations (TIEs) may elucidate the causes of the toxic responses. However, given that many of these sites were in reference condition for benthic macroinvertebrate communities, the need to investigate sources of toxicity should be decided on a site-specific basis.

Although this survey took a comprehensive approach in characterizing the ecological condition of streams in southern California, sample and survey design imposed a few constraints on the ability to make assessments of the region as a whole. Chief among these constraints was the fact that this survey was designed to assess the health of perennial streams only. Sampling reconnaissance determined that nonperennial streams make up the majority of stream length in southern California, and the survey was unable to assess the health of this portion of the region. The distribution of nonperennial streams was disproportionately in open watersheds. A more comprehensive survey that includes nonperennial streams may provide an entirely different impression of the ecological condition of the region. Other constraints include the time of sampling, which misses peak storm flows (which occur before sampling was initiated), as well as peak algal blooms (which may occur during or after sampling ends). Furthermore, sediments, which may provide better temporal integration than the water column, were not assessed for chemistry or toxicity. These issues may be considered in future refinements to the program design.

Key Findings and Recommendations

Key Findings

1. *The first year of the SMC program proved that a collaborative approach can answer key management questions*

Collaboration among SMC member agencies achieved the primary goals of this survey by leveraging resources and coordinating effort. Collaborating agencies implemented a program that produced a preliminary assessment of the condition of southern California's perennial streams. In doing so, they achieved many benefits from participation including a 10-for-1 match in regional sampling effort (minimum 1-for-1 match in watershed sampling effort), extension of expertise not currently available within most agencies, staff training in necessary protocols, improved data management, development and execution of a common quality assurance plan (including auditing of field crews and independent quality assurance evaluations), and creating SWAMP comparable data sharing infrastructures for internal use and for sharing with other agencies or regulators. Furthermore, coordination among local agencies allowed easier integration with statewide programs, such as SWAMP's Perennial Stream Assessment, which, in turn, provides a larger regional context for evaluating the streams of Southern California. Most importantly, the investment in the regional program enhanced communication and interaction among regulated and regulatory agencies, both local and statewide, allowing common interpretations and acceptance of the results

2. *Reconnaissance surveys identified that more than half of the streams in southern California are nonperennial*

The SMC survey was purposefully designed to assess the health of perennial wadeable streams in southern California coastal watersheds. Excluding nonperennial streams from the target population restricted the assessment of watershed health to 44% of the total stream miles in the region. The constraint to perennial streams was adopted because the validity of assessment tools (e.g., the IBI) in nonperennial streams is not yet known.

3. *Each indicator showed a different extent of streams in reference condition, but most showed that reference conditions were most widespread in undeveloped watersheds*

    a. *Threshold exceedances of typical stormwater-associated pollutants were rare in perennial streams*

    Typical runoff-associated pollutants (e.g., metals) rarely exceeded thresholds. For example, copper exceeded thresholds in less than 4% of all streams. Several constituents, such as zinc and arsenic, never exceeded thresholds. Pyrethroid pesticides, which do not yet have a statewide threshold, were detected in 28% of stream miles regionally.

b. *Non-reference biology and nutrient concentrations in perennial streams were widespread in urban and agricultural streams*

The biological condition of perennial streams, as measured by the Southern California IBI, indicated that 53% of streams were in non-reference condition, and that the distribution of non-reference streams was closely associated with land use. Approximately 98% of urban, and 65% of agricultural streams, were in non-reference condition, but only 10% of open streams were in non-reference condition. Total nitrogen was above a threshold of 1.0 mg/L in approximately two-thirds of streams regionally, and total phosphorous was above a threshold of 0.1 mg/L in 42% of streams regionally. Both of these nutrients commonly exceeded these thresholds in urban and agricultural streams, but nitrogen was also above the threshold in 37% of open streams. Exceedances of these non-regulatory thresholds for nutrients do not necessarily signify impairment.

c. *Toxicity to reproduction was widespread, especially in undeveloped streams.*

Across the region, 47% of streams showed evidence of toxicity to reproduction. The extent was greatest in open streams (63%) and lower in urban (41%) and agricultural (37%) streams. Stressors for toxicity are not yet clear.

4. *Relative risk and correlation analyses identified potential stressors to major indicators*

Analyses of stressor relationships indicated that physical habitat (i.e., channel alteration, substrate, riparian cover) and nutrient concentrations may play roles in limiting biological condition. In contrast, traditional water chemistry contaminants had weak associations with biological condition; moreover, water column toxicity showed no association with IBI scores, and many of the sites with the highest IBI scores also showed evidence of toxicity. These analyses do not infer cause and effect at specific sites, but instead provide regional answers and can prioritize stressors for further site-specific investigations.

Recommendations

1. *Continue the monitoring program with the current level of effort, but modify the design to increase efficiencies*

One year of sampling provided new and invaluable answers to two of the three management questions addressed by this program: status assessments of ecological health and identification of potential stressors. However, several data gaps remain, including the third management question about trends in ecological condition and making assessments of individual watersheds. Providing that sampling continues, the original 5-year design of the program will attain sufficient sample size for making scientifically robust estimates to meet these objectives. Relatively minor modifications may improve the efficiency of the program by increasing sampling success and statistical power. These modifications include reallocating sampling effort towards strata and indicators with higher variability (i.e., more 2nd

order than 5th order streams) to improve statistical power. Additionally, data submission protocols should be improved to ensure completeness, particularly for quality assurance purposes.

2. *Develop assessment tools to include non-perennial streams.*

The first year of sampling indicated that non-perennial streams comprised the majority of streams in the region and, therefore, a large portion of the stream miles in southern California coastal watersheds remain unassessed. Two challenges need to be overcome before these assessments can occur: 1. Calibrate and validate biological assessment tools like the IBI in nonperennial streams; and 2. Improve stream maps to accurately represent hydrologic regimes. Some of this is already underway in the region, but the additional investment to overcome these hurdles will ensure the inclusion of all of the region's streams in future surveys.

3. *Help the State identify appropriate management goals for non-reference streams*

The State Water Resources Control Board (SWRCB) has begun a process to develop biological objectives (also known as biocriteria) for benthic macroinvertebrates in perennial wadeable streams. First-year results indicated that most streams in developed portions of southern California were not in reference condition for biology. Consequently, setting achievable management objectives may be difficult. The SMC should interact with the SWRCB as they explore several options for setting biological objectives in developed streams. Similarly, in light of the extent of nutrient concentrations greater than 1.0 mg/L, the SMC should engage with the SWRCB to develop meaningful thresholds for nitrogen and phosphorus based on biological impacts (e.g., algae biomass).

4. *Conduct site-specific stressor analyses at sites of interest*

The stressor analyses in this study identified regionally important stressors that are correlated with non-reference biological condition. However, these analyses are unable to prove causality, and do not identify the mechanisms of impact at specific sites. For those sites of particular interest to SMC member agencies, site-specific stressor identification will need to be conducted. For example, toxicity identification evaluation (TIE) tests may provide useful information for diagnosing or ruling out causes of biological degradation at sites where non-reference biology and reproductive toxicity co-occur. There are opportunities and resources available to SMC member agencies to conduct this analysis including the USEPA's Causal Analysis/Diagnostic Decision Information System (CADDIS; USEPA 2010b).

5. *Expand biological indicators to include multiple assemblages*

Although benthic macroinvertebrates provide a valuable tool in assessing ecological condition, multi-assemblage assessments are preferable because they provide multiple lines of evidence to support findings of non-reference biology. Different assemblages have unique properties that can help identify stressors. For example, benthic algae communities may respond more to water chemistry disturbance than to physical habitat alteration, relative to benthic macroinvertebrates; using both indicators may help identify causes of impairment where both stressors are present. Thus, future reports for this survey should include assessments of benthic algae and riparian wetlands, and explore ways to integrate multiple indicators.

Table 1. Size and characteristics of the watersheds assessed in the survey.

Watersheds	Stream Order (max)	Area (km^2)	Total Stream Length (km)	Land Use by Stream Length (%)		
				Open	Agricultural	Urban
Ventura	6	642	236	68	15	17
Santa Clara	7	4,327	1,429	81	14	6
Calleguas	5	891	315	28	35	36
Santa Monica Bay	4	1,171	200	73	2	25
Los Angeles	5	2,160	519	41	1	59
San Gabriel	5	1,758	487	50	0	50
Santa Ana River	6	7,092	1,708	49	15	36
–Lower Santa Ana	6	1,253	298	36	10	53
–Middle Santa Ana	6	2,135	519	38	14	48
–Upper Santa Ana	5	1,721	523	64	12	24
–San Jacinto	4	1,984	367	55	24	21
San Juan	4	1,019	337	66	5	29
Northern San Diego	6	3,640	1,055	58	28	14
Central San Diego	5	1,725	430	38	12	51
Mission Bay and San Diego River	5	1,270	322	64	4	32
Southern San Diego	5	2,355	535	80	6	14
Entire region	7	28,051	7,574	59	13	28

Table 2. Median, 25th percentile (Q1) and 75th percentile (Q3) of selected GIS metrics, by land use. n = number of samples used to calculate estimates. Zero values are shown by '—'. WS: Watershed scale. 5k: 5-km buffer, clipped to watershed scale. 1k: 1-km buffer, clipped to watershed scale. Code 21: A category that includes a diverse range of land uses that are prominently characterized by heavily managed vegetation (e.g., low-density residential, parks, golf courses, highway medians, etc.). Code 21 was not included in calculations of % urban or % agricultural, but was included in % developed.

Metric	Median	Q1	Q3
Natural			
Location			
Area (km^2)	50	19	175
Agricultural	144	18	661
Open	41	18	149
Urban	52	19	230
Elevation (m)	253	130	499
Agricultural	175	90	257
Open	562	425	931
Urban	162	51	224
Climate			
Precipitation (cm)	47	40	58
Agricultural	40	37	45
Open	61	52	71
Urban	41	36	47
Temperature (°C)	24.1	23.1	25.1
Agricultural	24.6	23.4	25.4
Open	23.6	22.4	24.4
Urban	24.5	23.9	25.4
Geology			
% Sedimentary	10.9	—	97.8
Agricultural	11.5	—	91.8
Open	—	—	97.9
Urban	28.7	5.0	98.0
% Cenozoic	16	—	94
Agricultural	66	—	92
Open	—	—	70
Urban	35	—	100
% CaO geology	4.0	3.1	5.2
Agricultural	4.6	2.0	5.1
Open	3.7	3.1	5.0
Urban	4.4	3.1	6.2
% MgO geology	2.2	1.6	2.8
Agricultural	2.3	1.1	2.4
Open	2.1	1.6	3.0
Urban	2.2	1.6	2.9

Table 2. Continued

Metric	Median	Q1	Q3
Natural			
Geology (Continued)			
% N geology	0.05	0.01	0.22
Agricultural	0.15	0.05	0.48
Open	0.01	0.01	0.04
Urban	0.15	0.06	0.30
% P geology	0.14	0.13	0.15
Agricultural	0.13	0.13	0.15
Open	0.15	0.13	0.16
Urban	0.13	0.12	0.15
% S geology	0.05	0.03	0.35
Agricultural	0.08	0.04	0.32
Open	0.04	0.02	0.06
Urban	0.28	0.04	0.78
Landcover			
Imperviousness			
ws	1.4	0.2	14.2
5k	1.6	0.1	23.9
1k	2.9	0.3	23.7
Agricultural			
ws	2.8	1.8	8.0
5k	2.8	0.7	4.9
1k	1.8	0.3	5.5
Open			
ws	0.2	—	0.4
5k	0.1	—	0.4
1k	0.1	—	0.9
Urban			
ws	14.2	6.6	20.1
5k	25.1	10.8	39.1
1k	28.2	11.7	42.3
% Developed			
ws	13	4	47
5k	21	3	72
1k	27	8	86
Agricultural			
ws	24	13	41
5k	35	21	57
1k	50	42	78

Table 2. Continued

Metric	Median	Q1	Q3
Landcover			
% Developed (Continued)			
Open			
ws	4	1	5
5k	2	1	6
1k	5	—	10
Urban			
ws	44	19	63
5k	72	50	85
1k	86	52	90
% Agricultural			
ws	—	—	—
5k	—	—	1
1k	—	—	—
Agricultural			
ws	4	1	11
5k	16	8	25
1k	34	19	51
Open			
ws	—	—	—
5k	—	—	—
1k	—	—	—
Urban			
ws	—	—	2
5k	—	—	1
1k	—	—	—
% Urban			
ws	2	—	29
5k	2	—	49
1k	4	—	45
Agricultural			
ws	5	3	16
5k	4	1	9
1k	3	—	8
Open			
ws	—	—	—
5k	—	—	—
1k	—	—	1

Table 2. Continued

Metric	Median	Q1	Q3
Landcover			
% Urban (Continued)			
Urban			
ws	29	12	38
5k	49	24	67
1k	54	25	69
% Code 21			
ws	10	4	15
5k	11	2	17
1k	11	3	24
Agricultural			
ws	11	7	13
5k	11	7	18
1k	13	6	23
Open			
ws	3	1	5
5k	2	1	6
1k	5	—	9
Urban			
ws	15	11	19
5k	16	12	21
1k	22	13	28
% Natural			
ws	86	51	96
5k	78	28	97
1k	71	14	92
Agricultural			
ws	76	57	87
5k	64	41	78
1k	49	21	58
Open			
ws	96	94	99
5k	98	94	99
1k	94	90	100
Urban			
ws	52	37	81
5k	28	13	50
1k	14	10	47

Table 2. Continued

Metric	Median	Q1	Q3
Landcover (Continued)			
% Forest			
Agricultural			
ws	7	2	29
5k	2	1	15
1k	1	—	5
Agricultural			
ws	2	1	10
5k	—	—	2
1k	—	—	1
Open			
ws	29	12	39
5k	16	4	29
1k	7	1	26
Urban			
ws	2	1	7
5k	1	—	2
1k	—	—	1
% Shrubs			
ws	51	35	65
5k	51	15	71
1k	37	5	78
Agricultural			
ws	43	37	58
5k	48	19	56
1k	22	10	41
Open			
ws	60	51	71
5k	71	58	80
1k	81	57	90
Urban			
ws	41	26	55
5k	16	8	34
1k	5	1	24

Table 2. Continued

Metric (Continued)	Median	Q1	Q3
Transportation			
Road density (km/km^2)			
ws	3.1	0.5	6.3
5k	3.5	0.3	10.3
1k	3.8	0.4	10.7
Agricultural			
ws	3.3	1.7	4.9
5k	2.9	2.2	4.2
1k	2.7	1.6	4.4
Open			
ws	0.4	—	1.4
5k	0.2	—	1.2
1k	0.1	—	1.4
Urban			
ws	5.9	3.5	10.0
5k	10.5	5.9	13.2
1k	10.7	4.6	12.0
Road crossings (crossings/km)			
ws	0.9	0.2	2.4
5k	1.4	0.1	2.6
1k	0.9	—	2.5
Agricultural			
ws	1.2	0.8	1.8
5k	1.4	0.8	1.9
1k	0.6	—	1.9
Open			
ws	0.2	—	0.7
5k	0.1	—	0.6
1k	—	—	0.3
Urban			
ws	2.0	1.1	4.0
5k	2.6	2.0	3.7
1k	2.5	1.0	3.8
Hydrology			
Dam density (dams/km^2)			
ws	—	—	0.0051
5k	—	—	—
1k	—	—	—

Table 2. Continued

Metric	Median	Q1	Q3
Hydrology (Continued)			
Agricultural			
ws	0.0035	—	0.0105
5k	—	—	—
1k	—	—	—
Open			
ws	—	—	—
5k	—	—	—
1k	—	—	—
Urban			
ws	0.0010	—	0.0106
5k	—	—	—
1k	—	—	—
% Canals, ditches, or pipes			
ws	—	—	4
5k	—	—	—
1k	—	—	—
Agricultural			
ws	3	—	10
5k	—	—	17
1k	—	—	16
Open			
ws	—	—	—
5k	—	—	—
1k	—	—	—
Urban			
ws	2	—	9
5k	—	—	18
1k	—	—	—
Mining			
Mine density (mines/km^2)			
Entire region			
ws	0.0893	0.0134	0.1338
5k	—	—	0.1365
1k	—	—	—
Agricultural			
ws	0.0309	0.0134	0.1088
5k	—	—	—
1k	—	—	—

Table 2. Continued

Metric	Median	Q1	Q3
Mining			
Mine density (mines/km^2) Continued			
Open			
ws	0.0439	0.0083	0.1638
5k	—	—	0.1175
1k	—	—	—
Urban			
ws	0.0952	0.0171	0.1339
5k	0.0367	—	0.1731
1k	—	—	—
In-stream gravel mine density (mines/km)			
WS	—	—	0.0069
5k	—	—	—
1k	—	—	—
Agricultural			
WS	—	—	0.0164
5k	—	—	—
1k	—	—	—
Open			
WS	—	—	—
5k	—	—	—
1k	—	—	—
Urban			
WS	—	—	0.0287
5k	—	—	—
1k	—	—	—

Table 3. Median, 25th percentile (Q1) and 75th percentile (Q3) of water chemistry analytes, by land use. n = number of samples used to calculate estimates. Zero values are shown by '—'. Metrics for which all estimates were zero are not shown. TSS: Total suspended solids.

Analyte	n	Median	Q1	Q3
Field water quality measurements				
Alkalinity (mg/L)	105	203	172	280
Agricultural	21	198	135	228
Open	38	200	164	247
Urban	46	245	181	343
Dissolved oxygen (mg/L)	136	8.43	6.99	9.20
Agricultural	23	8.84	6.68	9.56
Open	57	8.59	7.09	9.03
Urban	56	7.57	6.51	9.36
pH	135	8.00	7.80	8.23
Agricultural	23	8.07	7.91	8.39
Open	56	8.11	7.80	8.20
Urban	56	7.93	7.75	8.26
Specific conductivity (µS/cm)	132	960	421	1569
Agricultural	22	1220	782	1504
Open	55	435	286	766
Urban	55	1382	961	2320
Turbidity (NTU)	53	2.0	0.8	12.4
Agricultural	10	3.6	1.6	38.4
Open	18	0.8	0.5	1.0
Urban	25	10.3	2.1	18.9
Conventional analytes and major ions				
Silica (mg/L)	97	27	17	31
Agricultural	20	27	20	35
Open	34	21	17	29
Urban	43	28	18	34
TSS (mg/L)	97	4.7	1.5	12.7
Agricultural	19	6.3	1.4	7.9
Open	35	1.5	0.4	2.9
Urban	43	12.5	4.2	18.2
Chloride (mg/L)	105	91	12	244
Agricultural	20	107	70	210
Open	43	11	4	50
Urban	42	259	155	325
Hardness (mg/L)	110	374	222	580
Agricultural	21	424	199	503
Open	44	223	170	323
Urban	45	556	384	838

Table 3. Continued

Analyte	n	Median	Q1	Q3
Conventional analytes and major ions (Continued)				
Sulfate (mg/L)	104	188	70	306
Agricultural	19	304	125	367
Open	43	80	29	201
Urban	42	289	188	393
Metals				
Arsenic (µg/L dissolved)	97	1.5	0.5	3.0
Agricultural	20	2.5	0.8	4.7
Open	34	0.8	0.5	2.0
Urban	43	1.8	0.5	3.1
Arsenic (µg/L total)	101	2.0	0.8	4.1
Agricultural	19	2.7	0.9	4.4
Open	39	0.8	0.5	1.9
Urban	43	2.5	1.9	5.2
Cadmium (µg/L dissolved)	86	0.038	0.008	0.084
Agricultural	15	0.080	0.060	0.090
Open	33	0.034	0.007	0.080
Urban	38	0.060	0.008	0.090
Cadmium (µg/L total)	93	0.080	0.009	0.090
Agricultural	16	0.090	0.080	0.100
Open	39	0.031	0.007	0.080
Urban	38	0.090	0.009	0.200
Chromium (µg/L dissolved)	97	0.20	0.03	0.90
Agricultural	20	0.20	0.03	0.50
Open	34	0.20	0.04	0.80
Urban	43	0.20	0.03	0.90
Chromium (µg/L total)	104	0.30	0.10	1.20
Agricultural	19	0.20	0.04	0.70
Open	41	0.20	0.05	0.90
Urban	44	0.70	0.20	2.60
Copper (µg/L dissolved)	94	1.5	0.7	2.9
Agricultural	20	1.7	1.0	3.3
Open	32	0.7	0.1	1.2
Urban	42	2.6	1.5	3.4
Copper (µg/L total)	99	2.0	0.8	4.0
Agricultural	19	1.6	1.0	3.2
Open	38	0.9	0.2	2.0
Urban	42	3.7	2.0	7.0

Table 3. Continued

Analyte	n	Median	Q1	Q3
Metals (Continued)				
Nickel (µg/L dissolved)	97	2.7	1.2	5.2
Agricultural	20	3.4	1.0	7.8
Open	34	1.7	0.1	4.1
Urban	43	3.7	1.9	7.8
Nickel (µg/L total)	100	2.6	1.2	7.0
Agricultural	19	3.6	0.5	9.2
Open	38	1.7	0.2	4.3
Urban	43	4.6	1.9	12.5
Lead (µg/L dissolved)	97	0.020	0.008	0.050
Agricultural	20	0.020	0.010	0.020
Open	34	0.020	0.008	0.020
Urban	43	0.020	0.017	0.190
Lead (µg/L total)	99	0.100	0.008	0.400
Agricultural	19	0.040	0.020	0.200
Open	37	0.020	0.008	0.050
Urban	43	0.200	0.050	1.600
Selenium (µg/L dissolved)	97	1.0	0.4	2.1
Agricultural	20	3.6	0.8	5.1
Open	34	0.7	0.1	1.7
Urban	43	1.0	0.4	1.7
Selenium (µg/L total)	102	1.1	0.5	2.1
Agricultural	19	4.0	0.8	4.9
Open	40	1.0	0.2	2.0
Urban	43	1.1	0.6	2.0
Zinc (µg/L dissolved)	97	1.7	0.8	4.9
Agricultural	20	3.4	1.3	7.5
Open	34	1.2	0.3	2.5
Urban	43	4.6	1.4	8.2
Zinc (µg/L total)	98	4.0	2.2	15.0
Agricultural	20	4.5	1.8	10.5
Open	34	2.3	1.0	3.3
Urban	44	9.5	3.9	34.4
Nutrients				
Total Nitrogen (mg/L)	110	1.00	0.50	2.90
Agricultural	21	1.80	0.90	4.60
Open	44	0.40	0.30	0.90
Urban	45	2.80	1.10	5.50

Table 3. Continued

Analyte	n	Median	Q1	Q3
Nutrients (Continued)				
Ammonia-N (µg/L)	109	0.02	0.01	0.04
Agricultural	21	0.03	0.01	0.05
Open	43	0.01	0.01	0.03
Urban	45	0.03	0.02	0.05
Nitrate + Nitrite-N (mg/L)	110	0.20	0.02	1.90
Agricultural	21	0.60	0.30	5.20
Open	44	0.02	0.00	0.30
Urban	45	1.90	0.04	3.60
Total Phosphorus (mg/L)	100	0.05	0.02	0.20
Agricultural	20	0.10	0.05	0.80
Open	40	0.02	0.01	0.03
Urban	40	0.20	0.10	0.30
Orthophosphate-P (mg/L)	79	0.04	0.02	0.10
Agricultural	13	0.10	0.04	0.50
Open	34	0.02	0.01	0.03
Urban	32	0.10	0.07	0.20
Pyrethroids				
Bifenthrin (µg/L)	97	—	—	—
Agricultural	17	—	—	0.0009
Open	41	—	—	—
Urban	39	—	—	0.0001
Cyfluthrin (µg/L)	97	—	—	—
Agricultural	17	—	—	—
Open	41	—	—	—
Urban	39	—	—	—
Cyhalothrin-lambda (µg/L)	97	—	—	—
Agricultural	17	—	—	—
Open	41	—	—	—
Urban	39	—	—	—
Cypermethrin (µg/L)	97	—	—	—
Agricultural	17	—	—	—
Open	41	—	—	—
Urban	39	—	—	—
Deltamethrin (µg/L)	97	—	—	—
Agricultural	17	—	—	—
Open	41	—	—	—
Urban	39	—	—	—

Table 3. Continued

Analyte	n	Median	Q1	Q3
Pyrethroids (Continued)				
Esfenvalerate-Fenvalerate (µg/L)	97	—	—	—
Agricultural	17	—	—	—
Open	41	—	—	—
Urban	39	—	—	—
Permethrin (µg/L)	97	—	—	—
Agricultural	17	—	—	—
Open	41	—	—	—
Urban	39	—	—	—

Table 4. Error rates in biological samples submitted for re-identification. MQO: Measurement quality objective. Error rates of zero are shown as –.

Lab	Batch	Sample #	Recount Accuracy	Taxa Count Error Rate	Taxa ID Error Rate	Individual ID Error Rate	Taxonomic Resolution Errors
A	1st	1	100	–	4	–	–
		2	99	–	3	–	–
B	2nd	1	99	–	–	–	–
		2	100	–	–	–	–
		3	100	–	5	–	–
C	1st	1	100	–	7	2	1
D	2nd	1	100	–	–	–	–
E	1st	1	100	2	7	2	1
		2	100	–	–	–	–
		3	100	2	4	2	1
		4	100	4	9	–	–
MQO			>95%	<10%	<10%	<10%	<10%

Table 5. Thresholds used for estimating extent of streams in reference condition. Regulatory thresholds are derived from water quality criteria developed for California. Benchmark thresholds come from other sources, including scientific literature and regulations developed for specific streams. Thresholds for metals do not reflect adjustments for water hardness.

Indicator	Threshold	Source	Type of threshold
Water Chemistry			
Conventional analytes and major ions			
Alkalinity	20000 mg/L	USEPA(1986)	Regulatory
Chloride	230 mg/L	USEPA(1986)	Regulatory
Sulfate	250 mg/L	USEPA(1986)	Regulatory
Metals (dissolved)			
Arsenic	150 μg/L	USEPA (2000)	Regulatory
Cadmium	2.2 μg/L	USEPA (2000)	Regulatory
Chromium	180 ug/L	USEPA (2000)	Regulatory
Copper	9 μg/L	USEPA (2000)	Regulatory
Nickel	2.5 μg/L	USEPA (2000)	Regulatory
Lead	52 μg/L	USEPA (2000)	Regulatory
Selenium	5 μg/L	USEPA (2000)	Regulatory
Zinc	120 μg/L	USEPA (2000)	Regulatory
Nutrients			
Total Nitrogen	1 mg/L	CA RWQCB SD (2006)	Benchmark
Ammonia-N	1.71 mg/L	USEPA (2004)	Benchmark
Total Phosphorus	0.1 mg/L	CA RWQCB SD (2006)	Benchmark
Pyrethroids			
Bifenthrin	0.0006 μg/L	Palumbo et al. (2010)	Benchmark
Cyfluthrin	0.00005 μg/L	Fojut et al. (2010)	Benchmark
Cyhalothrin-lambda	0.0001 μg/L	Fojut and Tjeerdema (2010)	Benchmark
Cypermethrin	0.0053 μg/L	CA DFG (2000)	Benchmark
Esfenvalerate-Fenvalerate	0.26 μg/L	CDFG (2000)	Benchmark
Permethrin	0.1 μg/L	CDFG (2000)	Benchmark
Toxicity			
Survival	80% of control	USEPA(2002)	Benchmark
Reproduction	75% of control	USEPA (2010a)	Benchmark
Biology			
IBI	39	Ode et al. (2005)	Benchmark

Table 6. Median, 25th percentile (Q1) and 75th percentile (Q3) of biological metrics and the Southern California IBI (Ode et al. 2005), by land use. n = number of samples used to calculate estimates. Zero values are shown by '—'. All estimates were based on 109 samples (21 agricultural, 46 open, and 42 urban).

Metric	Median	Q1	Q3	Response to Degradation
IBI	33	17	56	Decline
Agricultural	27	17	44	
Open	57	47	64	
Urban	16	12	27	
Coleoptera taxa	1	—	3	Decline
Agricultural	—	—	1	
Open	3	1	4	
Urban	—	—	—	
EPT taxa	4	2	10	Decline
Agricultural	3	1	7	
Open	10	3	13	
Urban	2	1	3	
Predator taxa	4	2	6	Decline
Agricultural	5	1	8	
Open	6	3	9	
Urban	3	1	4	
% Collector individuals	85	69	94	Increase
Agricultural	85	83	94	
Open	70	60	83	
Urban	93	91	97	
% Intolerant individuals	—	—	12	Decline
Agricultural	—	—	1	
Open	12	2	19	
Urban	—	—	—	
% Non-insect taxa	26	19	43	Increase
Agricultural	31	28	40	
Open	20	18	25	
Urban	42	26	47	
% Tolerant taxa	27	20	36	Decline
Agricultural	30	24	39	
Open	22	17	28	
Urban	36	25	39	

Table 7. Length of streams in each of the three land use and stream order classes. SE: standard error.

	Total (km)	Target (km)	SE	Non-target (km)	SE
Region	7269	2970	217	4299	216
Land use					
Agricultural	6772	257	35	6515	48
Open	4444	1618	143	2826	192
Urban	1953	1095	172	858	75
Stream order					
2nd	3892	1311	175	2581	163
3rd	1913	927	119	986	88
4th	902	453	49	449	34
5th+	563	279	33	284	32

Table 8. Percent of stream miles meeting thresholds for water chemistry analytes. n = number of samples. SE = standard error. Thresholds and their sources are described in Table 5.

Analyte	Threshold	n	n passing	% of streams meeting threshold	SE
Conventional analytes and major ions					
Alkalinity	20000 mg/L	105	105	100	0
Agricultural		21	21	100	0
Open		38	38	100	0
Urban		46	46	100	0
Chloride	230 mg/L	105	82	74	5
Agricultural		20	17	77	7
Open		43	41	97	2
Urban		42	24	45	9
Sulfate	250 mg/L	104	57	59	6
Agricultural		19	10	44	12
Open		43	32	78	5
Urban		42	15	37	9
Metals (dissolved)					
Arsenic	150 µg/L	97	97	100	0
Agricultural		20	20	100	0
Open		34	34	100	0
Urban		43	43	100	0
Cadmium	2.2 µg/L	86	85	100	0
Agricultural		15	15	100	0
Open		33	33	100	0
Urban		38	37	100	0
Chromium	180 µg/L	97	97	100	0
Agricultural		20	20	100	0
Open		34	34	100	0
Urban		43	43	100	0
Copper	9 µg/L	94	89	96	2
Agricultural		20	18	93	5
Open		32	32	100	0
Urban		42	39	94	4
Nickel	2.5 µg/L	97	94	99	1
Agricultural		20	19	94	5
Open		34	34	100	0
Urban		43	41	99	1

Table 8. Continued

Analyte	Threshold	Source	n	n passing	% of streams meeting threshold	SE
Metals (dissolved) Continued						
Lead	52 µg/L	4	97	97	100	0
Agricultural			20	20	100	0
Open			34	34	100	0
Urban			43	43	100	0
Selenium	5 µg/L	4	97	71	87	3
Agricultural			20	14	62	11
Open			34	28	94	3
Urban			43	29	85	5
Zinc	120 µg/L	4	97	97	100	0
Agricultural			20	20	100	0
Open			34	34	100	0
Urban			43	43	100	0
Nutrients						
Total Nitrogen	1 mg/L	6	110	47	37	6
Agricultural			21	3	22	9
Open			44	33	63	8
Urban			45	11	17	6
Ammonia-N	1.71 mg/L	3	109	108	100	0
Agricultural			21	20	97	3
Open			43	43	100	0
Urban			45	45	100	0
Total Phosphorus	0.1 mg/L	6	100	51	58	6
Agricultural			20	9	46	12
Open			40	34	93	3
Urban			40	8	18	6
Pyrethroids						
Bifenthrin	0.0006 µg/L	2	97	85	85	6
Agricultural			17	14	73	12
Open			41	39	99	1
Urban			39	32	73	12
Cyfluthrin	0.00005 µg/L	7	97	95	97	2
Agricultural			17	17	100	0
Open			41	40	98	2
Urban			39	38	94	5
Cyhalothrin-lambda	0.0001 µg/L	8	97	90	98	1
Agricultural			17	16	96	4
Open			41	39	99	1
Urban			39	35	97	2

Table 8. Continued

Analyte	Threshold	Source	n	n passing	% of streams meeting threshold	SE
Pyrethroids (Continued)						
Cypermethrin	0.0053 µg/L	1	97	97	100	0
Agricultural			17	17	100	0
Open			41	41	100	0
Urban			39	39	100	0
Esfenvalerate-Fenvalerate	0.26 µg/L	1	97	97	100	0
Agricultural			17	17	100	0
Open			41	41	100	0
Urban			39	39	100	0
Permethrin	0.1 µg/L	1	97	97	100	0
Agricultural			17	17	100	0
Open			41	41	100	0
Urban			39	39	100	0

Table 9. Percent of stream length with toxicity to survival and reproduction. n = number of sites. SE = standard error. Number in parentheses are the number of samples indicating toxicity; because samples had unequal weights, the percent of toxic samples may be different from the percent of toxic stream length.

	n	% stream length with reproductive toxicity	SE	% stream length with survival toxicity	SE
Region	111	51 (43)	6	3 (6)	1
Agricultural	21	37 (9)	11	9 (2)	7
Open	44	63 (21)	7	2 (1)	2
Urban	46	41 (13)	11	2 (3)	1

Table 10. Relative risks to chronic and acute toxicity from water chemistry constituents. SE: Standard error. RR: Relative risk estimate. LC95: Lower 95% confidence bound on relative risk. UC95: Upper 95% confidence bound on relative risk. Sources are summarized in Table 5.

Stressor	Extent of stressor (km)	SE	Relative risk RR	LC95	UC95
Reproduction					
Chloride	384	94	0.4	0.2	0.7
Copper	58	32	0.3	0.1	1.3
Nitrate+Nitrite-N	828	137	0.4	0.3	0.5
Selenium	222	38	1.2	0.9	1.7
Sulfate	623	105	0.8	0.6	1.0
Total N	1107	172	0.6	0.5	0.7
Total P	562	105	0.5	0.3	0.7
Survival					
Chloride	384	94	0.8	0.4	1.8
Nitrate+Nitrite-N	828	137	0.1	0.0	0.3
Selenium	222	38	1.2	0.9	1.7
Sulfate	623	105	1.4	0.7	2.6
Total N	1107	172	3.5	1.4	9.1
Total P	562	105	0.2	0.1	0.6

Table 11. Median, 25th percentile (Q1) and 75th percentile (Q3) of selected physical habitat metrics, by land use. n = number of samples used to calculate estimates. Zero values are shown by '—'. Metrics for which all estimates were zero are not shown. W1_Hall: Proximity-weighted human disturbance index (Stoddard et al. 2005). XFC_NAT: Natural instream habitat cover index (Stoddard et al. 2005).

Metric	n	Median	Q1	Q3
Channel morphology				
Slope	128	1.3	0.7	2.1
Agricultural	23	0.8	0.5	1.2
Open	50	2.0	1.6	5.2
Urban	55	1.2	0.4	1.4
Bank height (m)	136	0.6	0.5	1.0
Agricultural	23	0.5	0.4	0.7
Open	57	0.5	0.4	0.8
Urban	56	0.8	0.6	1.0
Bank width (m)	136	8.5	6.6	17.0
Agricultural	23	12.8	5.9	29.1
Open	57	7.7	5.6	11.6
Urban	56	10.0	7.4	18.0
Bank height:width ratio	136	15.3	9.4	22.9
Agricultural	23	26.8	16.4	50.3
Open	57	14.0	9.9	20.3
Urban	56	12.2	9.0	27.8
Max depth (cm)	136	19.2	9.4	28.6
Agricultural	23	18.4	9.9	20.8
Open	57	20.1	13.9	24.2
Urban	56	16.0	6.7	38.1
Wetted width (cm)	136	3.1	2.0	5.4
Agricultural	23	3.2	1.9	6.8
Open	57	3.0	2.1	4.8
Urban	56	3.1	1.8	5.9
Visual habitat characterizations				
Channel alteration	135	14.8	6.1	18.7
Agricultural	22	15.7	13.5	17.9
Open	56	17.9	15.8	19.3
Urban	57	6.6	0.4	12.9
Epifaunal substrate	135	10.6	4.4	14.6
Agricultural	22	9.5	2.0	12.2
Open	56	14.5	12.2	15.9
Urban	57	6.4	0.8	10.0
Sediment deposition	135	14.3	7.9	16.7
Agricultural	22	6.7	4.6	12.9
Open	56	14.8	11.7	16.6
Urban	57	11.5	7.1	18.0

Table 11. Continued

Metric	n	Median	Q1	Q3
Bank stability				
% Stable	136	89.9	17.9	97.4
Agricultural	23	71.5	10.1	96.0
Open	57	91.0	28.8	97.1
Urban	56	95.5	17.1	97.7
% Eroded or vulnerable	136	5.5	0.0	78.0
Agricultural	23	23.9	0.0	85.7
Open	57	4.4	0.0	66.6
Urban	56	0.0	0.0	80.7
Flow habitats				
% Fast water	136	33.7	9.9	75.9
Agricultural	23	47.7	10.6	65.9
Open	57	53.8	22.4	79.7
Urban	56	12.5	1.8	75.2
% Cascades or falls	136	0.0	0.0	0.6
Agricultural	23	0.0	0.0	0.0
Open	57	0.3	0.0	4.8
Urban	56	0.0	0.0	0.0
% Rapids	136	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	56	0.0	0.0	0.0
% Riffles	136	17.6	1.2	36.2
Agricultural	23	30.7	6.8	62.3
Open	57	24.6	10.8	36.7
Urban	56	4.5	0.0	23.1
% Runs	136	0.0	0.0	6.9
Agricultural	23	0.0	0.0	2.8
Open	57	0.0	0.0	19.3
Urban	56	0.0	0.0	5.5
% Glides	136	38.5	13.4	79.9
Agricultural	23	35.5	17.1	78.1
Open	57	34.7	9.9	69.7
Urban	56	62.2	14.8	96.6
% Pools	136	0.0	0.0	11.7
Agricultural	23	0.0	0.0	1.9
Open	57	2.3	0.0	14.4
Urban	56	0.0	0.0	11.0

Table 11. Continued

Metric	n	Median	Q1	Q3
Human influence				
W1_HALL	136	1.6	0.6	4.6
Agricultural	23	0.5	0.2	3.6
Open	57	0.7	0.0	1.6
Urban	56	5.2	2.6	7.4
Walls, riprap, or dams	136	0.0	0.0	0.1
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	56	0.0	0.0	2.9
Buildings	136	0.0	0.0	0.3
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	56	0.0	0.0	0.7
Pavement or cleared lot	136	0.0	0.0	0.2
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	56	0.0	0.0	0.6
Roads or railroads	136	0.0	0.0	0.9
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.6
Urban	56	0.9	0.0	1.3
Pipes	136	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	56	0.0	0.0	0.5
Landfill or trash	136	0.6	0.0	1.9
Agricultural	23	0.3	0.0	0.6
Open	57	0.1	0.0	1.3
Urban	56	1.6	0.5	3.0
Row crop	136	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.5
Open	57	0.0	0.0	0.0
Urban	56	0.0	0.0	0.0

Table 11. Continued

Metric	n	Median	Q1	Q3
Instream habitat complexity				
All instream habitat	136	9.5	4.2	13.0
Agricultural	23	7.7	3.0	14.2
Open	57	11.1	7.2	13.2
Urban	56	7.2	2.6	13.0
XFC_NAT	136	9.1	2.8	15.1
Agricultural	23	3.9	2.0	13.3
Open	57	13.3	9.2	16.8
Urban	56	4.2	0.3	8.9
Large instream habitat	136	6.2	0.9	13.9
Agricultural	23	0.8	0.0	2.8
Open	57	13.2	4.7	18.4
Urban	56	3.2	0.5	8.1
Filamentous algae	136	6.3	1.2	25.2
Agricultural	23	21.3	10.3	31.1
Open	57	4.8	0.5	22.1
Urban	56	11.6	1.9	28.4
Aquatic macrophytes	136	4.0	0.0	12.2
Agricultural	23	10.6	4.4	31.2
Open	57	5.5	2.3	12.2
Urban	56	0.0	0.0	6.6
Boulders	136	6.5	0.0	39.0
Agricultural	23	0.0	0.0	3.5
Open	57	39.0	8.4	53.5
Urban	56	0.0	0.0	8.1
Large woody debris	136	1.5	0.0	6.5
Agricultural	23	0.2	0.0	3.9
Open	57	1.8	0.0	6.3
Urban	56	1.5	0.0	8.2
Small woody debris	136	2.0	0.0	8.2
Agricultural	23	0.5	0.0	9.9
Open	57	4.6	0.2	12.1
Urban	56	0.1	0.0	6.1
Undercut banks	136	0.8	0.0	4.6
Agricultural	23	1.1	0.0	4.7
Open	57	1.7	0.0	4.7
Urban	56	0.0	0.0	1.4

Table 11. Continued

Metric	n	Median	Q1	Q3
Instream habitat complexity (Continued)				
Overhanging vegetation	136	8.5	2.0	24.6
Agricultural	23	10.4	4.6	31.4
Open	57	10.6	5.0	21.8
Urban	56	2.4	0.0	27.5
Live tree roots	136	2.2	0.0	6.1
Agricultural	23	0.8	0.0	12.7
Open	57	2.6	0.1	5.2
Urban	56	0.3	0.0	6.2
Artificial substrate	136	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	56	0.0	0.0	1.5
Productivity				
% Macroalgae cover	115	18.2	4.7	45.4
Agricultural	22	28.5	5.2	45.9
Open	47	17.7	4.3	23.2
Urban	46	25.9	4.9	47.6
% Macrophyte cover	115	2.6	0.0	12.9
Agricultural	22	6.6	3.0	22.2
Open	47	4.6	0.2	13.8
Urban	46	0.9	0.0	12.6
Average microalgae thickness	113	0.6	0.1	1.0
Agricultural	22	1.0	0.1	1.4
Open	47	0.6	0.3	0.9
Urban	44	0.4	0.0	1.0
% Microalgae cover	113	36.0	9.8	80.6
Agricultural	22	53.6	5.0	84.2
Open	47	35.9	26.6	69.7
Urban	44	34.3	1.0	81.9
% Visible microalgae cover	113	13.7	0.0	29.9
Agricultural	22	23.5	0.0	51.2
Open	47	14.1	1.9	28.5
Urban	44	8.4	0.0	19.7
Shading				
% Shading	134	49.6	10.6	87.6
Agricultural	23	23.0	0.4	67.8
Open	55	54.6	36.3	92.5
Urban	56	35.1	1.3	85.2

Table 11. Continued

Metric	n	Median	Q1	Q3
Riparian vegetation				
Average number of vegetated layers	136	2.3	1.4	2.8
Agricultural	23	2.5	1.0	2.7
Open	57	2.4	2.1	2.8
Urban	56	1.7	0.2	2.8
Average upper canopy vegetation	136	12.1	1.2	28.2
Agricultural	23	20.4	0.0	37.9
Open	57	17.2	7.9	34.0
Urban	56	4.3	0.0	28.1
Average lower canopy vegetation	136	23.6	6.1	38.9
Agricultural	23	24.9	5.1	48.7
Open	57	26.1	16.3	39.0
Urban	56	7.8	0.4	30.9
Average ground woody vegetation	136	14.2	4.9	26.3
Agricultural	23	15.5	2.9	18.4
Open	57	20.8	12.8	30.7
Urban	56	5.6	1.0	18.5
Average ground herbaceous vegetation	136	12.0	5.7	26.6
Agricultural	23	10.8	6.0	35.4
Open	57	17.3	11.9	37.8
Urban	56	5.8	4.2	11.9
% with 3 vegetated layers	136	40.7	0.0	77.8
Agricultural	23	55.9	0.0	67.5
Open	57	46.2	36.8	77.6
Urban	56	2.0	0.0	80.5
% with > moderate ground vegetation	136	55.4	7.6	92.8
Agricultural	23	67.7	47.9	94.3
Open	57	72.7	49.2	96.0
Urban	56	7.8	0.0	88.5
% with upper canopy vegetation	136	80.0	17.8	95.6
Agricultural	23	92.3	0.0	97.2
Open	57	85.6	60.3	96.1
Urban	56	55.9	0.0	91.0
Substrate measurements				
% CPOM cover	136	29.4	15.4	55.8
Agricultural	23	36.5	13.2	52.2
Open	57	29.1	24.6	46.2
Urban	56	29.5	4.9	56.0

Table 11. Continued

Metric	n	Median	Q1	Q3
Substrate measurements (Continued)				
% Embeddedness	104	36.2	24.9	43.2
Agricultural	14	31.8	24.0	42.4
Open	56	36.2	29.7	45.1
Urban	34	37.4	4.6	43.1
Median particle size	127	7.1	0.5	48.7
Agricultural	21	0.7	0.3	7.8
Open	56	39.9	7.5	56.1
Urban	50	0.6	0.3	1.0
% Large substrates (>1 m or bedrock)	137	1.9	0.0	18.9
Agricultural	23	0.0	0.0	6.0
Open	57	4.9	1.0	10.1
Urban	57	0.0	0.0	85.5
% Sands and fines	137	34.4	11.4	62.8
Agricultural	23	62.8	38.3	82.9
Open	57	29.8	13.4	41.3
Urban	57	37.7	9.4	78.8
% Fine gravel	137	7.6	1.1	14.9
Agricultural	23	7.1	1.5	18.2
Open	57	11.8	6.7	21.4
Urban	57	1.3	0.0	9.7
% Coarse gravel	137	6.8	1.0	14.1
Agricultural	23	4.8	2.1	9.3
Open	57	12.3	6.6	16.3
Urban	57	1.4	0.0	7.2
% Cobbles	137	5.9	0.0	17.4
Agricultural	23	0.8	0.0	5.7
Open	57	14.9	7.4	22.3
Urban	57	1.0	0.0	3.8
% Small boulders	137	1.7	0.0	12.9
Agricultural	23	0.0	0.0	0.6
Open	57	12.1	2.6	18.6
Urban	57	0.0	0.0	1.5
% Large boulders	137	0.0	0.0	1.6
Agricultural	23	0.0	0.0	0.0
Open	57	1.3	0.0	5.3
Urban	57	0.0	0.0	0.0

Table 11. Continued

Metric	n	Median	Q1	Q3
Substrate measurements (Continued)				
% Rough bedrock	137	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	57	0.0	0.0	0.0
% Smooth bedrock	137	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	57	0.0	0.0	0.0
% Concrete substrate	137	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	57	0.0	0.0	85.5
% Wood substrate	137	0.0	0.0	0.8
Agricultural	23	0.0	0.0	0.0
Open	57	0.5	0.0	2.5
Urban	57	0.0	0.0	0.0
% Hardpan	137	0.0	0.0	0.0
Agricultural	23	0.0	0.0	0.0
Open	57	0.0	0.0	0.0
Urban	57	0.0	0.0	0.0
% Other substrate	137	0.0	0.0	1.9
Agricultural	23	0.0	0.0	5.0
Open	57	0.0	0.0	1.8
Urban	57	0.0	0.0	1.8

Table 12. Estimated extent of streams with IBI scores within 2 standard deviations of reference (i.e., 39, Ode et al., 2005). n = number of samples (≥450 individuals). SE = standard error. Number in parentheses are the number of samples in reference condition; because samples had unequal weights, the percent of reference condition samples may be different from the percent of reference condition stream length.

Land use	n	# Samples in reference condition	% Stream length in reference condition	SE
Entire region	109	47	47 (47)	6
Agricultural	21	6	35 (6)	11
Open	46	38	90 (38)	4
Urban	42	3	2 (3)	1

Table 13. Relative risks to IBI scores from chemistry and toxicity. SE: Standard error. RR: Relative risk estimate. LC95: Lower 95% confidence bound on relative risk. UC95: Upper 95% confidence bound on relative risk. Sources of chemistry thresholds are summarized in Table 5. Thresholds for toxicity are based on statistical difference from controls using TST (for reproduction) or t-tests (for survival). Thresholds for the IBI are provided by Ode at al. 2005. Single asterisk (*) denotes stressors that were always below thresholds, preventing calculations of relative risks. Double asterisks (**) denotes calculations that were based on 5 or fewer samples in a single cell.

	Stressor	Extent of stressor (km)	SE	RR	Relative risk LC95	UC95
Water chemistry						
Conventional						
	Alkalinity	0	0	*	*	*
**	Chloride	373	96	2.5	2.1	3.0
	Sulfate	612	111	2.1	1.6	2.6
Metals						
	Arsenic	0	0	*	*	*
**	Cadmium	3	3	1.8	1.6	1.9
	Chromium	0	0	*	*	*
**	Copper	58	32	1.5	1.1	1.9
**	Nickel	16	9	0.8	0.3	2.7
	Lead	0	0	*	*	*
	Selenium	222	40	1.4	1.2	1.7
	Zinc	0	0	*	*	*
Nutrients						
**	Ammonia	6	5	1.8	1.6	1.9
	Nitrate+Nitrite	830	147	1.7	1.4	2.0
	Total N	1099	177	2.2	1.7	2.8
	Total P	553	107	4.0	2.9	5.4
Pyrethroids						
**	Bifenthrin	231	105	2.0	1.8	2.3
**	Cyfluthrin	56	33	1.3	0.9	1.9
**	Cyhalothrin-L	37	13	1.1	0.6	2.0
	Cypermethrin	0	0	*	*	*
	Esfenvalerate/Fenvalerate	0	0	*	*	*
	Permethrin	0	0	*	*	*
Toxicity						
	Reproduction	796	147	0.6	0.5	0.7
**	Survival	172	66	0.5	0.3	0.8

Table 14. Relative and attributable risks for IBI scores from physical habitat and biological stressors. SE: Standard error. RR: Relative risk estimate. LC95: Lower 95% confidence bound on relative risk. UC95: Upper 95% confidence bound on relative risk. Threshold for IBI scores were from Ode et al. (2005). Sources: BPJ: Best professional judgment. SOP: Thresholds established in the standard operating protocol (Ode et al. 2007). M: Survey median. Double asterisks (**) denotes calculations that were based on 5 or fewer samples in a single cell.

	Stressor	Threshold	Source	Extent of stressor (km)	Relative risk			
					SE	RR	LC95	UC95
	Physical habitat							
	Bank stability							
	% Eroded or vulnerable banks	25	BPJ	577	156	1.4	1.1	1.6
	Visual habitat characterizations							
	Channel alteration	15	SOP	991	176	3.5	2.6	4.7
**	Epifaunal substrate	15	SOP	1392	185	8.4	4.0	17.8
	Sediment deposition	15	SOP	1057	154	1.3	1.0	1.6
	Human influence							
	W1_Hall	1.6	M	910	170	3.1	2.4	4.1
**	Bridges or abutments	0	BPJ	232	96	1.4	1.1	1.7
	Buildings	0	BPJ	532	115	1.5	1.2	1.8
**	Row crops	0	BPJ	83	26	1.6	1.2	2.0
**	Parks or lawns	0	BPJ	173	37	1.6	1.3	1.9
**	Pasture	0	BPJ	25	14	1.8	1.7	2.0
**	Pavement or cleared lot	0	BPJ	515	139	2.0	1.7	2.3
**	Pipes	0	BPJ	350	98	2.2	1.9	2.5
	Roads	0	BPJ	860	172	2.0	1.6	2.5
	Trash or landfill	0	BPJ	1321	190	2.2	1.6	3.2
**	Vegetation management	0	BPJ	184	90	1.9	1.7	2.2
**	Walls, riprap, or dams	0	BPJ	583	138	2.3	1.9	2.7
	Instream habitat complexity							
	All habitat cover	9.5	M	766	150	1.6	1.3	2.0
	All natural habitat cover	10.1	M	760	149	1.8	1.5	2.2
	XFC_NAT	9.1	M	792	140	3.0	2.4	3.8
	Large habitat cover	6.2	M	686	109	2.1	1.7	2.6
	Filamentous algae	6.3	M	808	171	0.7	0.5	0.8
**	Artificial	0	BPJ	455	106	1.8	1.5	2.1
	Boulder	6.5	M	830	137	2.8	2.2	3.5
	Large woody debris	0	BPJ	476	76	1.1	0.9	1.3
	Small woody debris	2	M	830	150	1.6	1.3	2.0
	Macrophyte	4	M	704	175	2.0	1.6	2.4
	Overhanging vegetation	8.5	M	837	160	1.3	1.0	1.5
	Live tree roots	2.2	M	719	116	1.3	1.1	1.6
	Undercut banks	0.8	M	741	109	1.4	1.1	1.6

Table 14. Continued

Stressor	Threshold	Source	Extent of stressor (km)	SE	Relative risk RR	LC95	UC95
Physical habitat (Continued)							
Productivity							
% Macroalgae cover	18	M	883	113	1.3	1.1	1.6
% Macrophyte cover	2.6	M	907	89	0.7	0.6	0.8
Microalgae thickness	0.6	M	892	133	0.9	0.7	1.1
% Microalgae cover	36	M	954	138	0.8	0.6	0.9
% Visible microalgae cover	14	M	884	136	0.7	0.6	0.9
Riparian vegetation							
Number of layers	2	BPJ	706	143	2.3	1.9	2.8
% of reach with 3 layers	41	M	751	142	2.3	1.9	2.8
% of reach with >moderate ground cover	25	BPJ	743	150	2.1	1.7	2.5
% of reach with upper canopy	25	BPJ	538	107	1.6	1.4	1.9
Shading							
Canopy cover	50	M	802	118	1.3	1.0	1.5
Substrate							
Embeddedness	36	M	528	123	1.7	1.2	2.5
% Sands and fines	34	M	901	150	4.3	2.7	6.7
Biology							
Invasive species							
** Any invasive species	0	BPJ	332	101	1.7	1.4	2.0
** *Corbicula* sp.	0	BPJ	270	99	1.5	1.3	1.8
** *Melanoides tuberculata*	0	BPJ	6	5	1.8	1.6	2.0
** *Potamopyrgus antipodarum*	0	BPJ	50	16	1.8	1.7	2.0
** *Procambarus clarkii*	0	BPJ	37	21	1.8	1.6	2.0

Table 15. Relative risks for IBI scores from GIS-based metrics SE: Standard error. RR: Relative risk estimate. LC95: Lower 95% confidence bound on relative risk. UC95: Upper 95% confidence bound on relative risk. Sources: BPJ: Best professional judgment. M: Survey median. Double asterisks (**) denotes calculations that were based on 5 or fewer samples in a single cell.

	Stressor	Scale	Threshold	Source	Extent of stressor (km)	SE	Relative risk RR	LC95	UC95
	Landcover								
	% Developed	ws	13.5%	M	904	137	4.2	3.1	5.6
		5k	21.5%	M	902	135	4.6	3.4	6.2
	% Impervious	ws	1.4%	M	900	136	4.4	3.3	6.0
		5k	2.6%	M	903	136	4.8	3.5	6.5
**		1k	2.9%	M	933	162	7.9	5.3	11.9
	% Agricultural	ws	0%	BPJ	948	124	1.4	1.1	1.7
		5k	0%	BPJ	595	110	1.6	1.3	1.9
		1k	0%	BPJ	397	105	1.4	1.2	1.7
	% Urban	ws	2.4%	M	900	136	4.6	3.4	6.3
		5k	2.5%	M	903	136	4.8	3.5	6.5
		1k	4.2%	M	951	162	8.4	5.5	12.9
	Transportation								
	Paved road density	ws	2.0 km/km^2	M	926	138	3.7	2.8	4.9
		5k	2.5 km/km^2	M	901	135	4.5	3.3	6.0
		1k	2.6 km/km^2	M	934	163	5.0	3.6	7.0
	Census								
	Population density	ws	100/km^2	M	904	136	4.6	3.4	6.2
		5k	58/km^2	M	915	140	3.8	2.9	5.1
		1k	86/km^2	M	912	166	4.4	3.3	6.0
	Housing density	ws	36/km^2	M	903	137	4.0	3.0	5.3
		5k	28/km^2	M	912	140	3.7	2.8	4.8
		1k	34/km^2	M	903	165	4.1	3.1	5.4
	Hydrology								
	Canals or pipes	ws	Present	BPJ	805	140	2.5	2.0	3.1
	Dams	ws	Present	BPJ	654	102	2.0	1.6	2.3
**	Distance to nearest dam	ws	5 km	BPJ	218	89	1.6	1.4	1.9
	Mining								
**	Mines	ws	Present	BPJ	1399	161	1.1	0.8	1.3
		5k	Present	BPJ	830	149	1.1	0.9	1.3
		1k	Present	BPJ	146	50	0.3	0.2	0.7
	Grazing								
	Grazing allotment	ws	Present	BPJ	339	42	0.6	0.5	0.9

Table 16. Spearman rank correlations (Rho) between water chemistry analytes and IBI scores. Single asterisks (*) denotes p values below 0.05, and double asterisks (**) denote p values below 0.001.

	IBI		
Analyte	**n**	**Rho**	**p**
Conventional analytes and field-based measurements			
Alkalinity	104	-0.04	
Chloride	104	-0.65	**
Dissolved oxygen	115	-0.09	
Hardness	109	-0.40	**
pH	114	0.02	
Silica	96	0.00	
Specific conductivity	111	-0.53	**
Sulfate	103	-0.46	**
TSS	96	-0.52	**
Turbidity	51	-0.38	*
Nutrients			
Ammonia	108	-0.45	**
Nitrate+Nitrite-N	109	-0.35	**
Orthophosphate	78	-0.39	**
Total N	109	-0.58	**
Total P	99	-0.54	**
Metals (dissolved)			
Arsenic	96	-0.44	**
Cadmium	85	-0.34	*
Chromium	96	0.13	
Copper	93	-0.40	**
Nickel	96	-0.11	
Lead	96	-0.27	*
Selenium	96	-0.16	
Zinc	96	-0.33	*
Pyrethroids			
Bifenthrin	96	-0.22	*
Cyfluthrin	96	0.03	
Cyhalothrin-lambda	96	-0.08	
Cypermethrin	96	-0.26	*
Esfenvalerate/Fenvalerate	96	-0.13	
Permethrin	96	-0.04	
Total pyrethroids	96	-0.24	*

Table 17. Spearman rank correlations (Rho) between physical habitat metrics and IBI scores. Single asterisks (*) denotes p values below 0.05, and double asterisks (**) denote p values below 0.001.

	IBI		
Metric	**n**	**Rho**	**p**
Channel and bank morphology			
% Eroded or vulnerable banks	116	-0.11	
Bank height	116	0.04	
Bank width	116	-0.17	
Bank width to height ratio	116	-0.16	
Slope	112	0.47	**
Max depth	116	-0.07	
% Zero depth	116	-0.10	
Wetted width	116	-0.17	
Visual habitat characterizations			
Channel alteration	115	0.62	**
Epifaunal substrate	115	0.64	**
Sediment deposition	115	0.15	
Human influence			
W1_Hall	116	-0.53	**
Bridges	116	0.00	
Buildings	116	-0.30	**
Row crops	116	-0.05	
Parks and lawns	116	-0.30	*
Pasture	116	-0.04	
Pavement or cleared lot	116	-0.35	**
Pipes	116	-0.35	**
Trash or landfill	116	-0.31	**
Vegetation management	116	-0.21	*
Walls, riprap, or dams	116	-0.42	**
Flow habitats			
% Fast water	116	0.16	
% Cascades/falls	116	0.39	**
% Glides	116	0.04	
% Pools	116	0.00	
% Rapids	116	0.25	*
% Riffles	116	0.26	*
% Runs	116	-0.05	
Instream habitat			
XFC_All	116	0.00	
XFC_NAT	116	0.35	**
Large habitat types	116	0.30	**
Filamentous algae	116	-0.19	*
Artificial substrate	116	-0.46	**
Boulders	116	0.60	**
Large woody debris	116	0.10	
Small woody debris	116	0.13	
Macrophytes	116	0.06	
Overhanging vegetation	116	0.07	
Live roots	116	0.02	
Undercut banks	116	0.04	
Shading			
Canopy cover	115	0.15	
Productivity			
% Macroalgae	114	-0.21	*
% Macrophytes	114	0.07	
Microalgae thickness	112	-0.01	
% Microalgae	112	-0.03	
% Visible microalgae	112	-0.02	

Table 18. Spearman rank correlations (Rho) between GIS metrics and IBI scores. Single asterisks (*) denotes p values below 0.05, and double asterisks (**) denote p values below 0.001.

Metric	Scale	n	IBI Rho	p
Location				
Watershed area	ws	117	-0.10	
Elevation	Point	117	0.65	**
Stream order	Point	117	0.01	
Climate				
Precipitation	Point	117	0.64	**
Temperature	Point	117	-0.15	
Geology				
% Sedimentary geology	ws	117	-0.22	*
% Volcanic geology	ws	117	-0.21	*
% Cenozoic geology	ws	117	-0.29	*
% Quarternary geology	ws	117	-0.06	
% CaO geology	ws	117	-0.06	
% MgO geology	ws	117	-0.01	
% N geology	ws	117	-0.60	**
% P geology	ws	117	0.30	*
% S geology	ws	117	-0.39	**
Landcover				
% Developed	1k	117	-0.72	**
% Developed	5k	117	-0.74	**
% Developed	ws	117	-0.69	**
% Impervious	1k	117	-0.76	**
% Impervious	5k	117	-0.78	**
% Impervious	ws	117	-0.72	**
% Agricultural	1k	117	-0.11	
% Agricultural	5k	117	-0.13	
% Agricultural	ws	117	-0.14	
% Urban	1k	117	-0.74	**
% Urban	5k	117	-0.78	**
% Urban	ws	117	-0.73	**
% Code 21	1k	117	-0.45	**
% Code 21	5k	117	-0.55	**

Metric	Scale	n	IBI Rho	p
Transportation				
Road density	1k	117	-0.68	**
Road density	5k	117	-0.72	**
Road density	ws	117	-0.66	**
Road crossing density	1k	117	-0.35	**
Road crossing density	5k	117	-0.64	**
Road crossing density	ws	117	-0.59	
Census				
Population density	1k	117	-0.66	**
Population density	5k	117	-0.70	**
Population density	ws	117	-0.71	**
Housing density	1k	117	-0.62	**
Housing density	5k	117	-0.67	**
Housing density	ws	117	-0.67	**
Grazing				
% alloted for grazing	ws	117	0.29	*
Hydrology				
Dam density	ws	117	-0.30	*
Dam storage	ws	117	-0.21	*
% Pipes or canals	1k	117	-0.11	
% Pipes or canals	5k	117	-0.26	*
% Pipes or canals	ws	117	-0.40	**
Mining				
Mine density	1k	117	0.13	
Mine density	5k	117	0.00	
Mine density	ws	117	0.04	
Gravel mine density	1k	117	0.05	
Gravel mine density	5k	117	-0.13	
Gravel mine density	ws	117	-0.40	**

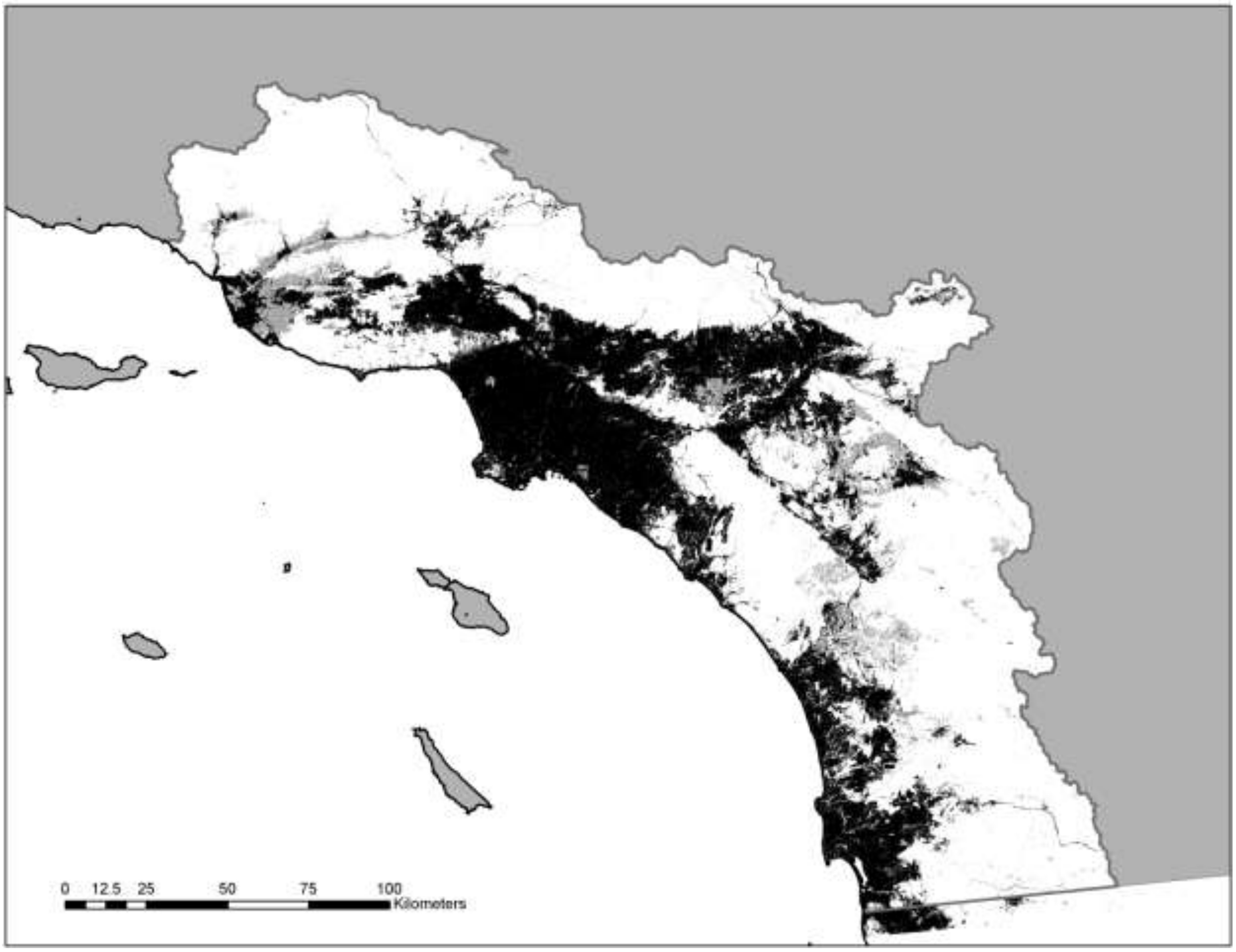

Figure 1. Major land uses in southern California. Urban land is shown as black; agricultural land is shown as gray; and open space is shown as white.

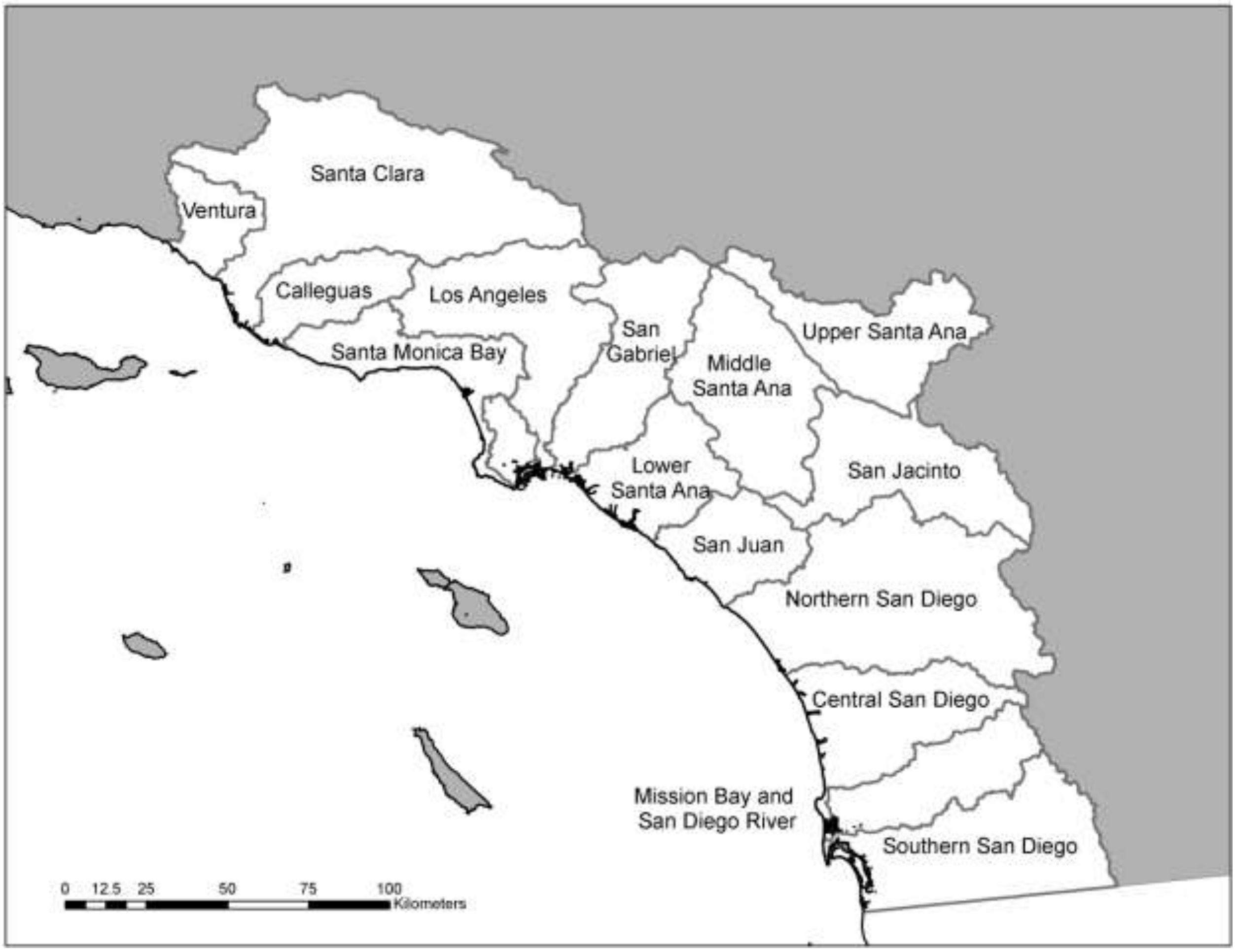

Figure 2. Major watersheds in the study area. The watershed of the Dominguez Channel, which is unlabeled, was excluded from the study.

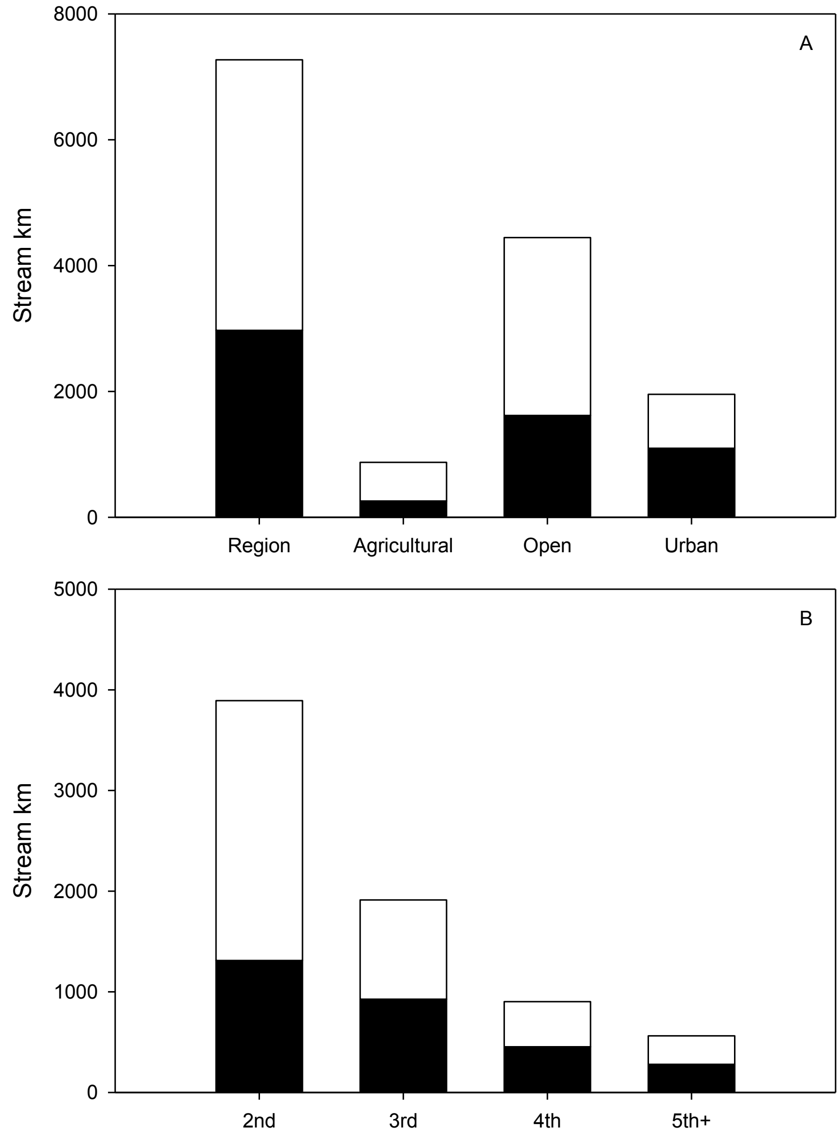

Figure 3. Extent of target and non-target stream in each class of land use (A) and stream order (b). Black portions of bars indicate target portions, and white portions indicate non-target portions. The distribution of target and non-target streams for the entire region is included in Panel A.

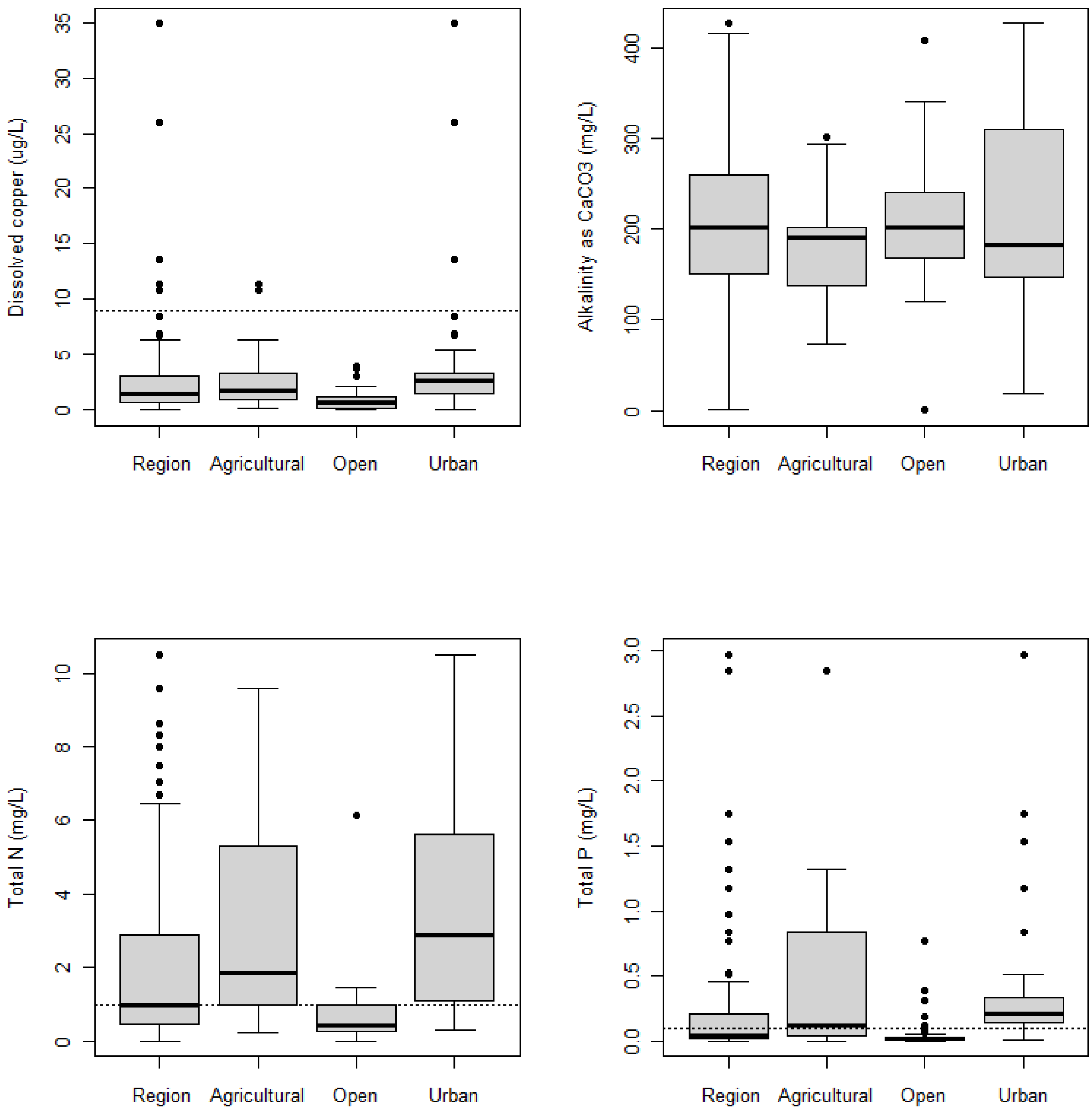

Figure 4. Distribution of dissolved copper, alkalinity, total N, and total P in streams across the region and by land use. Threshold concentration for a constituent are designated with a dashed line across the figure. Threshold for alkalinity is greater than the highest value in the study. Threshold values are provided in Table 5. All boxplots have been weighted to reflect unequal area weights associated with each sample (Willmott et al. 2007).

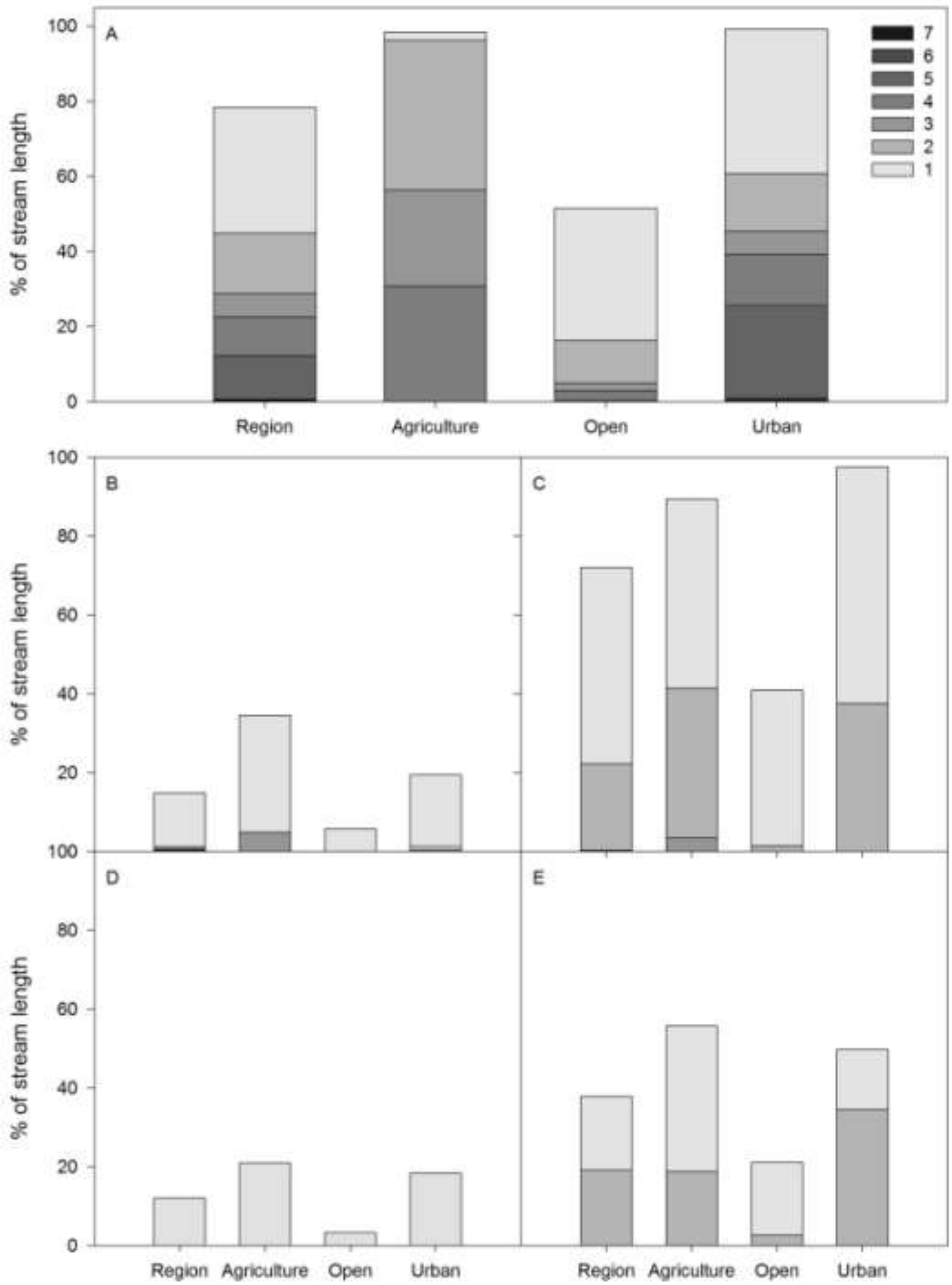

Figure 5. The extent of streams with chemical constituents in excess of biologically-based thresholds for all water chemistry analyses (22 analytes assessed; A); metals (8 analytes assessed; B); nutrients (4 analytes assessed; C); pyrethroids (6 analytes assessed:;D); and other analytes (3 analytes assessed; E). The color key shown in panel A applies to all panels.

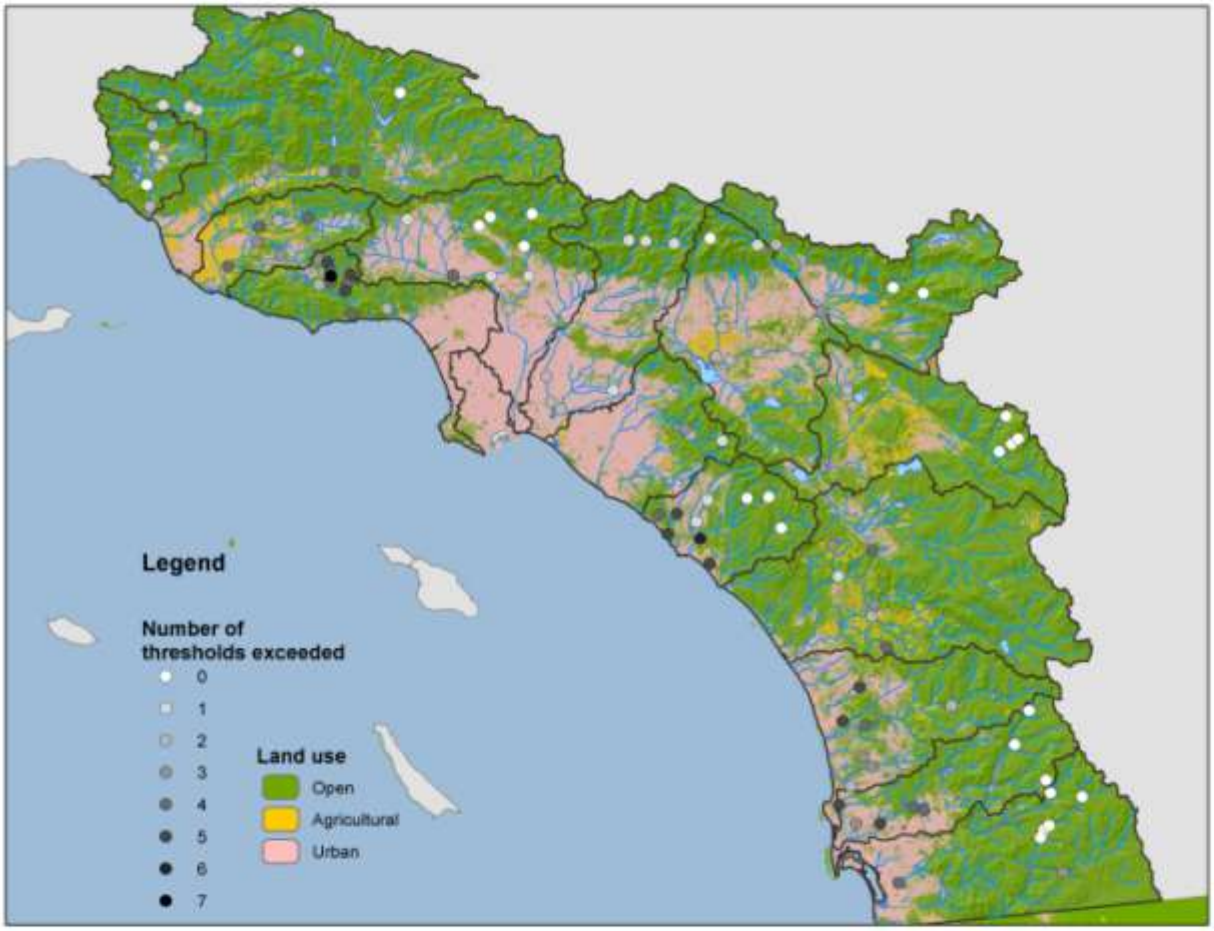

Figure 6. Spatial distribution of exceedances for water chemistry.

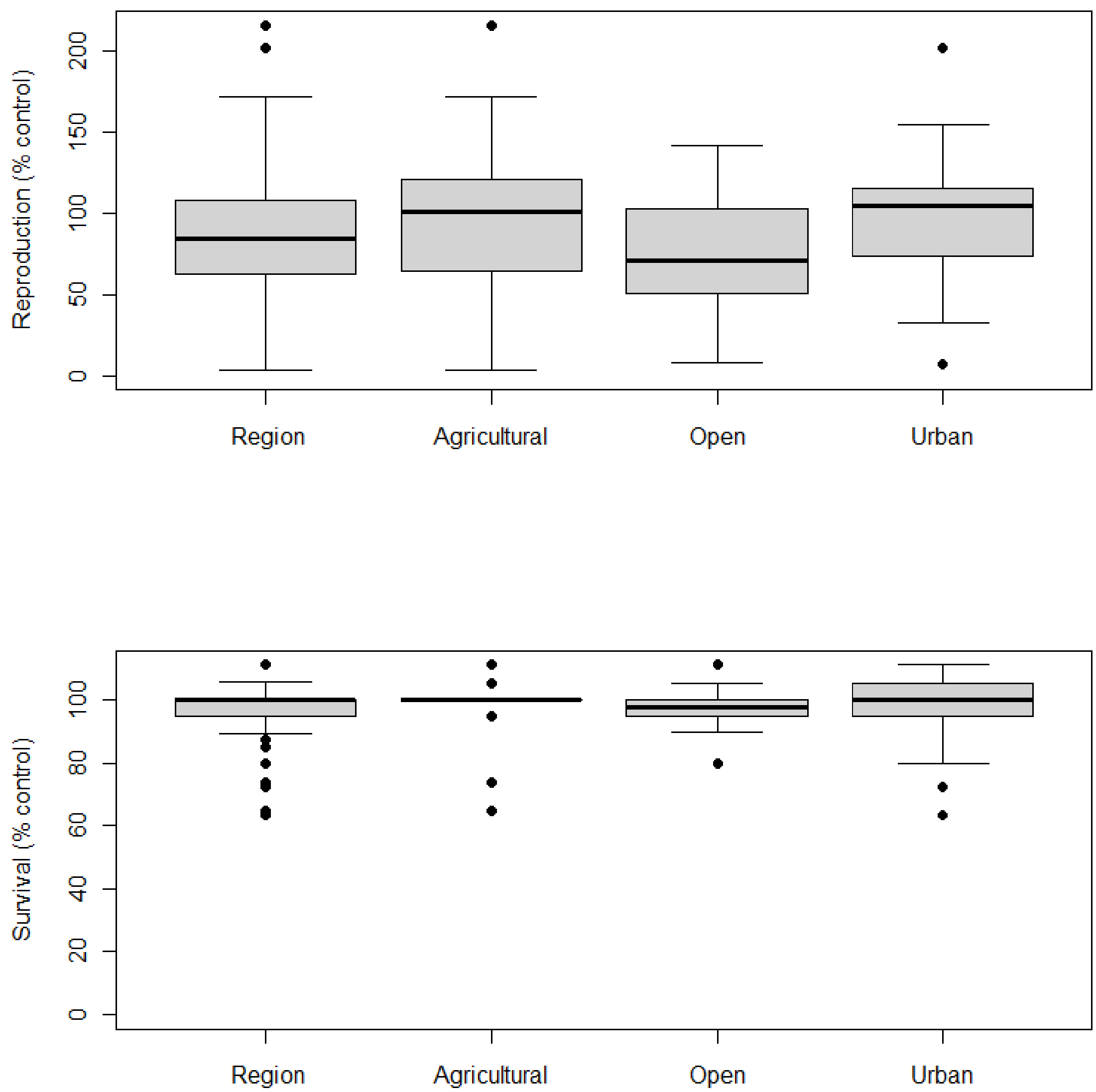

Figure 7. Distribution of control-normalized toxicity endpoints for reproduction and survival by land use.

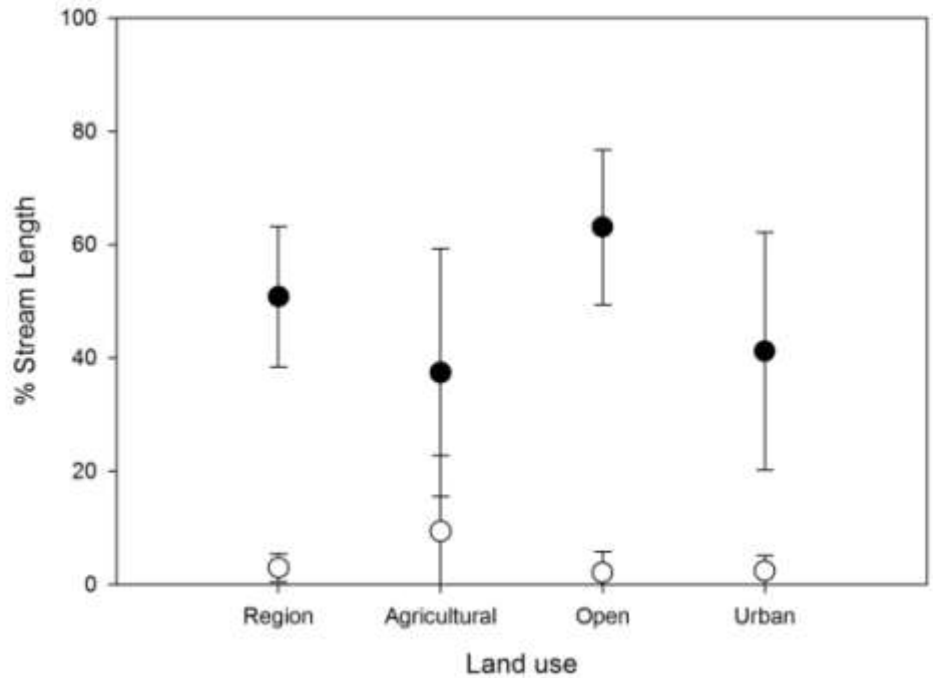

Figure 8. Extent of streams with toxicity to survival and reproductive endpoints, by land use. Black symbols indicate reproductive endpoints, and white symbols indicate survival endpoints. Error bars indicate the 95% confidence interval.

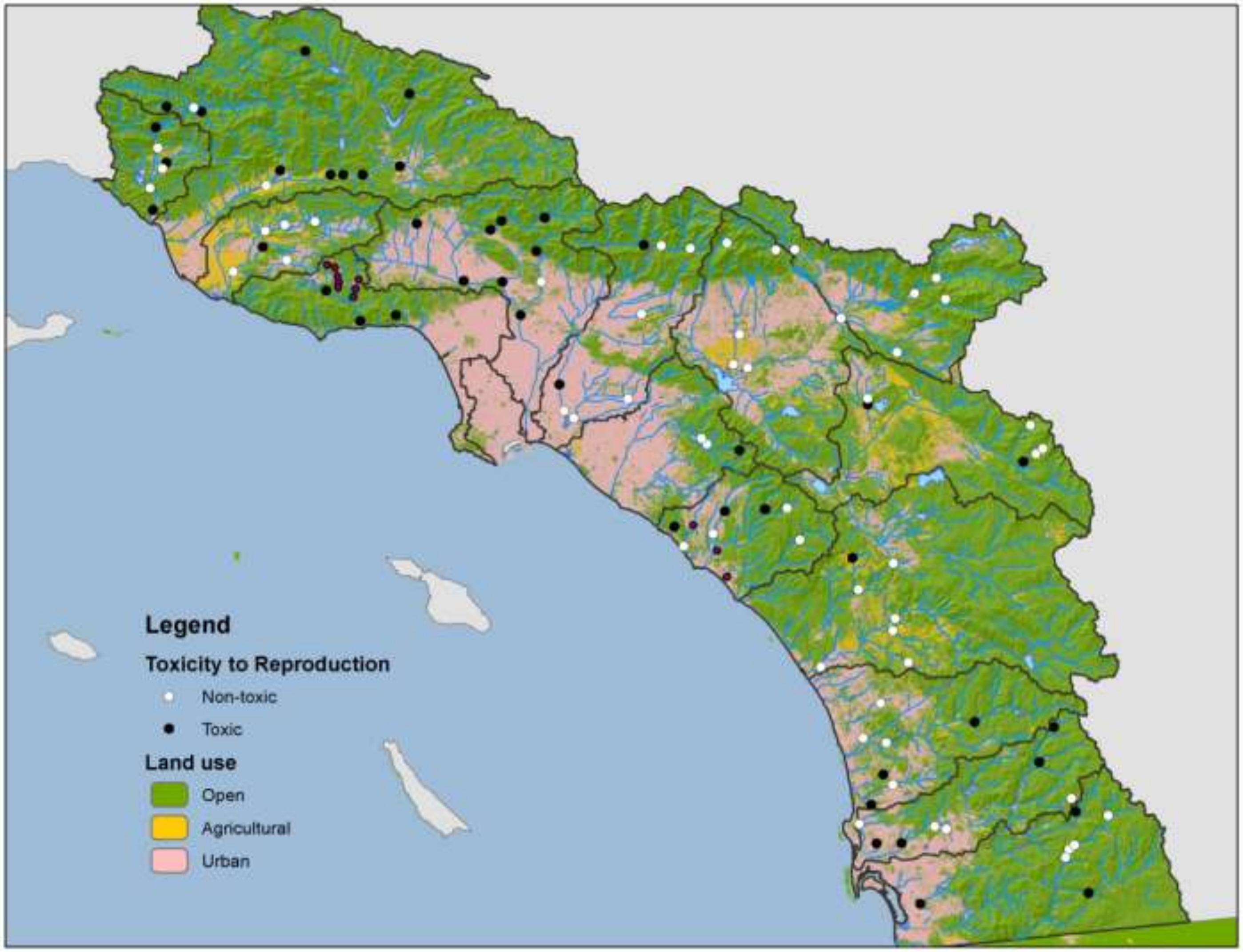

Figure 9. Spatial distribution of sites with chronic toxicity.

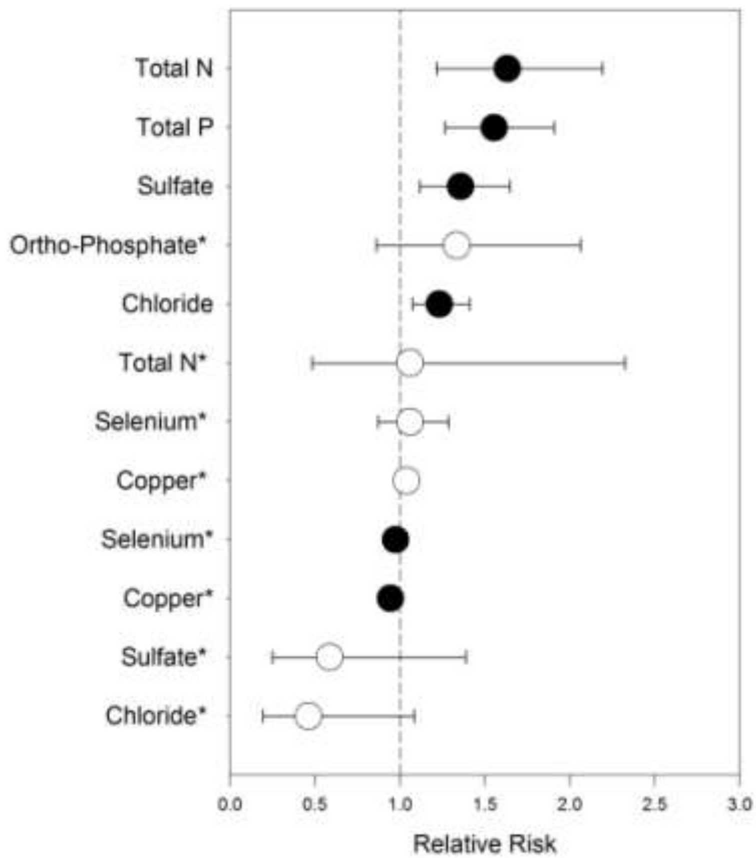

Figure 10. Relative risks to survival and reproductive toxic endpoints. Black symbols indicate reproductive endpoints, and white symbols indicate survival endpoints. Error bars indicate 95% confidence intervals. The dashed line indicates a relative risk of 1 (i.e., no increased risk from stressor). Asterisks indicate stressors that did not meet data distribution requirements for relative risk assessments.

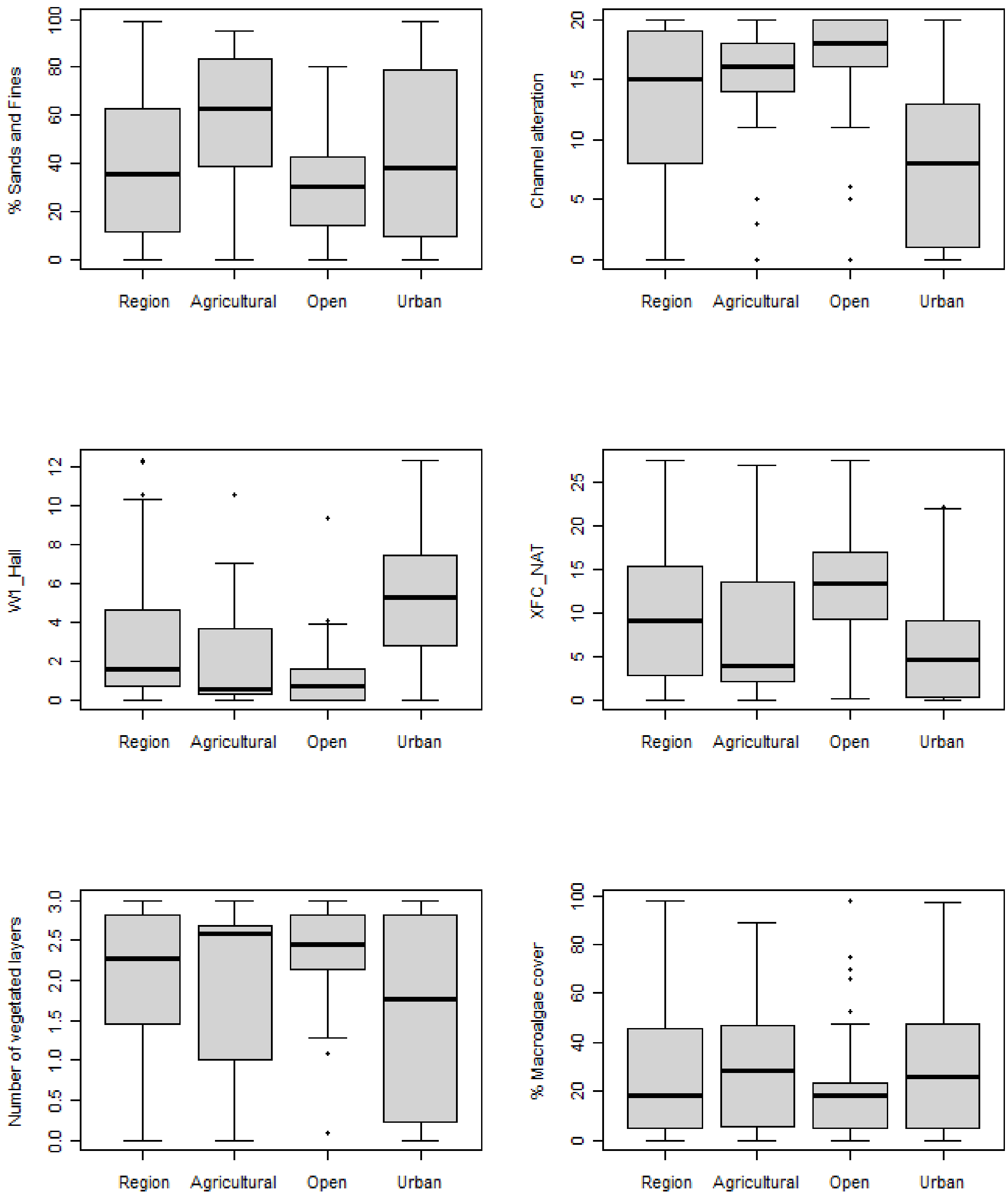

Figure 11. Distribution of % sands and fines, channel alteration, W1_Hall, XFC_NAT, average number of vegetation layers in the riparian zone, and % macroalgae cover, across the region and by land use. X-axes are identical for all panels in the figure.

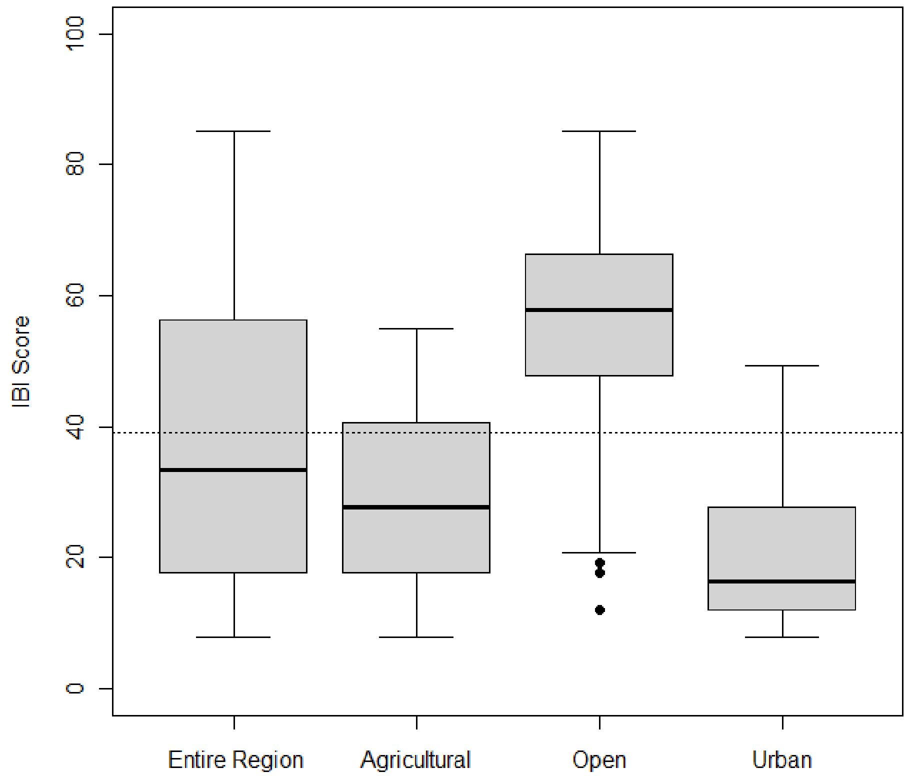

Figure 12. Distribution of IBI scores across the region and by land use. The dashed line indicates the threshold of impairment (Ode et al. 2005).

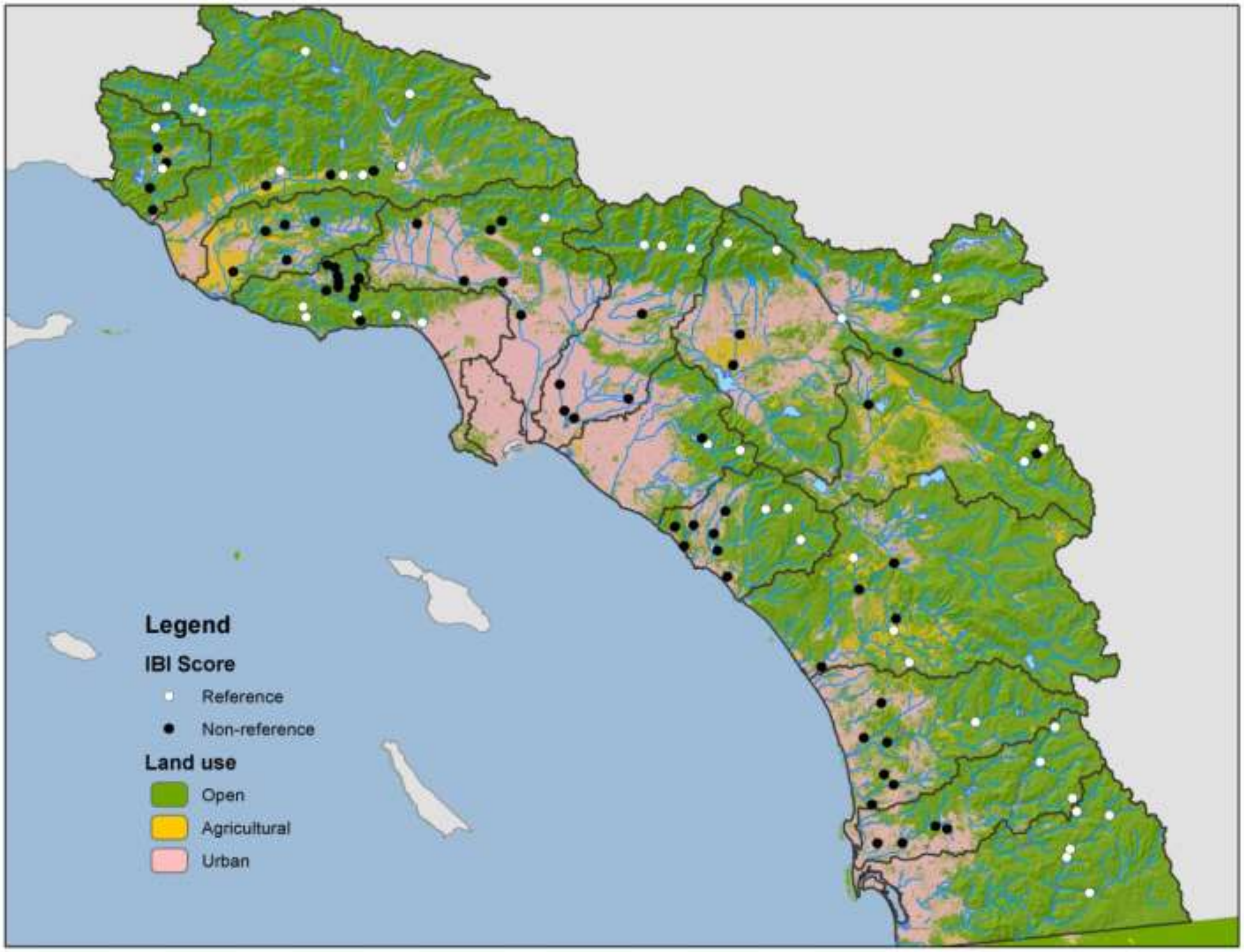

Figure 13. Distribution of IBI scores across the region.

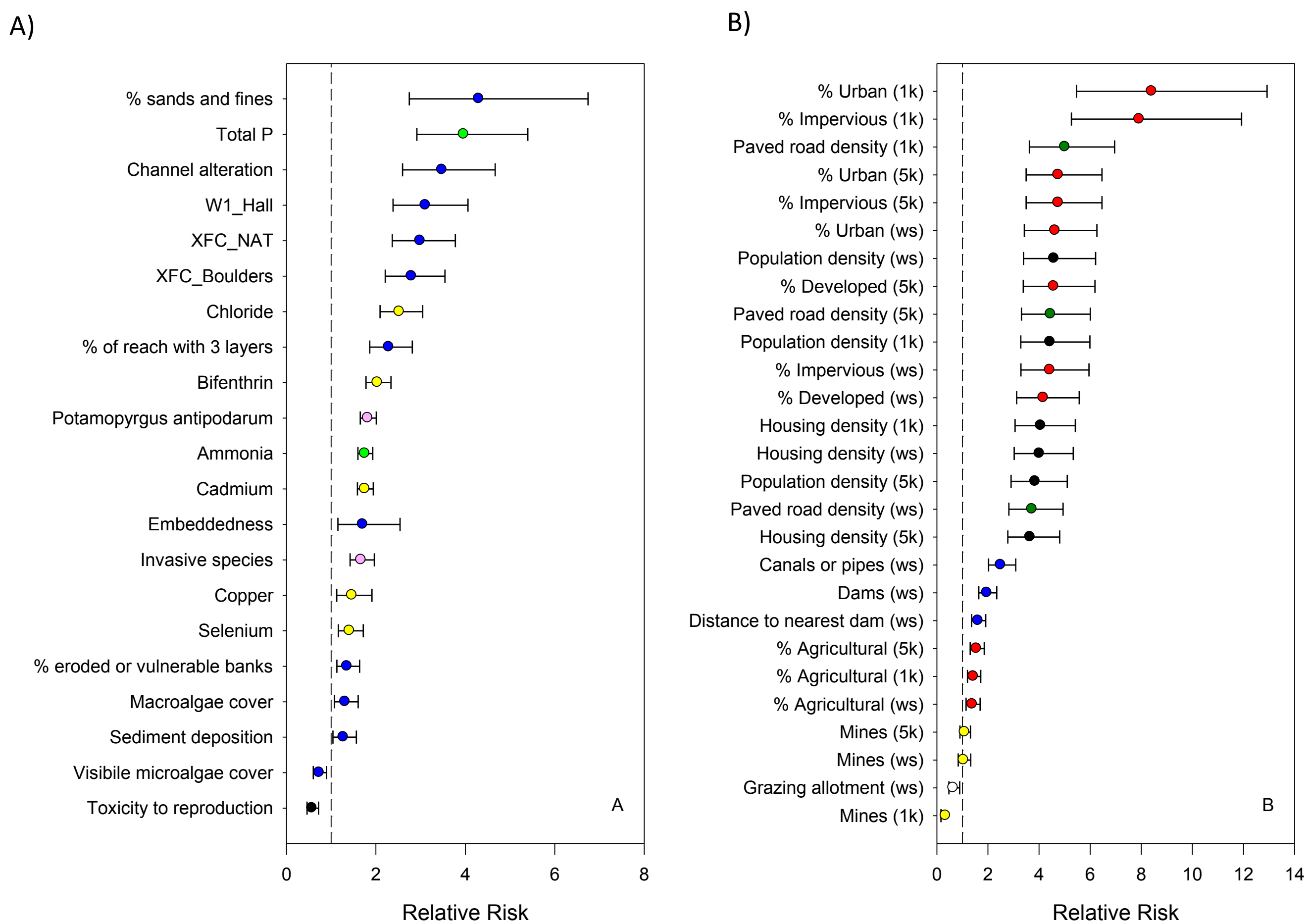

Figure 14. Relative risks of selected stressors for non-reference IBI scores (≤39). Physical habitat, water chemistry, and toxicity stressors (A). Blue symbols indicate stressors related to physical habitat. Green symbols indicate stressors related to nutrients. Yellow symbols indicate stressors related to water chemistry. Black symbols indicate stressors related to toxicity. Pink symbols indicate stressors related to biology. GIS stressors. Red symbols indicate metrics related to landcover. Green symbols indicate metrics related to transportation. Black symbols indicate metrics related to census data (B). Blue symbols indicate metrics related to hydrology. Yellow symbols indicate metrics related to mining. White symbols indicate metrics related to grazing. Error bars indicate 95% confidence intervals. The dashed line indicates a relative risk of 1 (i.e., no increased risk from stressor).

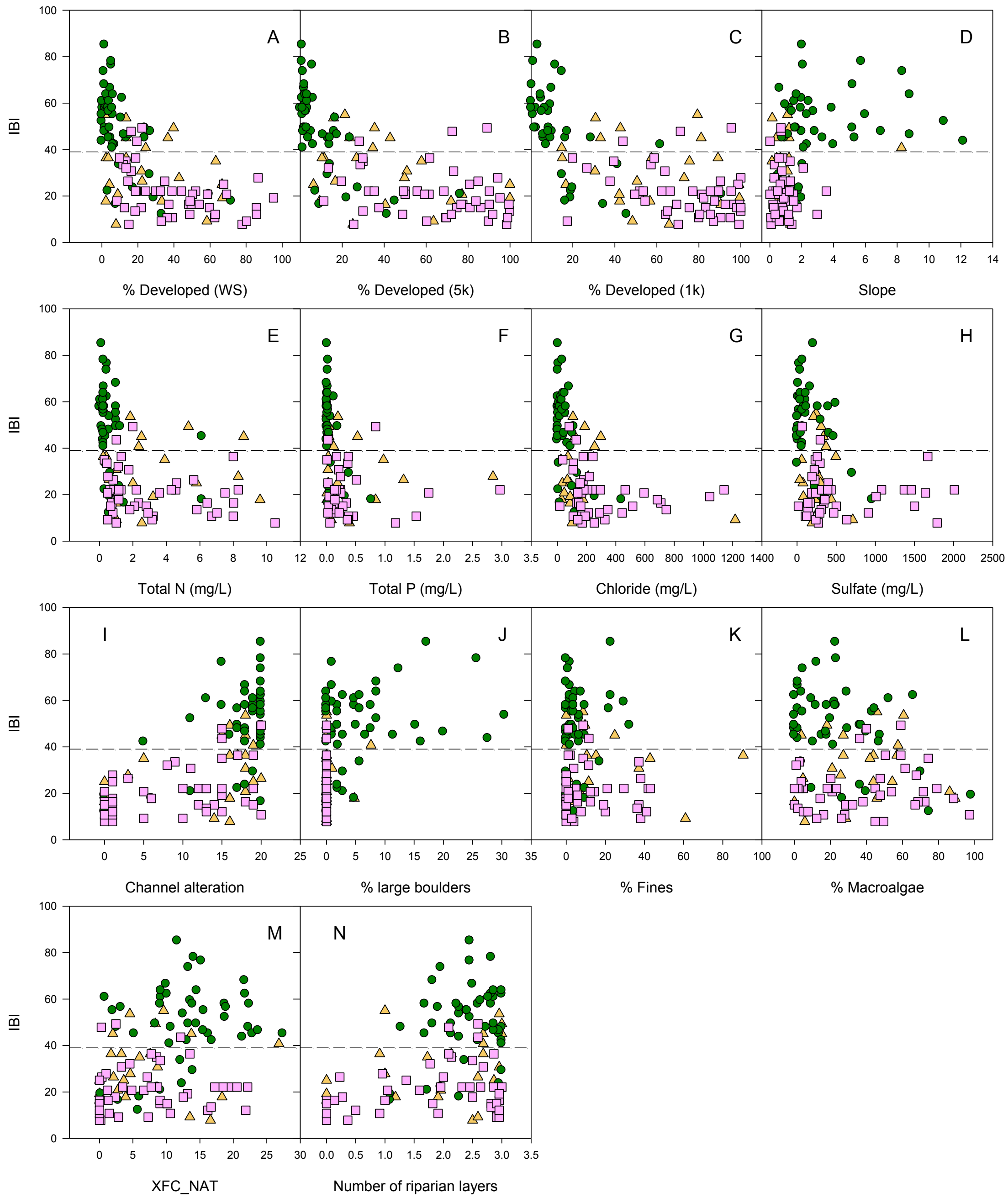

Figure 15. Scatterplots of IBI scores and selected environmental variables. In all plots, orange triangles represent agricultural sites, green circles represent open sites, and pink squares represent urban sites. The dashed line represents the threshold for non-reference.

Literature Cited

Barbour, M.T., J. M. Diamond and C. O. Yoder. 1996. Biological assessment strategies: Applications and Limitations. Pp 245-270 *in* D.R. Grothe, K. L. Dickson, and D.K. Reed-Judkins (editors). Whole Effluent Toxicity Testing: An evaluation of methods and prediction of receiving system impacts. SETAC Press. Pensacola, FL.

Bêche, L.A., E.P. McElravy and V.H. Resh. 2006. Long-term seasonal variation in biological traits of benthic-macroinvertebrates in two Mediterranean-climate streams in California, USA. *Freshwater Biology* 51:56-75.

Buchwalter, D.B., D.J. Cain, C.A. Martin, L. Xie, S.N. Luoma and T. Garland. 2008. Aquatic insect ecophysiological traits reveal phylogenetically based differences in dissolved cadmium susceptibility. *Proceedings of the National Academy of Sciences of the United States of America* 105:8321-8326.

Burnham, K.P. and D.R. Anderson. 2002. Model Selection and Multimodel Inference: A practical information-theoretic approach. 2nd edition. Springer. New York, NY.

California Department of Fish and Game. 2000. Hazard Assessment of the Synthetic Pyrethroid Insecticides Befenthrin, Cypermethrin, Esfenvalerate, and Permethrin to Aquatic Organisms in the Sacramento-San Joaquin River System. Office of Spill Prevention and Response Administrative Report 00-6 2000.

California Department of Forestry and Fire Protection. 2004. The California Interagency Watershed Map of 1999, version 2.2.1.

California Regional Water Control Board—San Diego Region. 2006. Basin Plan Amendment and Final Technical Report for Total Nitrogen and Total Phosphorus Total Maximum Daily Loads for Rainbow Creek. Resolution No. R9-2005-0036.

Codd, G.A., L.F. Morrison and J.S. Metcalf. 2005. Cyanobacterial toxins: Risk management for health protection. *Toxicology and Applied Pharmacology* 203:264-272.

Collins, J.N., E.D. Stein, M. Sutula, R. Clark, A.E. Fetscher, L. Grenier, C. Grosso and A. Wiskind. 2008. California Rapid Assessment Method (CRAM) for Wetlands and Riparian Areas. Version 5.0.2. 157 pp. Available from http://www.cramwetlands.org

Cuffney, T.F., R.A. Brightbill, J.T. May and I.R. Waite. 2010. Responses of benthic macroinvertebrates to environmental change associated with urbanization in nine metropolitan areas. *Ecological Applications* 20:1384-1401.

del Rosario, R.B., E.A. Betts and V.H. Resh. 2002. Cow manure in headwater streams: tracing aquatic insect responses to organic enrichment. *Journal of the North American Benthological Society* 21: 278-289.

Ellison, C.A., Q.D. Skinner and L.S. Hicks. 2009. Assessment of best-management practice effects on rangeland stream water quality using multivariate statistical techniques. *Rangeland Ecology and Management* 62:371-386.

Farag, A. M., J. N. Goldstein, D.F. Woodward and M. Samadpour. 2001. Water quality in three creeks in the backcountry of Grand Teton National Park, USA. *Freshwater Ecology* 16:135-143.

Fenn, M.E. and M.A. Poth. 1999. Temporal and spatial trends in streamwater nitrate concentrations in the San Bernardino Mountains, southern California. *Journal of Environmental Quality* 28:822-836.

Fenn, M.E., R. Haeuber, G.S. Tonnesen, J.S. Baron, S. Grossman-Clarke, D. Hope, D.A. Jaffe, S. Copeland, L. Geiser, H.M. Rueth and J.O. Sickman. 2003. Nitrogen emissions, deposition, and monitoring in the Western United States. *Biosciences* 53:391-403.

Fenn, M.E., S. Jovan, F. Yuan, L. Geiser, T. Meixner and B.S. Gimeno. 2008. Empirical and simulated critical loads for nitrogen deposition in California mixed conifer forests. *Environmental Pollution* 155:492-511.

Fetscher, A.F., L. Busse and P.R. Ode. 2009. Standard operating procedures for collecting stream algae samples and associated physical habitat and chemical data for ambient bioassessment in California. Surface Water Ambient Monitoring Program. Sacramento, CA. Available from http://swamp.mpsl.mlml.calstate.edu/wp-content/uploads/2009/11/SWAMP_SOP_Algae_Field_Collection_070109.pdf.

Fojut, T.L. and R.S. Tjeerdema. 2010. Water Quality Criteria Report for Lambda-cyhalothrin Phase III: Application of Pesticide Water Quality Criteria Methodology. Prepared for the Central Valley Regional Water Control Board.

Fojut, T.L., S. Chang and R.S. Tjeerdema. 2010. Water Quality Criteria Report for Cyfluthrin Phase III: Application of Pesticide Water Quality Criteria Methodology. Prepared for the Central Valley Regional Water Control Board.

Gibson, G.R., M.T. Barbour, J.B. Stribling, J. Gerritsen and J.R. Karr. 1996. Biological criteria: Technical guidance for streams and small rivers. Revised edition. US Environmental Protection Agency. Office of Water. Washington D.C. EPA 822-B-96-001.

Horvitz, D.G. and D.J. Thompson. 1952. A generalization of sampling without replacement from a finite universe. *Journal of the American Statistical Association* 47:663-685.

Hughes, R.M. 1995. Defining acceptable biological status by comparing with reference conditions. Pp. 31-47 *in* W.S. Davis and T. P. Simon (Editors). Biological assessment and criteria: Tools for water resource planning and decision making. Lewis Publishers. Ann Arbor, MI.

Izaguirrea, G., A.-D. Jungblut and B. A. Neilan. 2007 Benthic cyanobacteria (Oscillatoriaceae) that produce microsystin-LR, isolated from four reservoirs in southern California. *Water Research* 41:492-498.

Kincaid, T. and T. Olsen. 2009. SPSurvey package for R. Available from http://www,epa.gov/nheerl/arm

Koetsier, P., T.R.B. Krause and Q. M. Tuckett. 2010. Persistent effects of past wildfires on leaf litter breakdown in stream ecosystems. *Western North American Naturalist* 70:164-174.

Larsen, D.P., A.R. Olsen and D.L. Stevens. 2008. Using a master sample to integrate stream monitoring programs. *Journal of Agricultural, Biological, and Environmental Statistics* 13:243-254.

Lawrence, J.E., K.B. Lunde, R.D. Mazor, L.A. Bêche, E.P. McElravy and V.H. Resh. 2010. Long-term macroinvertebrate responses to climate change: Implications for biological assessment in Mediterranean-climate streams. *Journal of the North American Benthological Society* 29:1424-1440.

National Oceanic and Atmospheric Administration. 2001. Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. Technical Report NMFS 123. Department of Commerce. Available from http://www.csc.noaa.gov/crs/lca/pdf/protocol.pdf.

Mazor, R.D., T.B. Reynoldson, D.M. Rosenberg and V.H. Resh. 2006. Effects of biotic assemblage, classification, and assessment method on bioassessment performance. *Canadian Journal of Fisheries and Aquatic Sciences* 63:394-411.

Mazor, R.D., A.H. Purcell and V.H. Resh. 2009. Long-term variability in bioassessments: A twenty-year study from two northern California streams. *Environmental Management* 43:1269-1286.

Mazor, R.D., K. Schiff, K. Ritter, A. Rehn and P. Ode. 2010. Bioassessment tools in novel habitats: an evaluation of indices and sampling methods in low-gradient streams in California. *Environmental Monitoring and Assessment* 167:91-104.

Morais, M. P. Pinto, P. Guilherme, J. Rosado and I. Atunes. 2004. Assessment of temporary streams: The robustness of metric and multimetric indices under different hydrological conditions. *Hydrobiologia* 516:229-249.

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

Ode, P.R. 2007. Standard operating procedures for collecting benthic macroinvertebrate samples and associated physical and chemical data for ambient bioassessment in California. Surface Water Ambient Monitoring Program. Sacramento, CA. Available from http://mpsl.mlml.calstate.edu/phab_sopr6.pdf

Palumbo, A. J., T.L. Fojut, S.M. Brander and R.S. Tjeerdema. 2010. Water Quality Criteria Report for Bifenthrin Phase III: Application of Pesticide Water Quality Criteria Methodology. Prepared for the Central Valley Regional Water Control Board.

Peck, D.V., A.T. Herlihy, B.H. Hill, R.M. Hughes, P.R. Kaufmann, D.J. Klemm, J.M. Lazorchek, F.H. McCormick, S.A. Peterson, S.A. Ringold, T. Magee and M. Cappaert. 2006. Environmental Monitoring and Assessment Program—Surface Waters Western Pilot Study: field operations manual for wadeable streams. EPA/620/R-06/003. Office of Research and Development. US Environmental Protection Agnecy. Corvallis, Oregon.

The R Foundation for Statistical Computing. 2010. R. Version 2.11.1. Available from http://www.r-project.org/

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

Reynoldson, T.B., R. H. Norris, V. H. Resh, K. E. Day and D. M. Rosenberg. 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.

Richards, A.B. and D.C. Rogers. 2006. List of freshwater macroinvertebrate taxa from California and adjacent states including standard taxonomic effort levels. Southwest Association of Freshwater Invertebrate Taxonomists. Chico, Ca. Available from http://safit.org/ste.html.

Stevens, D.L. and A.R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. *Environmetrics* 14:593-610.

Stevens, D.L. and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99:262-278.

Stoddard, J.L., D.V. Peck, A.R. Olsen, D.P. Larsen, J.Van Sickle, C.P. Hawkins, R.M. Hughes, T.R. Whittier, G. Lomnicky, A.T. Herlihy, P.R. Kaufmann, S.A. Peterson, P.L. Ringold, S.G. Paulsen and R. Blair. 2005. Environmental Monitoring and Assessment Program (EMAP) Western Streams and Rivers Statistical Summary. Environmental Protection Agency. Office of Research and Development. Washington, DC. EPA 620/R-05/006.

Sandin, L. and R.K. Johnson. 2004. Local, landscape, and regional factors structuring benthic macroinvertebrate assemblages in Swedish streams. *Landscape Ecology* 19:501-514.

Stokes, M.E., C. S. Davis and G. G. Koch. 2000. Categorical Data Analysis Using the SAS System, 2nd Edition. The SAS Institute, Inc. Cary, NC.

Stormwater Monitoring Coalition. 2007. Regional Monitoring of Southern California's Coastal Watersheds. Technical Report 539. Southern California Coastal Water Research Project. Costa Mesa, CA.

Available from:
ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/539_SMCworkplan.pdf

Stormwater Monitoring Coalition. 2009. Quality Assurance Project Plan. Southern California Coastal Water Research Project. Costa Mesa, CA.

SWAMP QAT. 2008. Quality Assurance Program Plan. Surface Water Ambient Monitoring Program Quality Assurance Team. Sacramento, CA. Available from http://swamp.mpsl.mlml.calstate.edu/resources-and-downloads/quality-assurance/quality-assurance-program-plan.

United States Department of Agriculture. 2008. Forest Service Grazing Allotments GIS layer [RangelandMgtUnits_Allotments08_1]. Available from http://www.fs.fed.us/r5/rsl/clearinghouse/gis-download.shtml.

United States Environmental Protection Agency. 1986. Quality Criteria for Water. EPA 440/5-86-001.

United States Environmental Protection Agency. 2000. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California. 40 CFR Part 131.

United States Census. 2000. Census Block Demography Data. Available from http://www.census.gov/

United State Environmental Protection Agency. 2002. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Fourth Edition. EPA-821-R-02-013

United States Environmental Protection Agency. 2004. Classification Framework for Coastal Systems. EPA 600/R-04/061 May 2204

United State Environmental Protection Agency. 2010a. Nation Pollutant Discharge Elimination System Test of Significant Toxicity Implementation Document. EPA 833-R-10-003 (June/2010).

United States Environmental Protection Agency. 2010b. Causal Analysis/Diagnosis Decision Information System (CADDIS). Office of Research and Development, Washington, DC. Available online at http://www.epa.gov/caddis.

United States Geological Survey. 1999. National Elevation Database. Sioux Falls, SD. Accessed from: http://ned.usgs.gov

United States Geological Survey. 2005. Mineral Resources Data System. Reston, VA. Accessed from: http://tin.er.usgs.gov/mrds/

United States Geological Survey and United States Environmental Protection Agency. 2005. National Hydrography Dataset Plus.

Van Sickle, J., J.L. Stoddard, S.G. Paulsen and A.R. Olsen. 2006. Using relative risk to compare the effects of aquatic stressors at a regional scale. *Environmental Management* 38:1020-1030.

Vieira N.K.M, W.H. Clements, L.S. Guevara and B.F. Jacobs. 2004. Resistance and resilience of stream insect communities to repeated hydrologic disturbances after a wildfire. *Freshwater Biology* 49:1243-1259.

Williams, D.D. 2006. The Biology of Temporary Waters. Oxford University Press. New York, NY.

Willmott, C.J., S.M. Robeson and K. Matsuura. 2007. Geographic boxplots. *Physical Geography* 28:331-344.

Yuan, L.L. 2010. Estimating the effects of excess nutrients on stream invertebrates from observational data. *Ecological Applications* 20:110-125.