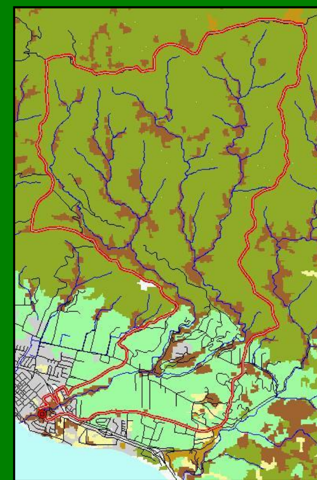
# SOUTHERN COASTAL SANTA BARBARA CREEKS BIOASSESSMENT PROGRAM



## 2009 REPORT AND UPDATED INDEX OF BIOLOGICAL INTEGRITY

**APRIL 2010**

**Prepared for:**

**City of Santa Barbara,
Creeks Division**

**County of Santa Barbara,
Project Clean Water**

**Prepared By:**

ECOLOGY CONSULTANTS

www.ecologyconsultantsinc.com

# Executive Summary

## Introduction

This report summarizes the results of the 2009 Southern Coastal Santa Barbara Creeks Bioassessment Program, an effort funded by the City of Santa Barbara and County of Santa Barbara. Ecology Consultants, Inc. (Ecology) prepared the report, and serves as the City and County's consultant for the Program. The purpose of the Program is to assess and monitor the biological integrity of creeks in the study area as they respond through time to natural and human influences. The Program involves annual collection and analysis of benthic macroinvertebrate (BMI) samples and other pertinent physiochemical and biological data in study creek reaches using U.S. Environmental Protection Agency (USEPA) endorsed rapid bioassessment techniques. BMI samples are analyzed in the laboratory to determine BMI abundance, composition, and diversity.

This report presents data collected in 2009 and previous years, and an updated Index of Biotic Integrity (IBI) for streams in the study area. The updated IBI was developed by Ecology using the 10 years of Program data from 2000 to 2009. The previous IBI was developed in 2003 using four years of Program data (2000 to 2003). The IBI is a system that yields a numeric score and classifies the biological integrity of a given stream as Very Poor, Poor, Fair, Good, or Excellent based on the BMI community present in the stream, as determined by completing a bioassessment survey and associated laboratory and analytical work. Several "core BMI metrics" are calculated and used to determine the IBI score. Ideally, core metrics are highly sensitive to human disturbance, and collectively represent different aspects of BMI community structure including diversity, community composition, and trophic group representation. By condensing complex biological data into an easily understood score and classification of biological integrity, the IBI serves as an effective tool for the City and County in monitoring the overall condition of local creeks, and taking appropriate watershed management actions.

## Study Area

The study area encompasses approximately 60 km of the southern Santa Barbara County coast from the Rincon Creek watershed at the Santa Barbara/Ventura County line west to Gaviota Creek. There are approximately 40 $1^{st}$ to $5^{th}$ order coastal streams along this stretch of coast, all of which drain the southern face of the Santa Ynez Mountains. A total of 49 stream study reaches in 20 watersheds have been surveyed on one or more occasions during the springs and summers from 2000 to 2009. 24 stream study reaches were surveyed this year.

## Methods

Physiochemical and biological data for the study reaches was gathered through a combination of methods including field surveys, laboratory analyses, spatial data analyses using geographic information system software, and review of United States Geological Survey (USGS) 7.5-minute quadrangle maps and recent aerial photographs. Numerous physiochemical and BMI parameters were calculated for each study reach based on the data collected.

Study reaches were separated into three groups based on physiochemical parameters including watershed land use patterns and physical habitat assessment score:

- REF (undisturbed to lightly disturbed by human development)
- MOD DIST (moderately disturbed by human development)
- HIGH DIST (highly disturbed by human development)

Statistical tests including analysis of variance (ANOVA) and linear regression were used to evaluate the data, including for differences in BMI metrics between the three study reach groups described above. The updated IBI was developed based on the statistical analyses.

**Results and Discussion**

Using the results of the statistical analyses, seven core BMI metrics were selected for inclusion in the updated IBI:

- # of insect families
- # of EPT families
- % EPT minus Baetidae
- % PT
- Tolerance value average
- % sensitive BMIs
- % predators + shredders

The core metrics were among the most sensitive to human disturbance among all the metrics tested, either increasing or decreasing from HIGH DIST to MOD DIST to REF groups. None had significant natural relationships with the group of physiochemical parameters among the REF sites. Collectively, the core metrics are diversified in that they represent different aspects of BMI community structure including diversity, disturbance sensitivity, and trophic structure. Scoring ranges for the core metrics and classifications of biotic integrity are provided in the report.

IBI scores were calculated for the study reaches, and classifications of biological integrity were compared to the *a priori* (i.e., prior to analyses of BMI metrics) designations as REF, MOD DIST, or HIGH DIST. The accuracy of the IBI in classifying biological integrity was determined to two and three classes of biological integrity using a Validation Set of 37 study reaches that were not used to develop the IBI. The IBI was accurate 81 percent of the time to two classes and 100 percent of the time to three classes of biological integrity for the Validation Set. These results indicate that the IBI is mostly reliable in classifying the biological integrity of streams in the study area. ANOVA and regression analyses results indicate highly significant relationships between IBI score and human disturbance metrics representing watershed land use patterns and localized physical habitat conditions.

**Recommendations**

The updated IBI is based on a set of streams that collectively represent a wide range of natural physiochemical variability and levels of human disturbance. In addition, significant fluctuations in rainfall and peak stream flow from year to year and their effects on the BMI communities of study area streams have been documented over the past 10 years. This has allowed for the development of an IBI that serves as a very reliable tool for classifying the biological integrity of streams in the study area, monitoring their condition through time, and identifying any changes that may occur in the future from increased development, habitat restoration projects, and even long term climatic changes (e.g., global warming).

There are ways in which the collective data set could be diversified, for example by including some of the streams in the study area that have not yet been surveyed, and expanding the study area further west and north to the Hollister and Bixby Ranch areas, Point Conception, Santa Ynez River watershed, etc. The IBI should be updated every 5 to 10 years to account for the greater range of conditions observed.

The updated IBI represents an excellent tool for assessing and monitoring the biological condition of freshwater streams in the study area. However, there is no equivalent tool for estuarine waters in the study area, which could be assessed using similar bioassessment methodology as used in this Program. IBIs have been produced for estuarine waters in many regions, and with adequate data one could be produced in the study area as well. Given the ecological importance of estuarine waters, and their importance as they relate to commercial and recreational uses and the local economy, the City and County should consider implementing an estuarine bioassessment program if funding allows.

## Acknowledgement

Special thanks go to Scott Cooper, Professor of Aquatic Biology at the University of California, Santa Barbara for reviewing this report and the Updated IBI, and for his invaluable input throughout the 10 years of this bioassessment program.

# TABLE OF CONTENTS



## FIGURES

# TABLES

# I. Introduction

This report summarizes the results of the 2009 Southern Coastal Santa Barbara Creeks Bioassessment Program, an effort funded by the City of Santa Barbara and County of Santa Barbara. 2009 is the $10^{th}$ year of the Program, which began in 2000. Ecology Consultants, Inc. (Ecology) prepared the report, and serves as the City and County's consultant for the Program. The purpose of the Program is to assess and monitor the "biological integrity" of southern coastal Santa Barbara County creeks as they respond through time to natural and human influences. Karr and Dudley (1981) defined biological integrity as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." (Miller et al., 1988). "Bioassessment" is the science of assessing the biological integrity of aquatic ecosystems by evaluating the biological assemblages (e.g., benthic macroinvertebrates, fish, amphibians, diatoms, etc.) that inhabit them. Because different species or groups of species (i.e., genera, families, orders, etc.) have varying habitat requirements and abilities to withstand water pollution and other forms of habitat degradation, the presence, abundance, or absence of particular species or groups of species provides information regarding the biological integrity of a particular water body. In addition, measurements of biological community structure relating to overall abundance, diversity, and trophic structure have proven to be reliable indicators of biological integrity in water bodies (Rosenberg and Resh, 1993, Barbour et al., 1999).

The Program involves annual collection and analysis of benthic macroinvertebrate (BMI) samples and other pertinent physiochemical and biological data in study creek reaches using U.S. Environmental Protection Agency (USEPA) endorsed rapid bioassessment techniques. BMI samples are analyzed in the laboratory to determine BMI abundance and composition. This report presents data collected in 2009 and previous years.

This report also presents an updated Index of Biotic Integrity (IBI) for streams in the study area, which was developed using data from a wide range of study reaches surveyed from 2000 to 2009. The IBI provides a numeric score and classification of biological integrity of a given stream as Very Poor, Poor, Fair, Good, or Excellent. Determination of the IBI score of a given study reach starts with collection of BMI samples during a bioassessment survey. Laboratory and analytical work are completed to determine BMI abundance and taxonomic composition. The BMI data is used to calculate several "core metrics", which are the basis of the IBI scores and classifications. Ideally, core metrics are highly sensitive to human disturbance, and collectively represent different aspects of BMI community structure including diversity, community composition, and trophic group representation. By condensing complex biological data into an easily understood score and classification of biological integrity, the IBI serves as an effective tool for the City and County in monitoring the overall condition of local creeks, and making appropriate creek and water quality management decisions.

The IBI was updated to use the considerable data set now available, which collectively represents wide variability in physiochemical conditions, human impacts, and year to year fluctuations in rainfall and stream flow patterns. The current data includes surveys conducted during several drought years and wetter years, including one of the wettest rainfall years on record (2005). Because year to year variability in rainfall and stream flow has been linked to considerable differences in BMI community structure, the updated IBI is more representative of the full range of the BMI community compared to its predecessor, which was produced in 2003 using the first four years of data (i.e., 2000 to 2003). More discussion of the IBI and its development is provided in III. Methods.

# II. Study Area

The study area encompasses approximately 60 km of the southern Santa Barbara County coast from the Rincon Creek watershed at the Santa Barbara/Ventura County line west to Gaviota Creek (see Figure 1). There are approximately 40 1st to 5th order coastal streams along this stretch of coast, all of which drain the southern face of the Santa Ynez Mountains. A total of 47 stream study reaches in 20 watersheds have been surveyed on one or more occasions during the springs and summers from 2000 to 2009. Table 1 lists the study reaches and their locations.

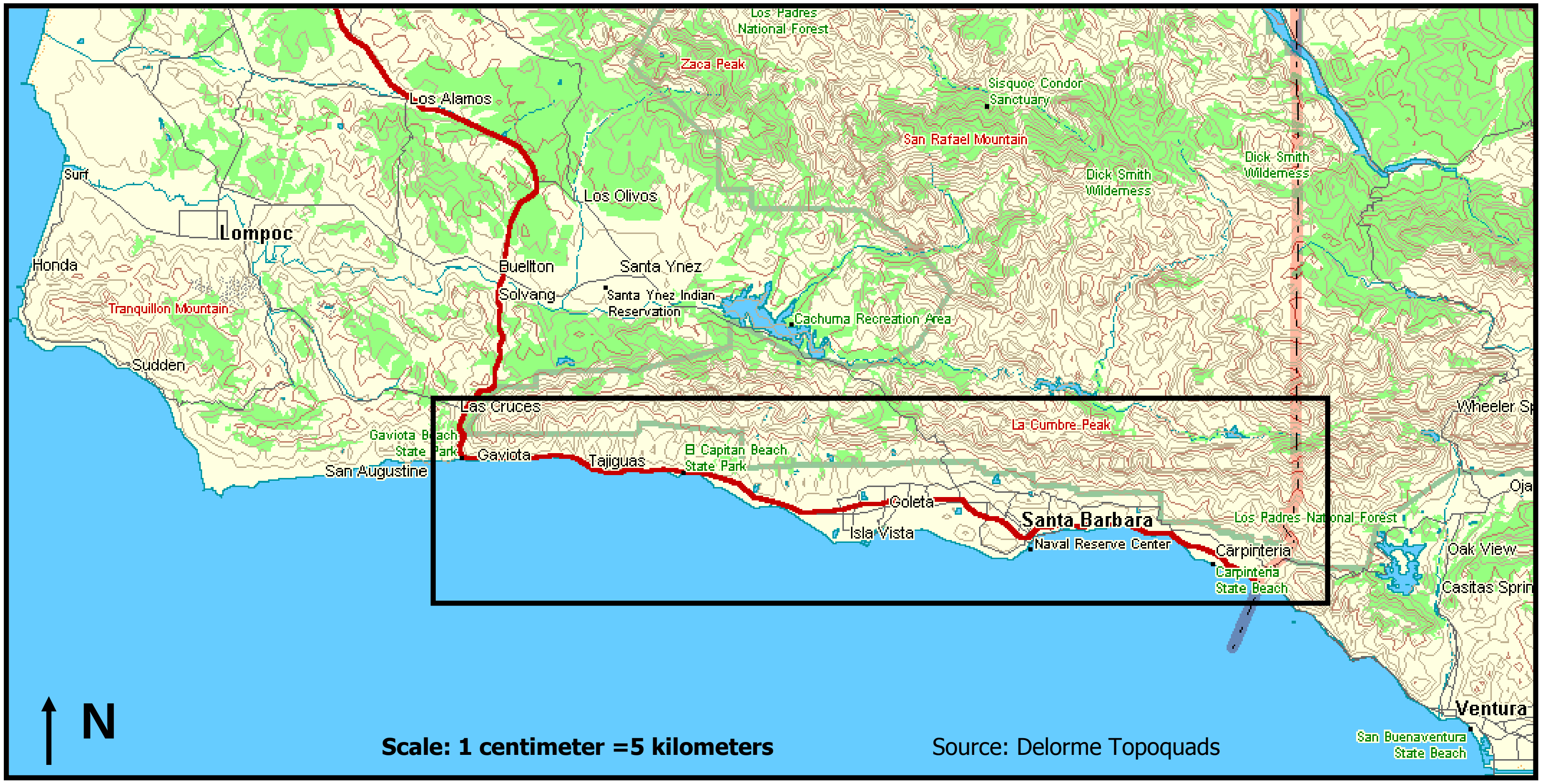
**Table 1: Study Reaches**

| Study Reach | Location |
|---|---|
| RIN0 | Rincon Creek just upstream of Rincon Rd. crossing |
| RIN1 | Rincon Creek, just upstream of Highway 150 crossing at Gobernador Cyn Rd. |
| C1 | Carpinteria Creek, 0.25 mi. downstream of Carpinteria Ave. |
| C2 | Carpinteria Creek, approx. 0.25 mi. upstream of U.S. 101 |
| C3 | Gobernador Creek, approx. 0.25 mi. upstream of County detention basin |
| F1 | Franklin Creek just upstream of entrance into Carpinteria Salt Marsh |
| SM1 | Santa Monica Creek just upstream of entrance into Carpinteria Salt Marsh |
| MONT1 | Montecito Creek at Val Verde prop., below Hot Springs/Cold Springs confluence |
| MONT2 | Montecito Creek just upstream of Hot Springs/Olive Mill Rd. |
| SY1 | Sycamore Creek just below Mason St. bridge |
| SY2 | Sycamore Creek just below Highway 192 crossing and Coyote/Sycamore confluence |
| SY3 | Sycamore Creek 300m below Highway 192 crossing and Coyote/Sycamore confluence |
| M1 | Mission Creek at De la Guerra St. |
| M2 | Old Mission Creek at Bohnet Park |
| M3 | Mission Creek at upstream end of Rocky Nook Park |
| M4 | Rattlesnake Creek, approx. 0.5 mi. upstream of Las Canovas Rd. crossing |
| M6 | Mission Creek, at three falls above Jesuita Trail crossing |
| M7 | Old Mission Creek just downstream of Anapamu St. |
| AB1 | Arroyo Burro at upstream end of Alan Rd. |
| AB2 | Arroyo Burro just downstream of Torino Rd. |
| AB3 | San Roque Creek, 0.25 mi. upstream of Foothill Rd. |
| AB4 | San Roque Creek just upstream of the confluence with Arroyo Burro |
| AB5 | Mesa Creek at entrance to Arroyo Burro estuary |
| AB6 | Arroyo Burro just downstream of U.S. 101 |
| AT1 | Atascadero Creek near Patterson Rd. |
| AT2 | Atascadero Creek just downstream of Cieneguitas Creek confluence |

| Table 1: Study Reaches | |
|---|---|
| SA1 | San Antonio Creek, approx. 0.5 mi. upstream of Tucker's Grove Park |
| SA2 | San Antonio Creek, approx. 0.25 mi. upstream of Highway 154 |
| MY1 | Maria Ygnacio Creek, approx. 0.25 mi. below San Marcos Rd. crossing |
| MY2 | Maria Ygnacio Creek, approx. 0.25 mi. upstream of FC detention basin |
| MY3 | Maria Ygnacio Creek, approx. 0.25 mi. upstream of Highway 154 |
| SJ1 | San Jose Creek, approx. 0.25 mile downstream of U.S. 101 |
| SJ2 | San Jose Creek, approx. 0.25 mile upstream of Patterson Rd. crossing |
| SJ3 | San Jose Creek at San Marcos Trout Club |
| T1 | Tecolote Creek, approx. 50 meters upstream of Vereda del Padre |
| T2 | Tecolote Creek, adjacent to Vereda Nueva |
| T3 | Tecolote Creek, 100 m downstream from Vereda Parque access |
| DP1 | Dos Pueblos Creek, approx. 50 meters downstream of U.S. 101 |
| EC1 | El Capitan Creek in State Park, approx. 100 meters upstream of mouth |
| R1 | Refugio Creek, approx. 1.5 mi. upstream of U.S. 101 |
| R2 | Refugio Creek, approx. 0.25 mi. downstream of Circle Barbee Ranch |
| AH1 | Arroyo Hondo, approx. 1 mi. upstream of U.S. 101. |
| AH2 | Arroyo Hondo, approx. 2 mi. upstream of U.S. 101. |
| SO1 | San Onofre Creek, just below U.S. 101 culvert |
| SO2 | San Onofre Creek, approx. 1 mi. upstream of U.S. 101 |
| GAV1 | Gaviota Creek at State Beach/Park, just below access rd./US 101 junction |
| GAV2 | Gaviota Creek, 200 meters downstream of Las Canovas Creek confluence |

The study reaches range from narrow mountain tributaries to wider lowland streams, and from relatively pristine to highly disturbed. Common human impacts observed in study streams include: (1) altered hydrology and geomorphology due to water diversions, land development, and flood control projects; (2) sedimentation of pool and riffle substrata due to increased deposition of fine sediments from actively eroding agricultural fields and creek banks; (3) degraded water quality due to inputs of fertilizers, pesticides, petroleum hydrocarbons, heavy metals, and other pollutants; (4) elevated stream temperatures due to drainage from impervious surfaces and the removal of riparian vegetation; (5) habitat fragmentation due to the construction of in-stream barriers such as dams, road crossings, bridges, and culverts; (6) introductions of invasive, non-native plants and animals; and (7) disturbances to vegetation and/or wildlife associated with trampling, noise, lighting, air pollution, and predation by domestic pets.

# FIGURE 1: STUDY AREA



# III. Methods

Physiochemical and biological data for the study reaches was gathered through a combination of methods including field surveys, laboratory analyses, spatial data analyses using geographic information system (GIS) software, and review of United States Geological Survey (USGS) 7.5-minute quadrangle maps and recent aerial photographs. Numerous physiochemical and biological parameters were calculated for each study reach based on the data collected. After the data set was finalized, statistical tests including analysis of variance (ANOVA) were used to evaluate the data, and the IBI was developed. Further discussion of methods is provided below.

## A. Field Surveys

As in previous years of the Program, field surveys were conducted in the spring during base stream flow conditions (i.e., low flows). The sampling was conducted in early May of 2009 by Ecology, City of Santa Barbara, and County of Santa Barbara staff. Sampling in the spring during base flow conditions provides consistency in the sampling from year to year, as the local stream biota is known to undergo seasonal succession (Cooper et al., 1986). The following was completed during each field survey:

- General observations were recorded on a standardized field data sheet, including location, date, time, weather, stream flow conditions, water clarity, and human impacts.
- A 100-meter study reach was delineated along the stream. Stream habitat units (i.e., riffles, runs, pools, etc.) within the study reach were mapped and quantified as a percentage of the total reach length.
- GPS coordinates were determined at the downstream end of each study reach using a Garmin E-Trex Venture handheld GPS unit.
- Stream widths (wetted perimeter, channel bottom, and bank full) were measured at three transects in the study reach. Wetted perimeter width is defined as the cross-sectional distance of streambed that is inundated with surface water. Channel bottom width is defined as the cross-sectional distance between the bottoms of the stream banks. Bank full width is defined as the distance from the ordinary high water mark from one stream bank to the other, as evidenced by visible signs of stream flow such as water marks, stream-carried deposits of sediments and debris, and scour features.
- Riparian canopy cover was estimated in the center of the stream channel at the three transects using a spherical densitometer.
- Plant and wildlife species observed in the creek and riparian zone were noted.
- Water temperature, specific conductance, pH, and dissolved oxygen concentration were measured in the field using YSI and Oakton handheld meters. Two measurements of each parameter were made, one in a riffle and the other in a pool, and the two values were averaged.
- BMI samples were collected using a standardized method based on the "multi-habitat" approach described in the USEPA's *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers* (Barbour et al., 1999). Three samples were collected per study reach: one

sample from the downstream third of the reach, one from the middle third, and one from the upstream third. Each sample represents approximately one square meter of stream bottom, collected from 10 individual, 0.1-square meter locations (approximately 30 centimeters square). The 10 locations that constituted each sample were selected based on the relative area each stream habitat (i.e., riffles, pools, falls, etc.) covered in the section of stream sampled. For example, if a given stream reach contained approximately 50 percent riffles and 50 percent pools, five locations in riffles and five in pools were selected and sampled. Samples were collected using a D-frame net with 500 μm mesh. In locations with flowing water (e.g., riffles and runs), the net was held upright against the stream bottom, and substrata immediately upstream within the 0.1-square meter area was scraped and stirred up for approximately 15 seconds using feet and hands. Dislodged BMIs and stream bottom materials were carried into the net by the stream current. In areas with little or no current (e.g., pools), stream bottom material was stirred up by foot, followed by a quick sweep of the net through the water column to capture dislodged BMIs. This was repeated three times in each pool sampling location.

- After each BMI sample was collected, it was rinsed with water in a 500 μm sieve to wash out fine sediments, transferred to a plastic container, and preserved in 70 percent ethanol.
- A semi-quantitative stream habitat assessment was conducted using the protocol provided in the USEPA's *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers*. Per this protocol, habitat components were visually assessed and scored, including stream substrate/cover, sediment embeddedness, stream velocity/depth regime, sediment deposition, channel flow status, human alteration, channel sinuosity, habitat complexity/variability, bank stability, vegetative protection, and width and composition of riparian vegetation. Each study reach was assigned a total score of between zero and 200 based on the sum of scores assigned to each habitat component. Criteria from the USEPA protocol were used to guide the scoring.
- Quality control measures were incorporated into the field surveys to insure accurate and consistent data gathering. Water monitoring equipment was calibrated regularly. Field crew members were trained to properly operate equipment, take measurements, collect BMI samples, and conduct stream habitat assessments. Stream habitat assessment scoring was done as a group by the field crew.

## B. Laboratory Analyses

BMI samples were processed in the laboratory to determine BMI community composition (i.e., taxa present and relative abundance) and overall density. Each BMI sample was strained through a 500-μm mesh sieve and washed with water to remove ethanol and fine sediments. The sample was placed in a plastic tray marked with equally-sized squares in a grid pattern. The entire sample was spread out evenly across the squares. Squares of material were randomly selected, and sorted one at a time under a dissecting microscope (7X to 50X magnification) until a specified number of BMIs were located and picked out. The proportion of the sample sorted was noted. 110 specimens were picked out from each sample (i.e., three samples, 330 BMIs per study reach). 100 of the 110 BMIs picked from each sample (300 total per study reach) were randomly selected for identification. BMIs were identified using standard taxonomic keys. Insect taxa were identified to the family level. Non-insect taxa (e.g., oligochaetes, crustaceans, etc.) were identified to order or class. After processing and identification, sorted BMIs and sample remnants were bottled separately in 70 percent ethanol for storage.

Quality control measures were incorporated into the laboratory analysis to ensure random selection and accurate enumeration and identification of BMIs. BMI sample processing methods were clearly established and strictly followed.

## C. GIS Analyses

GIS Arcview software was used to calculate upstream watershed area and watershed land use coverages for each study reach. Watershed area was calculated based on watershed boundaries generated by the GIS with a 30 meter digital elevation model using hydrologic processing tools in Arcview GIS. Watershed land use coverages for each study reach were calculated by superimposing watershed boundaries over a digital land cover GIS layer for the region. The land cover layer was produced the California Department of Forestry and Fire Protection's (CDF) Fire and Resource Assessment Program (FRAP). The land cover layer is titled LCMMP Vegetation Data, 1994 to 1997. The CDF land use map for the region showed coverage by the following eight land use categories: urban, agriculture, herbaceous, hardwood, shrub, conifer, water, and barren/other. Recent aerial photographs (i.e., 2008 and 2009) of the region available on Google Earth were reviewed to check the accuracy of the GIS land use layer. The GIS and aerial photograph land use maps were in close agreement, and only minor adjustments to the GIS-based calculations were necessary.

The parameter "percent watershed disturbed" was calculated for each study reach by using the following equation:

Percent watershed disturbed = percent urban + percent agriculture + 0.5(percent herbaceous)

Herbaceous areas were counted as partially (i.e., half) disturbed to reflect that much of the herbaceous lands in this region are used for livestock grazing or are previously cleared land.

## D. Review of Topographic Maps

USGS 7.5 minute quadrangle topographic maps (1:24,000 scale) for the study area were reviewed to determine stream order, elevation, and gradient for each study reach. Gradient was determined by dividing the elevation change between topographic contours immediately upstream and downstream of the study reach by the stream length between the contours. Stream length was determined by tracing a map wheel over the stream path.

## E. Study Reach Grouping

The study reaches were placed into three different groups based on their perceived level of human disturbance. These disturbance groups were assigned to study reaches "a priori" (i.e., before the analyses of biological data) based on physical habitat assessment scores and GIS data on watershed land uses. The following criteria were used to group the study reaches:

REF = Reference stream reaches are minimally disturbed by human activities. Habitat assessment score was 150 out of 200 or greater, and five percent or less of the upstream watershed was disturbed.

MOD DIST = Stream reaches that are lightly to moderately disturbed by human activities. Habitat assessment score was between 120 and 149. This category also includes stream reaches with a habitat assessment score of 150 or greater, but with greater than five percent of the upstream watershed disturbed.

HIGH DIST= Stream reaches that are heavily disturbed by human activities including agricultural and urban/suburban land uses. Habitat assessment score was less than 120.

## F. Calculation of Physiochemical Parameters and BMI Metrics

Numerous physiochemical parameters and BMI metrics were calculated for each study reach using the data collected. Table 2 lists each parameter calculated for the study reaches and the method of calculation (e.g., lab, field, etc.).

**Table 2**
**Physiochemical Parameters and BMI Metrics Calculated for Each Study Reach**

| Parameters | Units of Measurement | Method of Calculation |
|---|---|---|
| PHYSICAL PARAMETERS | | |
| Stream order | None | USGS Quad Maps |
| Elevation | Feet (ft.) | USGS Quad Maps |
| Stream gradient | None | USGS Quad Maps |
| Watershed area | Acres | GIS |
| Percent of watershed area disturbed | None | GIS |
| Wet stream width | Ft. | Field |
| Habitat assessment score | None | Field |
| Percent riparian canopy cover | None | Field |
| WATER CHEMISTRY PARAMETERS | | |
| Stream temperature | Degrees Celsius (°C) | Field |
| Ph | None | Field |
| Dissolved oxygen concentration | Milligrams per liter (mg/l) | Field |
| Conductivity | Microsiemens (µS) | Field |
| Specific conductance (corrected to 25° Celsius) | µS | Field |
| BIOLOGICAL PARAMETERS | | |
| BMI density | # per sq. meter (#/$m^2$) | Field/lab |
| # of insect families | None | Field/lab |
| # of Ephemeroptera/Plecoptera/Tricoptera (EPT) families | None | Field/lab |
| Percent EPT | None | Field/lab |
| Percent EPT minus Baetidae | None | Field/lab |
| Percent Plecoptera/Tricoptera (PT) | None | Field/lab |
| Percent Coleoptera | None | Field/lab |
| Tolerance value average | None | Field/lab |
| Percent sensitive BMIs | None | Field/lab |
| Percent tolerant BMIs | None | Field/lab |
| Percent non-insect BMIs | None | Field/lab |
| Percent non-insects + Diptera | None | Field/lab |
| Percent non-insects + Chironomidae | None | Field/lab |
| Percent collector-gatherers | None | Field/lab |
| Percent scrapers | None | Field/lab |
| Percent shredders | None | Field/lab |
| Percent collector-filterers | None | Field/lab |
| Percent predators | None | Field/lab |
| Percent predators + shredders | None | Field/lab |

**Table 2**
**Physiochemical Parameters and BMI Metrics Calculated for Each Study Reach**

| | | |
|---|---|---|
| Percent scrapers + shredders | None | Field/lab |
| Percent scrapers + shredders + predators | None | Field/lab |
| Percent collector-gatherers + scrapers + shredders | None | Field/lab |
| Percent collector-gatherers + collector-filterers | None | Field/lab |
| Percent collector-gatherers + predators | None | Field/lab |

Numerous BMI metrics were calculated for each study reach to reflect different aspects of community structure, including overall BMI density, richness, composition (i.e., taxa present), the relative and absolute abundances of component taxa or groups, trophic group representation, and sensitivity to human disturbance. BMI metrics for each study reach were calculated by combining the data from the three samples.

BMI density (number of individuals per $m^2$) was calculated by dividing the number of specimens picked out of the sample by the sub sampled area. Richness parameters were determined by counting the number of specified taxa identified in each sample. Functional feeding group parameters (e.g., percent collector-gatherers, % scrapers, etc.) were determined using functional feeding group designations for individual taxa provided in Merritt and Cummins (1996).

Tolerance value averages, percent sensitive BMIs, and percent tolerant BMIs were calculated using disturbance tolerance values for individual BMI taxa provided in *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* (California Department of Fish and Game, 2002). This document assigns tolerance values to individual taxa ranging from 0 to 10 based on their perceived ability to withstand human disturbance. A tolerance value of 0 indicates that a particular BMI is extremely intolerant of human disturbance, with increasing scores indicating greater tolerance to human disturbance. Composite tolerance value averages were calculated by adding the tolerance values for each BMI in the sample, and dividing by the total number of individuals. Percent sensitive BMIs was calculated by adding the number of BMIs in the sample with a tolerance value of 2 or less, dividing by the total number of individuals in the sample, and multiplying by 100. Percent tolerant BMIs was calculated by adding the number of BMIs in the sample with a tolerance value of 8 or greater, dividing by the total number of individuals in the sample, and multiplying by 100. Tolerance values were available for more than 95 percent of the taxa collected. BMIs without tolerance values were excluded from the calculations of tolerance value averages, percent sensitive BMIs, and percent tolerant BMI taxa.

### G. Development of New Tolerance Values for Study Area BMI Taxa, and New Tolerance Value Average, Percent Sensitive BMIs, and Percent Tolerant BMIs Metrics

In completing 10 years of the Program, it has become apparent that tolerance values assigned to some of the individual BMI taxa in the *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* do not agree with the occurrences observed in the study area. As an example, the mayfly family Caenidae is assigned a relatively high tolerance value of 7, yet it is rarely observed in significant numbers in highly disturbed creeks in the study area, and is often observed in significant numbers in minimally and moderately disturbed creeks. In an attempt to refine the accuracy of the tolerance value average, tolerance values specific to the study area were developed using the data from all study reaches surveyed in four or more years. This included data from 153 surveys.

Tolerance values were determined for all BMI taxa having a mean abundance of at least one individual per study reach in at least one of the study reach groups (REF, MOD DIST, and/or HIGH DIST). For BMI taxa not meeting these criteria, tolerance values from *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* were retained.

In order to evaluate their sensitivity to human disturbance, all qualifying BMI taxa were evaluated for differences between the REF, MOD DIST, and HIGH DIST study reach groups using analysis of variance (ANOVA). The results of the ANOVA tests were used to assign new tolerance values to the qualifying BMI taxa. An ANOVA test compares the means and distributions of a given metric among multiple sampling groups, and indicates the probability that the means for the groups are the same. The probability that the means are the same is expressed as p, which is between 0 and 1. The lower the p, the lower the probability is that the group means are the same. A p of 0.05 or less is generally accepted as indicating a statistically significant difference between group means. Rules for setting the new tolerance values are provided in Figure 2.

The revised tolerance values were used to calculate new versions of the tolerance value average, percent sensitive BMIs, and percent tolerant BMIs. The new version of percent sensitive BMIs was further revised to include BMIs with a tolerance value of 3 or less, while the new version of percent tolerant BMIs was revised to include those with a tolerance value of 7 or greater.

## H. Development of the Updated IBI

Developing the updated IBI required the completion of several distinct steps, including (1) selection of study reaches to be included in the IBI test group and those to be included in a separate validation group, (2) screening and selection of core metrics, (3) defining scoring ranges for core metrics, (4) defining IBI scoring categories and ranges, and (5) testing the IBI for accuracy in classifying the biological integrity of individual study reaches. These steps are discussed below.

### 1. Partitioning of Study Reaches into IBI Test Group and Validation Group

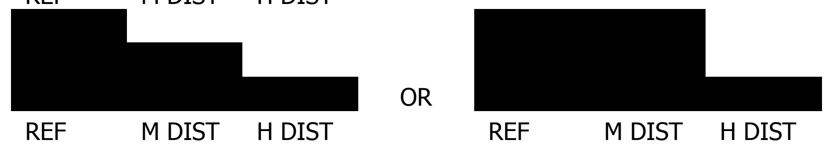
The IBI Test Group is composed of study reaches surveyed in four or more years. A total of 153 sampling replicates compose the Test Group, including 34 REF, 40 MOD DIST, and 79 HIGH DIST replicates, respectively. Data from these surveys was used to develop the IBI. All study reaches surveyed less than four times over the 10 year Program were held back, and included in a separate Validation Group composed of 37 surveys from 5 REF, 15 MOD DIST, and 17 HIGH DIST replicates, respectively. Since they were not used to develop the IBI, study stream reaches in the Validation Group can be used to independently test the accuracy of the IBI in correctly scoring and classifying biological integrity.

# Figure 2: Tolerance Values Rules

**Sensitive (0-3):**

0, 1: abundance significantly ($p<0.05$) highest in REF. MOD DIST and HIGH DIST not sign. different from one another. 0 for greater differences in mean values and p between REF and MOD/HIGH DIST, 1 for lesser differences.

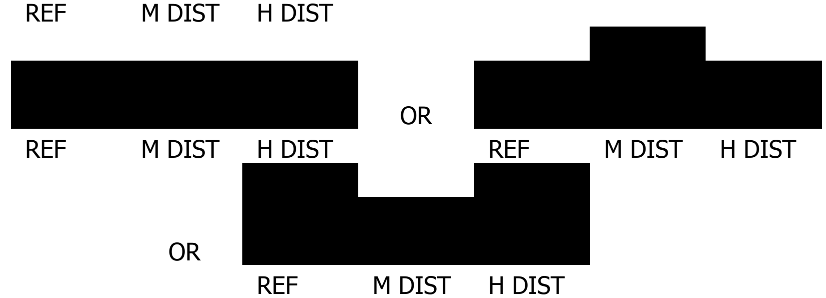

2,3: significant decrease in mean abundance from REF to MOD DIST to HIGH DIST, or from REF and MOD DIST to HIGH DIST. 2 for greater differences in mean values and p, 3 for lesser differences.




**Moderate (4-6):**

4: mean abundance significantly highest in MOD DIST, mean abundance in REF sign. higher than in HIGH DIST.

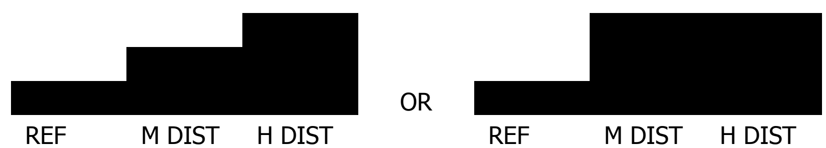

5: no significant difference in mean abundance between the three groups. Or mean abundance in MOD DIST sign. higher or lower, and REF and HIGH DIST means not sign. different from each other.



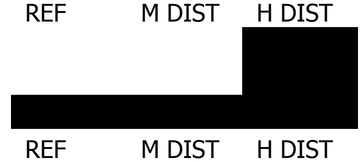

6: mean abundance significantly highest in MOD DIST, mean abundance in REF sign. lower than in HIGH DIST.


**Tolerant (7-10):**

7, 8: significant increase in mean abundance from REF to MOD DIST to HIGH DIST, or from REF to MOD DIST and HIGH DIST. 8 for greater differences in mean values and p, 7 for lesser differences.




9, 10: mean abundance significantly highest in HIGH DIST, REF and MOD DIST not significantly different from each other. 10 for greater differences in mean values and p, 9 for lesser differences.



## 2. Screening of BMI Metrics and Selection of Core Metrics

### Sensitivity to Human Disturbance

In order to evaluate their sensitivity to human disturbance, all of the BMI metrics calculated (see Table 2) were evaluated for differences between the REF, MOD DIST, and HIGH DIST study reach groups using ANOVA. BMI metrics that most significantly change (i.e., increase or decrease) with increasing levels of human disturbance (i.e., from the REF to MOD DIST to HIGH DIST groups) have most potential to serve as measures biological integrity, and core metrics in the IBI.

### Natural Relationships with Physiochemical Parameters

Multiple regression analyses were used to evaluate natural relationships (i.e., in the absence of human disturbance) between biological metrics and several physiochemical parameters using data REF study reaches group (n=39). It is important to screen potential core metrics on this basis, as significant natural relationships with physiochemical parameters could be difficult to separate from the effects of human disturbance. Such a situation may make a metric an unreliable indicator of biological integrity.

Multiple regression simultaneously evaluates and compares the effects of multiple independent variables (i.e., the physiochemical variables), or "regressors", on a single response variable (i.e., each biological metric). A best-fit equation is calculated that represents the response variable as a function of the independent variables. The correlation coefficient ($r^2$) and p-value (p) are calculated in regression analyses, and used to interpret the strength of the relationship between the response variable and the regressors. $r^2$ is given as a value between 0 and 1, and indicates the how well the equation fits the data. The higher the $r^2$, the better the fit of the equation. P indicates the probability that the response variable and regressors are not related as predicted by the best-fit equation, and is given as a value of between 0 and 1. A p of 0.05 or less is generally accepted as indicating a statistically significant relationship between the independent and response variables.

Landscape level, relatively constant physiochemical parameters including elevation, stream gradient, and watershed area were selected for use as regressors in the analyses. Stream temperature has been shown in many studies to have major effects on BMI community structure, and was also used as a regressor.

### Core Metric Selection

Once the above screening analyses were complete, core metrics were selected for inclusion in the IBI. All potential core metrics showed (1) highly significant responses to human disturbance, either increasing or decreasing between REF to MOD DIST to HIGH DIST groups, and (2) less than significant relationships with physiochemical parameters at the REF study reaches. This in theory at least avoids a situation of confusing biological responses to human disturbance with responses to natural physiochemical gradients. Collectively, core metrics were chosen to represent three major aspects of biological community structure: diversity, disturbance tolerance/sensitivity, and trophic composition (i.e., functional feeding groups).

## 3. Defining Core Metric Scoring Ranges

Scoring ranges of were established for each potential core metric on a dimensionless scale of 0 to 10, 0 indicating the lowest biological integrity, and 10 indicating highest biological integrity.

For metrics that decrease with human disturbance (i.e., highest at REF sites), higher values corresponded with higher scores. For metrics that increase with human disturbance (i.e., highest at HIGH DIST sites), higher values corresponded with lower scores. The distributions of each metric in the REF, MOD DIST, and HIGH DIST groups were used to establish the scoring ranges. Scoring criteria is provided in Table 3.

**Table 3: Core Metric Scoring Range Criteria**

| Score | Scoring Criteria |
|---|---|
| 10 | The 75th percentile or beyond of the REF group distribution for metrics that are highest in the REF group, or the 25$^{th}$ percentile or lower of REF group for metrics that are lowest in the REF group |
| 9 | The median (50th percentile) to 75$^{th}$ percentile of the REF group for metrics that are highest in the REF group, or the 25$^{th}$ percentile to the median of REF group for metrics that are lowest in the REF group |
| 8 | The range between the REF group and MOD DIST group medians is divided and evenly partitioned to provide each scoring range for 6, 7, and 8 |
| 7 | |
| 6 | |
| 5 | MOD DIST median is the top of the scoring range for 5 |
| 4 | The range between the MOD DIST group and HIGH DIST group medians is divided and evenly partitioned to provide each scoring range for 5, 4, 3, and 2 |
| 3 | |
| 2 | |
| 1 | The median to 25$^{th}$ percentile of the HIGH DIST group for metrics that are lowest in the HIGH DIST group, or the median to the 75$^{th}$ percentile to the median of HIGH DIST group for metrics that are highest in the HIGH DIST group |
| 0 | The 25$^{th}$ percentile or less of the HIGH DIST group distribution for metrics that are lowest in the HIGH DIST group, or the 75$^{th}$ percentile or higher of the HIGH DIST group for metrics that are highest in the HIGH DIST group |

## 4. Establishment of IBI Classifications of Biological Integrity

An overall IBI score was tabulated for each study reach by summing the respective scores of the core metrics. Based on the distribution of IBI scores for the REF, MOD DIST, and HIGH DIST groups, five categories of biological integrity were established: Excellent, Good, Fair, Poor, and Very Poor. Scoring criteria used to establish the categories is provided in Table 4.

| Table 4: IBI Classifications of Biological Integrity and Scoring Criteria | |
|---|---|
| **Classification of Biological Integrity** | **Scoring Range** |
| Excellent | Median of REF group or higher |
| Good | From REF group median to 2/3 of way down to MOD DIST group median |
| Fair | Upper end of Fair range is MOD DIST group median to 1/3 of way up to REF group median. Lower end of Fair range is MOD DIST group median to 1/3 of way down to HIGH DIST group median. |
| Poor | From HIGH DIST group median to 2/3 of way up to MOD DIST group median |
| Very Poor | Median of HIGH DIST group or less |

## 5. Testing the Accuracy of the IBI

Once the IBI was established, IBI scores were calculated for the study reaches, and classifications of biological integrity were compared to the *a priori* REF, MOD DIST, and HIGH DIST designations. This was done for:

1. the Validation Group only, or study reaches not used to develop the IBI (n=37), and;
2. all study reaches, including those used to develop the IBI (n=190).

The accuracy of the IBI in classifying biological integrity was determined to two and three classes of biological integrity. Table 5 provides criteria for correct classification by the IBI for these two levels of resolution. The percentage of sites properly classified (i.e., accuracy) was calculated for the IBI using these criteria.

| Table 5: IBI Accuracy of Classification Criteria | | |
|---|---|---|
| **Study Reach Group** | **Accurate to Two Classes** | **Accurate to Three Classes** |
| REF | Good to Excellent | Fair to Excellent |
| MOD DIST | Top half of Poor to bottom half of Good | Poor to Good |
| HIGH DIST | Very Poor to Poor | Very Poor to Fair |

Additional statistical analyses were performed to evaluate the IBI's sensitivity to human disturbance. First, an ANOVA was completed to compare IBI scores for the three study reach groups (REF, MOD DIST, and HIGH DIST). Next, regression analyses were used to evaluate the relationships of IBI score with (1) percent of upstream watershed undisturbed, (2) habitat assessment score, and (3) a composite of percent of upstream watershed undisturbed and habitat assessment score. $r^2$ and p were calculated for these analyses.

# IV. Results and Discussion

## A. Data

Table A-1 in Appendix A provides physiochemical and BMI data collected at the study reaches in all years of study, and BMI metrics calculated using the data. New tolerance values determined for individual BMI taxa are also provided, as are previous tolerance values for comparison. Functional feeding groups for individual BMI taxa are provided as well.

## B. New Tolerance Values

New tolerance values and sensitivity designations for individual BMI taxa are provided in Table A-1 of Appendix A. New tolerance values were assigned to 46 of 72 BMI taxa. Tolerance values from *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* were retained for the remaining 26 taxa, which did not have mean abundance of 1 individual per study reach in at least one of the three disturbance groups. An additional six taxa did not have tolerance values in *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort*, and did not meet the minimum criteria for establishment of tolerance values in this study.

For 20 of the 46 taxa, new tolerance values were in close agreement with the tolerance values provided in *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort*. There were notable changes for 26 taxa as follows:

| | |
|---|---|
| Caenidae | 7 (previous tolerance value) to 2 (new tolerance value) |
| Heptagenidae | 4 to 0 |
| Leptohyphidae | 4 to 2 |
| Nemouridae | 2 to 0 |
| Brachycentridae | 1 to 3 |
| Glossostomatidae | 0 to 3 |
| Helicopsychidae | 3 to 1 |
| Philoptomatidae | 3 to 5 |
| Polycentropodidae | 6 to 2 |
| Psychomiidae | 2 to 5 |
| Rhyacophilidae | 0 to 2 |
| Elmidae | 4 to 0 |
| Halipidae | 5 to 9 |
| Psphenidae | 4 to 2 |
| Chironomidae | 6 to 8 |
| Psychodidae | none available to 5 |
| Stratiomyidae | 8 to 3 |
| Tipulidae | 3 to 1 |

| | |
|---|---|
| Veliidae | none available to 3 |
| Coenagrionidae | 9 to 5 |
| Gomphidae | 4 to 0 |
| Lestidae | 9 to 5 |
| Acari | 5 to 3 |
| Gastropoda | 8 to 5 |
| Amphipoda | 8 to 5 |
| Oligochaeta | 5 to 9 |

Changes in tolerance values and the criteria for sensitive and tolerant BMIs resulted in differences in new tolerance value average, percent sensitive BMIs, and percent tolerant BMIs compared to the previous versions of these metrics. This will be discussed in more depth later in the report.

## C. Development of the Updated IBI

### 1. Screening and Selection of Potential Core Metrics

#### Sensitivity to Human Disturbance

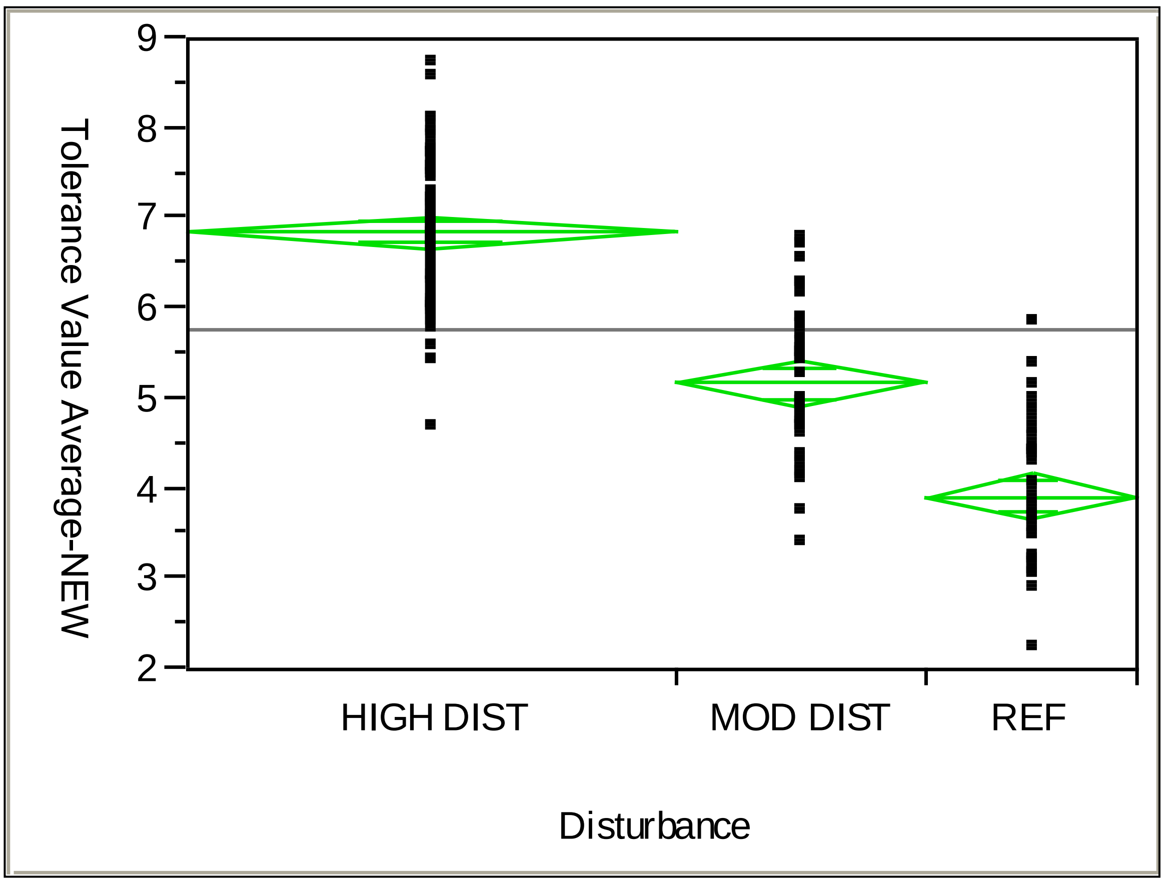
Table A-2 summarizes the results of the ANOVAs conducted to evaluate the sensitivities of the BMI metrics to human disturbance. As an example, Figure 3 illustrates the ANOVA for tolerance value average-new, which had a highly significant positive relationship with human disturbance ($p<0.0001$, $r^2=0.71$). Overall, 25 of the 27 BMI metrics evaluated had significant differences between the REF, MOD DIST, and HIGH DIST groups, many with $p<0.0001$. The only metrics evaluated that did not have significant differences between study reach groups were BMI density and percent scrapers.

The new tolerance value average, % sensitive BMIs, and % tolerant BMIs metrics were more responsive to human disturbance compared to the previous versions. The new versions of these metrics had greater differences in means between study reach groups and better p and $r^2$ compared with the previous versions (see Table A-2). This was particularly the case for % tolerant BMIs and tolerance value average.

BMI metrics with the strongest negative responses to human disturbance were # EPT families ($p<0.0001$, $r^2=0.68$), % sensitive BMIs-NEW ($p<0.0001$, $r^2=0.67$), % sensitive BMIs-OLD ($p<0.0001$, $r^2=0.65$), % EPT minus Baetidae ($p<0.0001$, $r^2=0.62$), % PT ($p<0.0001$, $r^2=0.59$), # insect families ($p<0.0001$, $r^2=0.58$), and % shredders + predators ($p<0.0001$, $r^2=0.57$). BMI metrics with the strongest positive responses to human disturbance were tolerance value average-NEW ($p<0.0001$, $r^2=0.71$) and % tolerant BMIs-NEW ($p<0.0001$, $r^2=0.56$). These metrics were all considered for further analyses as potential core metrics, except for % sensitive BMIs-OLD, which was slightly less responsive to human disturbance compared to % sensitive BMIs-NEW, and would be redundant with the new metric.

# Figure 3: ANOVA Comparison of Tolerance Value Average-NEW at REF, MOD DIST, and HIGH DIST Reaches

Means and distributions of tolerance value average-NEW for study reach groups are represented. Top and bottom of diamonds are the 95 percent confidence limits, and the center lines are the means. The lower and upper lines are the 25 percent and 75 percent quantiles. N=153, p<0.0001, $r^2 = 0.71$. The p value is for the ANOVA where IBI score is the dependent variable and disturbance category is the independent variable.



## Natural Relationships with Physiochemical Parameters

Table 6 summarizes the results of the multiple regression analyses conducted to evaluate relationships between the eight potential core metrics and the group of physiochemical regressors at the REF study reaches (n=39). As discussed in Methods, this is an important step in screening the potential core metrics.

**Table 6: Summary of Multiple Regression Analyses of Potential Core Metrics vs. Physiochemical Parameters (Elevation, Gradient, Watershed Area, and Stream Temperature) at REF Study Reaches (n=39)**

| Potential Core Metric | $R^2$ | P |
|---|---|---|
| # insect families | 0.10 | 0.39 |
| # EPT families | 0.23 | 0.06 |
| % EPT minus Baetidae | 0.03 | 0.86 |
| % PT | 0.12 | 0.33 |
| Tolerance value average-NEW | 0.15 | 0.18 |
| % sensitive BMIs-NEW | 0.06 | 0.72 |
| % tolerant BMIs-NEW | 0.26 | 0.03 |
| % predators + shredders | 0.09 | 0.46 |

The multiple regression for % tolerant BMIs was significantly related to the group of physiochemical regressors ($r^2$ = 0.26, p=0.03), with a positive relationship with elevation (p=0.01) being the strongest relationship with the individual regressors. Due to this statistically significant relationship, % tolerant BMIs was eliminated from consideration as a core metric. None of the other seven BMI metrics had statistically significant relationships (i.e., $p<0.05$) with the group of physiochemical regressors.

## Core Metric Selection

Based on the results presented above, seven core metrics were selected for inclusion in the IBI:

- # of insect families
- # of EPT families
- % EPT minus Baetidae
- % PT
- Tolerance value average-NEW
- % sensitive BMIs-NEW
- % predators + shredders

The core metrics were among the most sensitive to human disturbance among all the metrics tested, either increasing or decreasing from HIGH DIST to MOD DIST to REF groups. None had statistically significant natural relationships with the group of physiochemical parameters among the REF sites. Collectively, the core metrics are diversified in that they represent different aspects of community structure including diversity, disturbance sensitivity, and trophic structure.

### 2. Defining Scoring Categories and Ranges for Core Metrics

Scoring ranges were developed for the core metrics using the criteria presented in Methods. The scoring ranges are provided below in Table 7.

**Table 7**
**Core Metric Scoring Ranges**

| Score | # insect families | # EPT families | % EPT-Baetidae | % PT | Tolerance value avg. | % sensitive BMIs | %shredders +predators |
|---|---|---|---|---|---|---|---|
| 10 | 29+ | 15 | 49+ | 22+ | 3.21 or less | 60+ | 27+ |
| 9 | 26 to 28 | 14 | 37 to 49 | 15 to 22 | 3.22 to 3.82 | 46-59 | 19 to 26 |
| 8 | 25 | 12 to 13 | 32 to 36 | 12 to 14 | 3.83 to 4.32 | 39 to 45 | 16 to 18 |
| 7 | 24 | 11 | 27 to 31 | 10 to 11 | 4.33 to 4.81 | 32 to 38 | 14 to 15 |
| 6 | 23 | 10 | 23 to 26 | 8 to 9 | 4.82 to 5.29 | 26 to 31 | 12 to 13 |
| 5 | 19 to 22 | 9 | 18 to 22 | 6 to 7 | 5.30 to 5.68 | 20 to 25 | 10 to 11 |
| 4 | 16 to 18 | 7 to 8 | 13 to 17 | 4 to 5 | 5.69 to 6.07 | 14 to 19 | 8 to 9 |
| 3 | 13 to 15 | 5 to 6 | 8 to 12 | 3 | 6.08 to 6.47 | 8 to 13 | 6 to 7 |
| 2 | 10 to 12 | 3 to 4 | 2 to 7 | 2 | 6.48 to 6.87 | 2 to 7 | 4 to 5 |
| 1 | 7 to 10 | 1 to 2 | 1 | 1 | 6.88 to 7.48 | 1 | 2 to 3 |
| 0 | 0 to 6 | 0 to 1 | 0 | 0 | 7.49+ | 0 | 0 to 1 |

### 3. Defining IBI Classifications and Scoring Ranges

IBI classifications and scoring ranges were developed using the criteria presented in Methods, and are provided in Table 8.

**Table 8**
**Classifications of Biological Integrity and Scoring Ranges**

| Category | Scoring Range |
|---|---|
| Excellent | 61 to 70 |
| Good | 48 to 60 |
| Fair | 31 to 47 |
| Poor | 9 to 30 |
| Very Poor | 0 to 8 |

## 4. Testing the IBI

### Accuracy and Consistency of IBI Scores and Classifications

Table A-3 lists IBI scores and biological integrity classifications for each study reach in the Validation Group (n=37) and the Test Group (n=153). Since the Validation Group study reaches were not used to develop the IBI, they provide a means to independently assess the IBI's accuracy in classifying biological integrity. Using the criteria in Table 5, the IBI was accurate to two classes of biological integrity 81 percent of the time for the Validation Group, and to three classes 100 percent of the time. In theory, if the IBI is incorrect in classifying study reaches to two classes of biological integrity 19 percent of the time, the probability of being incorrect to this level of precision at a given study reach two years in a row would be less than 4 percent. Thus, the IBI appears to fairly reliable in determining biological integrity to two classes, which is the desired level of precision. All 37 study reaches in the Validation Set were correctly classified to three classes. It appears there is little chance for gross inaccuracies in classifying biological integrity with the IBI. Data from study reaches in future years of the Program can be used to further evaluate the IBI's accuracy in classifying biological integrity.

While use of the overall data set (i.e., all 190 study reaches) to validate the IBI's accuracy in classifying biological integrity would be circular (i.e., it includes the data used to develop it), it is useful to explore how the IBI's accuracy differed between study reach disturbance groups (i.e., REF, MOD DIST, and HIGH DIST). For the HIGH DIST study reaches (n=96), the IBI was accurate 94 percent of the time to two classes of biological integrity, and 100 percent of the time to three classes. For the REF study reaches (n=39), accuracy was 87 percent to two classes and 95 percent to three classes of biological integrity. Accuracy was lowest for the MOD DIST study reaches (n=55) at 73 percent to two classes and 93 percent to three classes of biological integrity.

Figure 4 provides a graphical illustration of IBI scores at the 12 study reaches that have been surveyed each and every year since 2002. Table 9 provides IBI scoring ranges and averages at the 12 study reaches for each year.

**Figure 4**
**IBI Score by Year at 12 Study Reaches Sampled Each Year Since 2002**

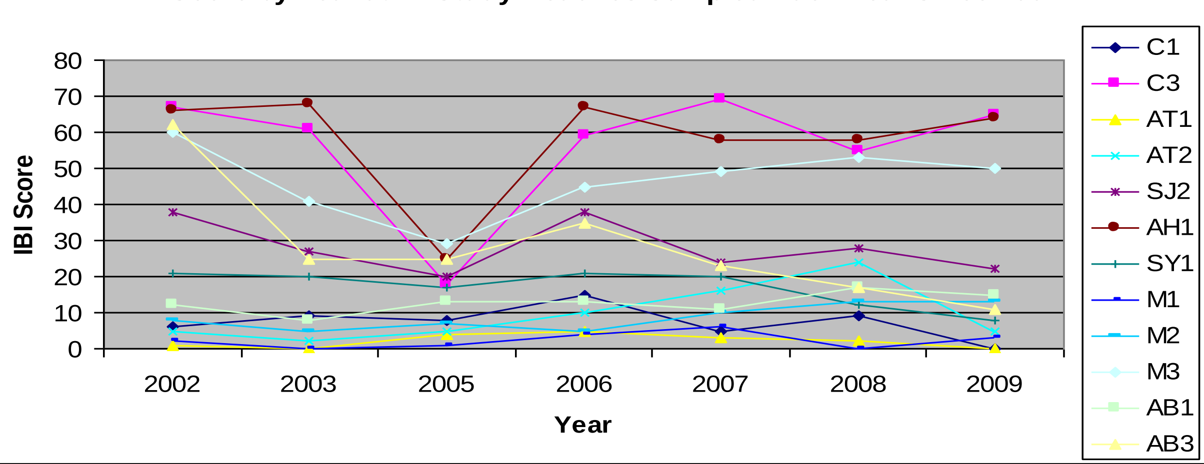


**Table 9**
**IBI Score by Year at 12 Study Reaches Sampled Each Year Since 2002**

| Study Reach | 2002 | 2003 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|
| C1 | 6 | 9 | 8 | 15 | 5 | 9 | 0 |
| C3 | 67 | 61 | 18 | 59 | 69 | 55 | 65 |
| AT1 | 1 | 0 | 4 | 5 | 3 | 2 | 0 |
| AT2 | 5 | 2 | 5 | 10 | 16 | 24 | 5 |
| SJ2 | 38 | 27 | 20 | 38 | 24 | 28 | 22 |
| AH1 | 66 | 68 | 25 | 67 | 58 | 58 | 64 |
| SY1 | 21 | 20 | 17 | 21 | 20 | 12 | 8 |
| M1 | 2 | 0 | 1 | 4 | 6 | 0 | 3 |
| M2 | 8 | 5 | 7 | 5 | 10 | 13 | 13 |
| M3 | 60 | 41 | 29 | 45 | 49 | 53 | 50 |
| AB1 | 12 | 8 | 13 | 13 | 11 | 17 | 15 |
| AB3 | 62 | 25 | 25 | 35 | 23 | 17 | 11 |
| AVERAGE | 29 | 22 | 14 | 26 | 25 | 24 | 21 |
| RANGE | 1 to 67 | 0 to 68 | 1 to 29 | 4 to 67 | 3 to 69 | 0 to 58 | 0 to 65 |

For the most part, IBI score ranges and averages were fairly consistent from year to year at the 12 study reaches. The exception to this was 2005, when the average IBI score was noticeably lower, and the scoring range was smaller and towards the lower end of the scale, with all 12 study reaches in the Very Poor and Poor range, including AH1 and C3, which are REF study reaches. Amongst all study reaches surveyed in 2005, accuracy of the IBI was relatively low at 74 percent to two classes of biological integrity and 84 percent to three classes.

2005 was the second heaviest rainfall year on record since rainfall data was first kept locally in 1867. Unusually high peak stream flows during the winter of 2004-2005 scoured out local creeks and significantly altered the BMI communities inhabiting them, which had much lower density and diversity at the time of the 2005 surveys as compared to other years. The scouring flows were followed by a biological succession where quick colonizers including Baetidae mayflies and Chironomidae midges were unusually dominant. Surveys were completed relatively early in 2005 (late April), which did not allow time for the BMI community to recover from this early state of biological succession. The accuracy of the IBI appears to have been impaired by this sequence of events. In future years with heavy rainfall and peak stream flows, field surveys should be delayed until late May or June to allow more recovery of the BMI community.

### Sensitivity to Human Disturbance

ANOVA results indicate highly significant differences in IBI scores between the REF, MOD DIST, and HIGH DIST groups, with $r^2$ of 0.70 and $p<0.0001$ (see Figure 5). All of the group means were significantly different from one another. Linear regression analyses showed highly significant positive relationships between IBI score and percent watershed undisturbed ($r^2=0.54$, $p<0.0001$), habitat assessment score ($r^2=0.64$, $p<0.0001$), and the composite of percent watershed undisturbed/habitat assessment score ($r^2$=0.66, $p<0.0001$). Exponential regressions provided slightly better $r^2$ for IBI score vs. percent watershed undisturbed (0.62), habitat assessment score (0.65), and the composite of percent watershed undisturbed/habitat assessment score (0.70). The regressions are illustrated in Figures 6, 7, and 8. The regressions of IBI score vs. the composite of percent watershed undisturbed/habitat assessment score and the ANOVA of IBI score amongst the study reach groups had the highest $r^2$ values. These results indicate that considering both watershed-level land use patterns and localized physical habitat conditions provided the best prediction of the biological integrity.

# V. Recommendations

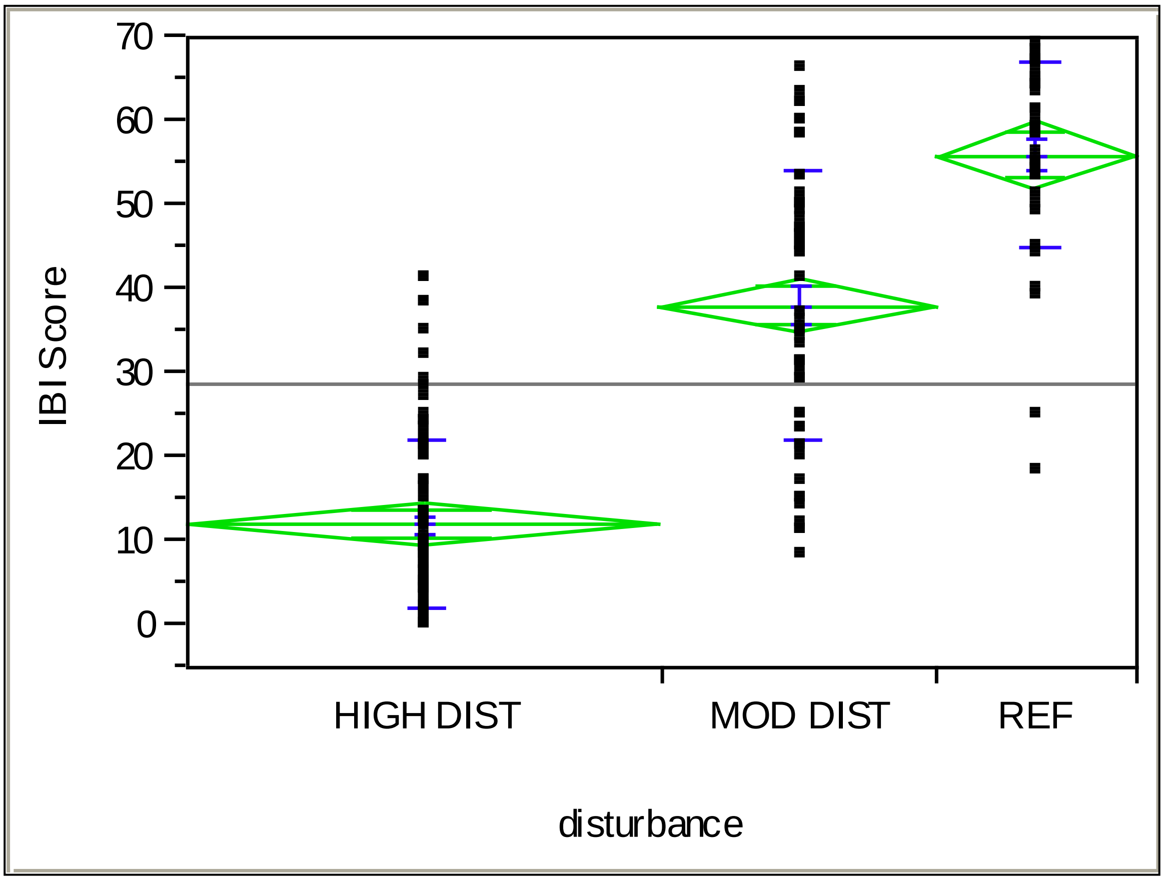
The updated IBI is based on a set of streams that collectively represent a wide range of natural physiochemical variability and levels of human disturbance. In addition, significant fluctuations in rainfall and peak stream flow from year to year and their effects on the BMI communities of study area streams have been documented over the past 10 years. This has allowed for the development of an IBI that serves as a reliable tool for classifying the biological integrity of streams in the study area, monitoring their condition through time, and identifying any changes that may occur in the future from increased development, habitat restoration projects, etc.

There are ways in which the collective data set could be diversified, for example by including streams in the study area that have not yet been surveyed, and expanding the study area further west and north to the Hollister and Bixby Ranch areas, Point Conception, Santa Ynez River watershed, etc. The IBI should be updated every 5 to 10 years to account for the greater range of conditions observed.

The updated IBI represents an excellent tool for assessing and monitoring the biological condition of freshwater streams in the study area. However, there is no equivalent tool for estuarine waters in the study area, which could be assessed using similar bioassessment methodology as used in this Program. IBIs have been produced for estuarine waters in many regions, and with adequate data one could likely be produced in the study area as well. Given the ecological importance of estuarine waters, and their importance as they relate to commercial and recreational uses and the local economy, the City and County should consider implementing an estuarine bioassessment program if funding allows.

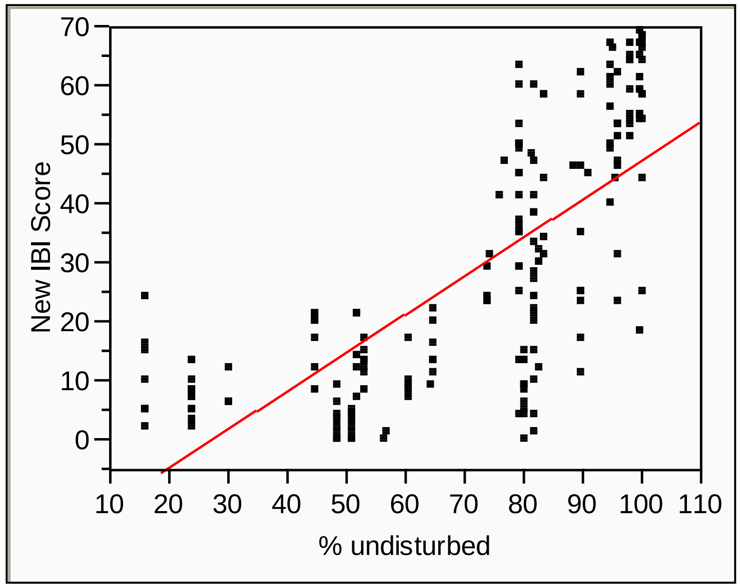
# Figure 5: ANOVA Comparison of IBI Score at REF, MOD DIST, and HIGH DIST Reaches

Means and distributions of IBI scores for study reach groups are represented. Top and bottom of diamonds are the 95 percent confidence limits, and the center lines are the means. The lower and upper lines are the 25 percent and 75 percent quantiles. N=190 (all study reaches), $p<0.0001$, $r^2 = 0.70$. The p value is for the ANOVA where IBI score is the dependent variable and disturbance category is the independent variable.



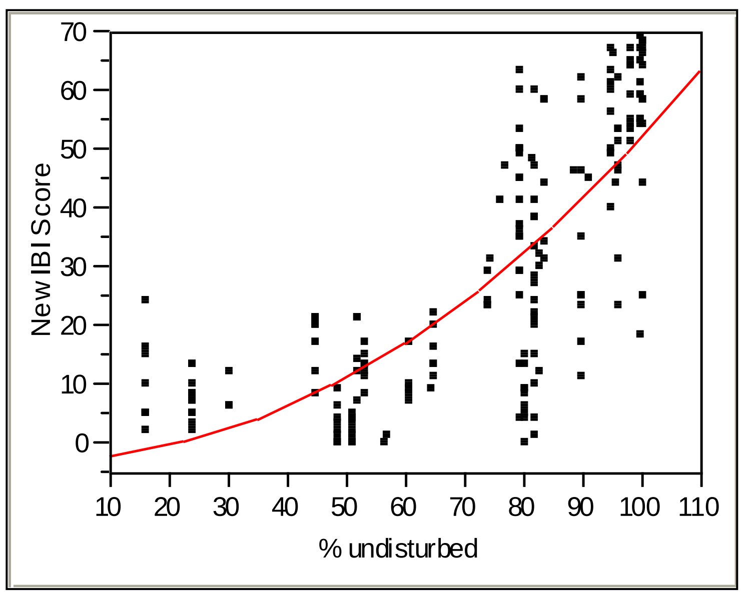
# Figure 6: Regressions of IBI Score vs. Percent of Watershed Undisturbed

The graph shows the linear relationship between IBI score (dependent variable, y-axis) and % watershed undisturbed (independent variable, x-axis) amongst all of the study reaches (n=190). A significant positive relationship is indicated by the regression analysis ($p<0.0001$, $r^2 = 0.54$). The best-fit line represents the relationship between the variables, the equation for which is:




IBI Score = -17.27667 + 0.6471196 (% watershed undisturbed)

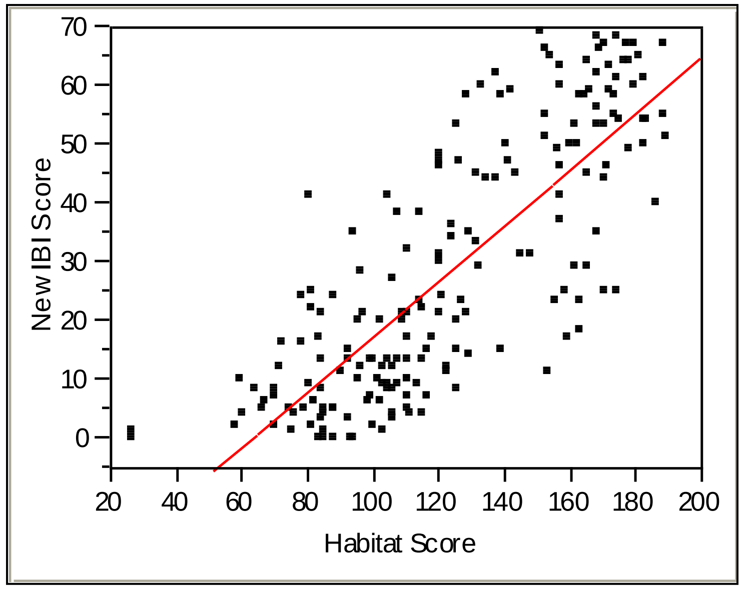
The graph shows the relationship between IBI score (dependent variable, y-axis) and percent of watershed undisturbed (independent variable, x-axis) amongst all of the study reaches (n=190) using an exponential transformation of the independent variable. A significant positive relationship is indicated by the regression analysis ($p<0.0001$, $r^2 = 0.62$). The best-fit line represents the relationship between the variables, the equation for which is:




IBI Score = -2.290715 + 0.0054781 (% undisturbed)$^2$

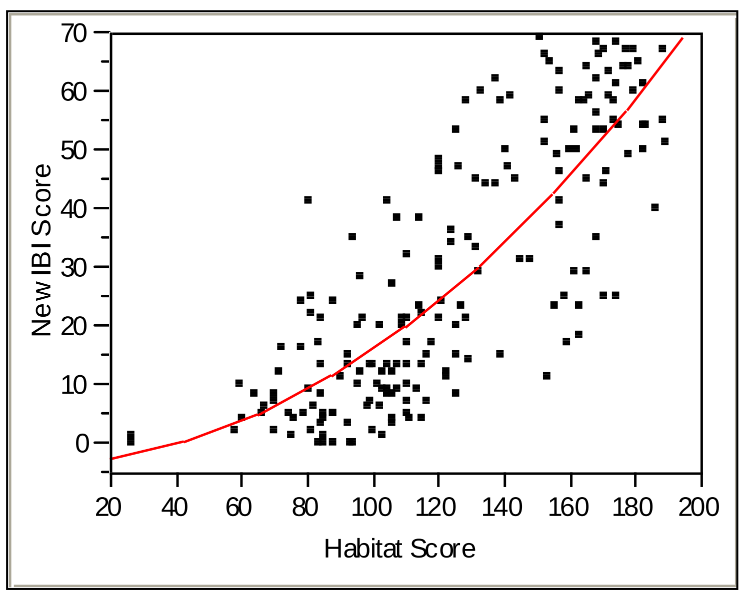
# Figure 7: Regressions of IBI Score vs. Habitat Assessment Score

The graph shows the linear relationship between IBI score (dependent variable, y-axis) and habitat assessment score (independent variable, x-axis) amongst all of the study reaches (n=190). A significant positive relationship is indicated by the regression analysis ($p<0.0001$, $r^2 = 0.64$). The best-fit line represents the relationship between the variables, the equation for which is:




IBI Score = -29.69897 + 0.4737229 Habitat Score

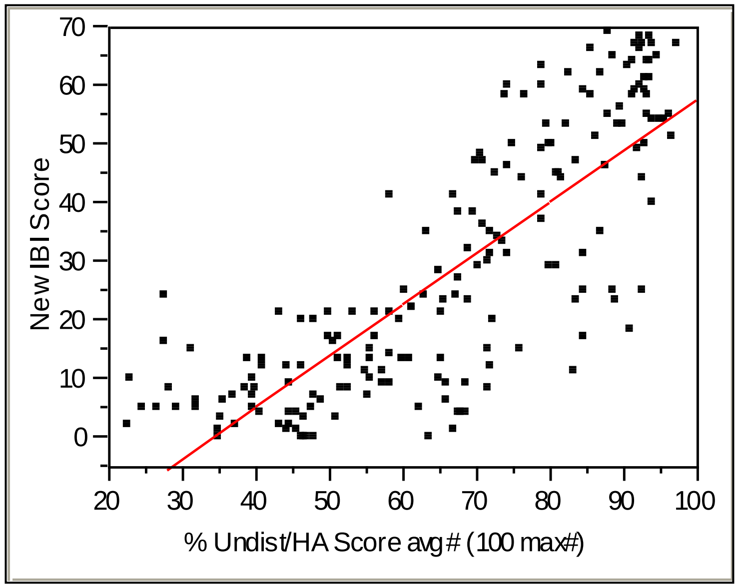
The graph shows the relationship between IBI score (dependent variable, y-axis) and percent of habitat assessment score (independent variable, x-axis) amongst all of the study reaches (n=190) using an exponential transformation of the independent variable. A significant positive relationship is indicated by the regression analysis ($p<0.0001$, $r^2 = 0.65$). The best-fit line represents the relationship between the variables, the equation for which is:




New IBI Score = -2.928329 + 0.0019125 $(\text{Habitat Score})^2$

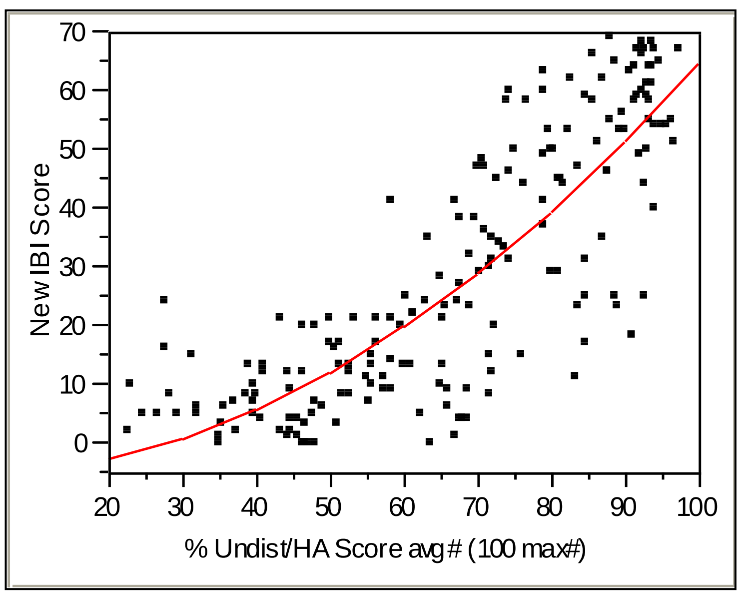
# Figure 8: Regressions of IBI Score vs. Percent Watershed Undisturbed/Habitat Assessment Score

The graph shows the linear relationship between IBI score (dependent variable, y-axis) and the percent watershed undisturbed/habitat assessment score composite (independent variable, x-axis) amongst all of the study reaches (n=190). A significant positive relationship is indicated by the regression analysis ($p<0.0001$, $r^2 = 0.66$). The best-fit line represents the relationship between the variables, the equation for which is:




IBI Score = -29.70958 + 0.8800597 (% Undist/HA Score avg)

The graph shows the relationship between IBI score (dependent variable, y-axis) and percent watershed undisturbed/habitat assessment score composite score (independent variable, x-axis) amongst all of the study reaches (n=190) using an exponential transformation of the independent variable. A significant positive relationship is indicated by the regression analysis ($p<0.0001$, $r^2 = 0.70$). The best-fit line represents the relationship between the variables, the equation for which is:




New IBI Score = -5.089113 + 0.0070268 $(\text{\% Undist/HA Score avg})^2$

# VI. References

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Creeks and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition, EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water. Washington, D.C.

Burt, W.H., and R.P. Grossenheider. 1976. A Field Guide to the Mammals, North America North of Mexico. Third Edition. Houghton Mifflin Company. Boston, New York.

California Department of Fish and Game, Aquatic Bioassessment Laboratory. 2002. List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort. Revised April 30, 2002.

Cooper, S.D., Dudley T.L., and N. Hemphill. 1986. The Biology of Chaparral Streams in Southern California. Proceedings of the Chaparral Ecosystems Research Conference, May 16-17, 1985, Santa Barbara, California. California Water Resources Center, University of California Santa Barbara. Report No. 62. June, 1986.

County of Santa Barbara, Project Clean Water. 2002. Santa Barbara County Coastal Creeks Bioassessment Program, Annual Report, Year 2001.

Dale, N. 1986. Flowering Plants, the Santa Monica Mountains, Coastal and Chaparral Regions of Southern California. Published by Capra Press in cooperation with the California Native Plant Society.

ECORP Consulting, Inc. 2005. Results of 2004 Benthic Macroinvertebrate (BMI) Surveys Conducted for the City of Santa Barbara BMI Monitoring Program.

Ecology Consultants, Inc. 2004. Santa Barbara County Creeks Bioassessment Program, 2003 Annual Report and Index of Biological Integrity.

Hickman, J.C. 1993. The Jepson Manual, Higher Plants of California. University of California Press. Berkeley, CA.

McAuley, M. 1996. Wildflowers of the Santa Monica Mountains. Second Edition. Canyon Publishing Company. Canoga Park, California.

Merritt, R.W. and K.W. Cummins. 1996. An Introduction to the Aquatic Insects of North America, Third Edition. Kendall/Hunt Publishing Company.

Moyle, P.B. 2002. Inland Fishes of California. University of California Press.

Peterson, R.T. 1990. A Field Guide to Western Birds. Third Edition. Houghton Mifflin Company. Boston, New York.

Stebbins, R.C. 1985. A Field Guide to Western Reptiles and Amphibians. Second Edition. Houghton Mifflin Company. Boston, New York.

Stewart, B.P. and C.R. Nelson. 1994. Nymphs of North American Stonefly Genera (Plecoptera). University of North Texas Press. Denton, Texas.

United States Geological Survey. Various dates. 7.5 minute quadrangle topographic maps.

# APPENDIX A

## DATA
## AND
## STATISTICAL ANALYSES SUMMARY

**Figure 2: Daily Discharge, Mission Creek at USGS**



Insert data and statistical analyses