I. INTRODUCTION

This report presents the results of the 2002 Santa Barbara County Creeks Bioassessment Program (Program) effort. The Program is envisioned by its participants the County of Santa Barbara Project Clean Water (PCW) and City of Santa Barbara as a long-term effort to assess and monitor the integrity of local stream communities as they respond through time to changing environmental conditions shaped by natural processes and human factors. Thus far, the Program has involved the study of more than 20 coastal streams in southern Santa Barbara County and western Ventura County over a three-year period from 2000 through 2002. The study involves annual collection and analysis of physiochemical and biological data from numerous individual stream reaches throughout the study area using standardized methods adapted from the U.S. Environmental Protection Agency's (USEPA's) *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers* (Barbour et. al., 1999).

In the context of this study, "bioassessment", or "biomonitoring" as it is also called, is the science of using biological assemblages including benthic macroinvertebrates (BMIs), fish, amphibians, and diatoms to assess and monitor aquatic ecosystem integrity (Rosenberg and Resh, 1993, Barbour, M.T., et. al., 1999). Bioassessment is used to assess and monitor many types of water bodies including streams, rivers, lakes, ponds, estuaries, and coastal marine waters. Bioassessment is most often applied to detect and monitor the responses of aquatic ecosystems to human influences. Other applications of bioassessment include (1) determining natural relationships between aquatic biota and variable physiochemical conditions; (2) classifying water bodies, for example classifying lakes as oligotrophic (i.e., low nutrient levels) or eutrophic (i.e., enriched nutrient levels) based on the assessment of algal communities, and; (3) paleolimnological investigations, for example determining historical pH levels in lakes through analysis of historical diatom community composition determined from sampling lake bottom sediments.

The origins of modern bioassessment date back to the early 1900's in Europe, where Kolkwitz and Marsson developed the now infamous Saprobien system to assess the impacts of organic pollution inputs on rivers and lakes using BMIs as biological indicators. Since then, bioassessment has been a key element in the assessment and monitoring of water bodies in Europe. Acceptance of bioassessment was slower in the United States and the rest of North America, even with the early work of S.A. Forbes, who documented the value of indicator fauna in the Illinois River in the 1870's, and the progress of European scientists. Until fairly recently, physiochemical measurements were relied upon almost exclusively in the U.S. to assess and monitor the integrity of receiving waters and set water body attainment standards, despite the well-documented arguments of biologists that pollution is primarily a biological problem (Wilhm, 1975).

There have been many important contributions to the development and acceptance of bioassessment in the U.S., perhaps none more important than the work of Ruth Patrick. Through the Philadelphia Academy of Sciences, Patrick and her co-workers conducted a series of river surveys in the eastern U.S. beginning in 1948. Patrick's work was strongly influenced by her taxonomic studies of diatoms, and her insistence on sampling several biological assemblages (e.g., diatoms, BMIs, and fish). Her classic work published in 1949 used measures of biological community diversity (i.e., number of species present) and composition (types of species present) to assess river ecosystem conditions. Patrick's work influenced the research and accomplishments of many others including MacArthur and Wilson, Wihlm, and Cairns (Resh and Rosenberg, 1993).

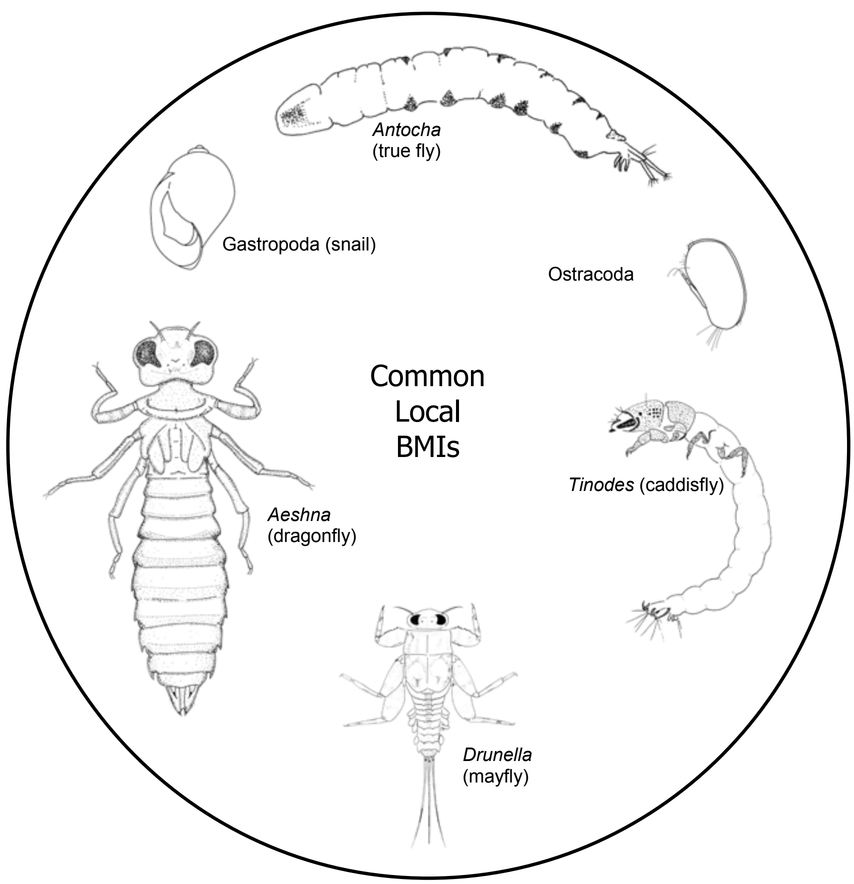
Within the last fifteen years or so, the use of bioassessment has increased dramatically throughout the U.S. This has been due largely to the evolution of rapid, cost-effective assessment and data analysis techniques, which have been developed by building on the work of early bioassessment pioneers (Rosenberg and Resh, 1993). Today, bioassessment is used across the country to assess and monitor water bodies of all types. In addition, several states have established official biological attainment criteria, or "biocriteria", that are used to regulate waste dischargers and developers, and help make other types of water body management decisions. The increased popularity of bioassessment is exemplified in southern California by the recent development and implementation of bioassessment-based stream and estuary monitoring programs by PCW and the City of Santa Barbara, County of Ventura, City of Ventura, County of Los Angeles, County of Orange, County of San Diego, and the state Regional Water Quality Control Boards among others. The California Department of Fish and Game (CDFG) coordinates and provides technical guidance for bioassessment efforts state-wide. Similarly, the USEPA and U.S. Geological Survey (USGS) provide technical guidance and administer nation-wide bioassessment programs.

The ability to use biological assemblages as indicators of aquatic ecosystem integrity is based on the fact that individual species have specific habitat requirements, and varying abilities to withstand or "tolerate" disturbances such as water pollution, physical habitat alterations, introduction of non-native species, etc. Thus, the presence (or absence) of certain species in a water body provides an indication of ecosystem integrity, and potential causes of habitat degradation. For example, the presence of a viable steelhead trout population or large numbers of stonefly nymphs in a stream indicates that the stream has cool, well-oxygenated waters and a sufficient prey base, as steelhead and stoneflies require these conditions to survive. In addition, steelhead and stoneflies are fairly intolerant of water pollution and other habitat alterations such as increased sedimentation and stream temperatures. Viable populations of these species indicate that the stream ecosystem is fairly intact. Besides individual species, biological community metrics relating to diversity (i.e., number of species present) and composition (i.e., which types of organisms are present) are often reliable indicators of ecological integrity.

It is important to realize that streams and other types of aquatic ecosystems (e.g., lakes, estuaries, marine waters) are dynamic, thus most aquatic species have somewhat broad tolerances to short-term variations in environmental conditions. Considering this, most aquatic organisms are not expected to respond quickly or adversely to minor changes in water quality or other habitat conditions. This does not detract from the application of bioassessment as an ecosystem management tool because the goal of ecological monitoring should be to detect significant changes in ecosystems, not minor fluctuations that are quickly dampened. If degraded conditions persist for a period sufficient to produce population effects (i.e., altered growth, altered reproduction, mortality) then biological community structure will change. Large numbers of species can become locally extinct due to water pollution and other forms of habitat degradation, with major ramifications for ecosystem stability, maintenance of food chains, and broad ecosystem processes including primary and secondary production, mineral and nutrient cycling, etc. (Rosenberg and Resh, 1993).

Another reason for using aquatic organisms as indicators of ecosystem integrity is the fact that they are continuously exposed to and integrate variable environmental conditions over the course of their lifetimes, which can span many months or years. For this reason, bioassessment studies that are conducted seasonally or annually can provide a great deal of insight as to the cumulative, long-term ecological integrity of the water body or bodies being studied. As a result, bioassessment is often more cost-effective in the context of water body assessment and monitoring compared to traditional water chemistry analyses, which typically must be conducted more often and at higher expense to provide a reflection of water quality, which has inherently high variability. Bioassessment also provides a more integrative picture of aquatic ecosystems compared to water quality analyses, which measures only chemical attributes.

Like most other stream bioassessment studies, this Program focuses on BMIs. BMIs are aquatic insects, crustaceans, gastropods, worms, and other invertebrates of a half-millimeter in size or greater that inhabit the bottom substrates of streams for at least part of their lifecycles (Rosenberg and Resh, 1993). There are several reasons why BMIs are advantageous for use as biological indicators. First, BMIs are a critical component of stream ecosystems in that they typically represent a large proportion of the stream community biomass, perform important functions in the cycling of nutrients and energy, and are food sources for predators such as fish and amphibians. Major changes in BMI assemblages can have profound ramifications in stream ecosystems. Secondly, their responsiveness to environmental perturbations including anthropogenic impacts is well-documented in the literature (Rosenberg and Resh, 1993; Allan, 1995, Hauer and Lamberti, 1996; Merritt and Cummins, 1996; Barbour et. al., 1999). There is a wealth of information available on life history, distribution, habitat requirements, and pollution tolerances for most BMIs. BMIs are also particularly advantageous for study in that they are typically abundant and diverse compared to other groups such as fish and amphibians, and are relatively easy to collect (Rosenberg and Resh, 1993; Hauer and Lamberti, 1996; Merritt and Cummins, 1996; Barbour et. al., 1999).



II. PROGRAM MISSION AND GOALS

The Program mission is to assess and monitor the ecological integrity of local stream communities as they respond through time to changing environmental conditions that are shaped by natural processes and human factors. Individual goals that support the Program mission are as follows:

1. Determine the strength and nature of natural relationships between local stream biota and physiochemical parameters including stream temperature, water chemistry, stream discharge, microhabitat (e.g., riffles vs. pools), stream width, elevation, gradient, stream order, catchment area, and climatic trends.
2. Determine the strength and nature of relationships between local stream ecosystem integrity and human disturbances including urban development, agricultural development, cattle grazing, physical habitat alterations (e.g., channelization), increased sedimentation, altered hydrology, and water pollution.
3. Determine which biological parameters are the most reliable indicators of local stream ecosystem integrity.
4. Determine how local stream biota responds through time to changing human influences, including changes in land use, and stream habitat restoration and water quality improvement efforts.

III. PROGRAM STUDY AREA

The Program study area extends from Gaviota Creek in southern Santa Barbara County east to Sespe Creek in western Ventura County (see Figure 1). A total of 42 study reaches in 17 coastal watersheds have been surveyed one or more times during the spring and summer of 2000, 2001, and 2002. Table 1 lists the study reaches, their locations, and the year(s) in which they were surveyed. Figures 2, 3, and 4 provide maps of individual study streams and reaches.

Collectively, the study reaches range from 1st order mountain tributaries to 5th order main stem streams, and from relatively pristine streams to streams that are severely impaired by human disturbance. The 42 study reaches have been grouped into four different categories based on the degree to which they have been disturbed by anthropogenic stressors: UNDIST, MOD DIST, DIST AG, and DIST URB. Table 1 provides definitions and criteria for each category and indicates which category each study reach has been placed into.

The severity of human disturbance in local streams is dictated by the nature and intensity of surrounding land uses. As a general observation, anthropogenic impacts appear to be more pronounced in local streams in urbanized areas compared to those in rural areas. Some of the major forms of human disturbance to local streams include: (1) altered hydrology and stream geomorphology due to watershed development, flood control projects, etc., (2) sedimentation of pools and riffle substrates due to increased erosion and deposition of fine sediments, (3) degraded water quality due to pollution inputs, (4) elevated stream temperatures due to loss of overhanging riparian vegetation and shade, (5) habitat fragmentation through the construction of in-stream barriers such as dams, road crossings, bridges, and culverts, (6) introductions of invasive, non-native plants (e.g., *Arundo donax*), and wildlife (e.g., bullfrogs and crayfish), and (7) disturbances to vegetation and wildlife associated with trampling (i.e., by cattle, vehicles, bikers, hikers, etc.), noise, lighting, air pollution, and predation by domestic pets.

Table 1 Study Reaches			
Study Reach	Location	Disturbance Category	Years Surveyed
SES1	Sespe Creek just below confluence with Little Sespe Creek	UNDIST	2002
MA1	Matilija Creek, approx. 1.25 mi. above dam, 0.25 mi. below first residential village	UNDIST	2002
MA2	Matilija Creek, approx. 1 mi. upstream of confluence with Old Man Mtn. Creek	UNDIST	2002
RIN1	Rincon Creek, just upstream of Highway 150 crossing at Gobernador Cyn Rd.	MOD DIST	2002
C1	Carpinteria Creek, approx. ¼-mi. downstream of Carpinteria Ave.	DIST URB	2000, 2001, 2002
C2	Carpinteria Creek, approx. ¼-mi. upstream of U.S. 101.	DIST AG	2000, 2001
C3	Gobernador Creek, approx. ¼-mile upstream of debris basin	UNDIST	2000, 2001, 2002
F1	Franklin Creek just upstream of entrance into Carpinteria Salt Marsh	DIST URB	2000
SM1	Santa Monica Creek just upstream of entrance into Carpinteria Salt Marsh	DIST URB	2000
SY1	Sycamore Creek just below Mason St. bridge	DIST URB	2002
M1	Mission Creek at De la Guerra St.	DIST URB	2000, 2002
M2	Old Mission Creek at Bohnet Park	DIST URB	2002
M3	Mission Creek at upstream end of Rocky Nook Park	MOD DIST	2000, 2002
M4	Rattlesnake Creek, approx. 0.5 mi. upstream of Las Canovas Rd. crossing	UNDIST	2000
M5	Rattlesnake Creek, approx. 0.25 mi. downstream of Gibraltar rd. crossing	UNDIST	2000
M6	Mission Creek, at falls above Jesuita Trail crossing	UNDIST	2000
AB1	Arroyo Burro at upstream end of Alan Rd.	DIST URB	2002
AB2	Arroyo Burro just downstream of Torino Rd.	DIST URB	2000, 2001, 2002
AB3	San Roque Creek, ¼-mi. upstream of Foothill Rd.	MOD DIST	2000, 2001, 2002
AT1	Atascadero Creek near Patterson Rd.	DIST URB	2001, 2002
AT2	Atascadero Creek just downstream of Cieneguitas Creek confluence	DIST URB	2001, 2002
SA1	San Antonio Creek, approx. ½ mi. upstream of Tucker's Grove Park	MOD DIST	2000
SA2	San Antonio Creek, approx. ¼ mi. upstream of Highway 154	MOD DIST	2000
MY1	Maria Ygnacio Creek, approx. ¼ mi. downstream of San Marcos Rd.	DIST URB	2000
MY2	Maria Ygnacio Creek, approx. ¼ mi. upstream of debris basin	UNDIST	2000
MY3	Maria Ygnacio Creek, approx. ¼ mi. upstream of Highway 154	UNDIST	2000
SJ1	San Jose Creek, approx. ¼ mile downstream of U.S. 101.	DIST URB	2000, 2001, 2002
SJ2	San Jose Creek, approx. ½-mile upstream of Patterson Rd. crossing	DIST AG	2000, 2001, 2002
SJ3	San Jose Creek at San Marcos Trout Club	UNDIST	2000, 2001, 2002
SJ4	San Jose Creek, adjacent to southeast junction of Kinevan Rd. and Hwy 154	UNDIST	2000
T1	Tecolote Creek, approx. 150 ft. upstream of Vereda del Padre	DIST URB	2000
T2	Tecolote Creek, adjacent to Vereda Nueva	DIST AG	2000
DP1	Dos Pueblos Creek, approx. 150 ft. downstream of U.S. 101.	DIST AG	2000
EC1	El Capitan Creek in State Park, approx. 300 ft. upstream of the mouth	MOD DIST	2002
R1	Refugio Creek, approx. 1.5 mi. upstream of U.S. 101	DIST AG	2000
R2	Refugio Creek, approx. ¼ mi. downstream of Circle Barbee Ranch	MOD DIST	2000
AH1	Arroyo Hondo, approx. 1 mi. upstream of U.S. 101.	UNDIST	2000, 2001, 2002
AH2	Arroyo Hondo, approx. 2 mi. upstream of U.S. 101.	UNDIST	2000
SO1	San Onofre Creek, just below U.S. 101 culvert	UNDIST	2000
SO2	San Onofre Creek, approx. 1 mi. upstream of U.S. 101	UNDIST	2000, 2001, 2002

Table 1 Study Reaches			
Study Reach	**Location**	**Disturbance Category**	**Years Surveyed**
GAV1	Gaviota Creek at State Beach, just below entrance road/U.S. 101 junction	MOD DIST	2002
GAV2	Gaviota Creek, approx. 600 ft. downstream of Las Canovas Creek confluence	MOD DIST	2002

Disturbance categories:

UNDIST = Undisturbed or minimally disturbed by anthropogenic factors. Minimal signs of human disturbance, habitat assessment score 150/200 or greater, five percent or less of upstream watershed disturbed.

MOD DIST = Lightly to moderately disturbed by anthropogenic factors. Habitat assessment score 120 or greater but less than 150, or if habitat assessment score is greater than 150, greater than five percent of upstream watershed is disturbed.

DIST AG = Heavily disturbed by anthropogenic factors, predominantly by agricultural/rural land uses. Habitat assessment score 120 or less, greater than five percent of upstream watershed disturbed.

DIST URB = Heavily disturbed by anthropogenic factors, predominantly by urban/suburban land uses. Habitat assessment score 120 or less, greater than five percent of upstream watershed disturbed.

Representative photographs from several of the study reaches are provided in Figures 5 through 9. The photographs have been chosen carefully to show the range of conditions the study reaches collectively represent with respect to position in the landscape and level of human disturbance. Program streams and study reaches were selected in part based on their importance to the community and as biological habitat. Examples of why selected streams and study reaches were thought to be particularly important for study are as follows:

- The selected streams have perennial flows at least in some sections, and many support diverse biological communities that include sensitive species such as steelhead trout, red-legged frog, California newt, southwestern pond turtle, and two-striped garter snake.
- Many of the selected streams including Gaviota Creek, San Jose Creek, Atascadero Creek, Franklin Creek, Santa Monica Creek, Matilija Creek, and Sespe Creek are tributaries to important coastal estuaries and wetlands, which support productive biological communities, and have been substantially reduced in area and function in California due to development.
- Several Program streams empty into the ocean near popular beaches such as Goleta Beach (San Jose Creek and Atascadero Creek), Hendry's Beach (Arroyo Burro), the Santa Barbara wharf area and East Beach (Mission Creek and Sycamore Creek), Carpinteria State Beach (Carpinteria Creek), and Rincon State and County Beaches (Rincon Creek). Poor water quality at these beaches has been a chronic problem due in part to polluted runoff from the creeks, resulting in numerous beach advisories.
- Many of the Program streams such as Arroyo Burro, Carpinteria Creek, San Jose Creek, Atascadero Creek, and Rincon Creek are listed as impaired by the State of California and the federal government pursuant to Section 303(d) of the Federal Clean Water Act (CWA). Per CWA, total maximum daily load (TMDL) plans will be required to reduce specific pollutants to acceptable levels in listed streams unless the problems are rectified beforehand.
- Watershed planning and restoration efforts are underway or in the works for several of the Program streams including Gaviota Creek, Arroyo Hondo, San Jose Creek, Arroyo Burro, Mission Creek, Sycamore Creek, Carpinteria Creek, and Matilija Creek. The Program is providing data that will be useful in establishing baseline data for restoration efforts.

INSERT FIGURE 1: STUDY AREA

BACKSIDE OF FIGURE 1

INSERT FIGURE 2: GAVIOTA COAST STUDY REACHES

BACKSIDE OF FIGURE 2

INSERT FIGURE 3: SANTA BARBARA AND GOLETA STUDY REACHES

BACKSIDE OF FIGURE 3

INSERT FIGURE 4: CARPINTERIA AND VENTURA STUDY REACHES

BACKSIDE OF FIGURE 4

INSERT FIGURE 5: SAN JOSE CREEK WATERSHED

BACKSIDE OF FIGURE 5

INSERT FIGURE 6: RELATIVELY UNDISTURBED STREAMS

BACKSIDE OF FIGURE 6

INSERT FIGURE 7: RELATIVELY UNDISTURBED STREAMS

BACKSIDE OF FIGURE 7

INSERT FIGURE 8: COMPARISON OF LOW GRADIENT STUDY REACHES GAV-1 VS. AB-1 AND M-1

BACKSIDE OF FIGURE 8

INSERT FIGURE 9: DISTURBED STREAMS

BACKSIDE OF FIGURE 9

IV. METHODS

Methods used to gather physiochemical and biological data for the study reaches include rapid bioassessment field surveys, laboratory analysis of water samples and BMI samples, spatial data analysis using geographic information system (GIS) software, and review of United States Geological Survey (USGS) 7.5-minute quadrangle maps and 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) and multiple regression analysis were used to characterize relationships among biological parameters, physiochemical parameters, and human disturbance. Table 2 lists each parameter calculated for the study reaches, parameter abbreviations used throughout the remainder of the report, and where (e.g., lab, field, etc.) each parameter was determined. Further discussion of data collection and analysis methods is provided below.

A. Rapid Bioassessment Field Surveys

Rapid bioassessment field surveys were conducted at a total of 30 study reaches in 2000, 12 in 2001, and 23 in 2002 (see Table 1). Surveys were conducted in the spring and early summer each year during base stream discharge (Q) conditions (i.e., low flows) for consistency, as the local stream biota is known to undergo seasonal succession (Cooper et. al., 1986). The surveys were conducted a bit earlier in 2002 (March-May) compared to 2000 and 2001 (May-July). 2002 was a relatively dry year, and it was feared that surface flow could dry up at many of the study reaches by June or July. Work completed during each field survey included the following:

- General observations were recorded on a standard field data sheet, including study reach location, date, time, weather, stream flow conditions, water clarity, and sources of human disturbance. An example field data sheet is provided in the Appendix.
- 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. Representation by each habitat type was quantified as a percentage of the total reach length.
- Stream width (wetted perimeter, channel bottom, and bank full) and riparian corridor width 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.
- Plants and wildlife species observed in the stream and riparian zone were recorded.
- Water temperature, specific conductance, and pH were measured in the field using YSI and Oakton handheld meters. Dissolved oxygen concentration was measured in 2000 and 2002 (not in 2001) using a YSI hand-held meter. Two measurements of each parameter were made, one in a riffle and the other in a pool, and the two values were averaged. Water measurements were made at various times during daylight hours, from mid-morning to late afternoon. Grab samples were collected in 2000 to determine concentrations of nutrients (NO_2, NO_3, NH_4, and PO_4) and suspended solids.

Table 2
List of Parameters Calculated for Each Study Reach

Parameters	Units of Measurement	Abbreviation	Where Measured
PHYSICAL PARAMETERS			
Stream order[1]	None	None	Maps
Elevation[1]	Feet (ft.)	None	Maps
Stream gradient[1]	None	None	Maps
Watershed area[1]	Acres	None	GIS
Percent of watershed area disturbed	None	None	GIS
Wet stream width	Ft.	None	Field
Stream discharge	Cubic feet per second (cfs)	Q	Field
Habitat assessment score	None	None	Field
WATER CHEMISTRY PARAMETERS			
Stream temperature	Degrees Fahrenheit (°F)	None	Field
pH	None	None	Field
Dissolved oxygen concentration[2]	Milligrams per liter (mg/l)	DO	Field
Specific conductance (corrected to 25° Celsius)	Microsiemens (µS)	None	Field
Nitrite concentration[3]	Micromoles/liter (µm/l)	NO_2	Field/lab
Nitrate concentration[3]	µm/l	NO_3	Field/lab
Ammonium concentration[3]	µm/l	NH_4	Field/lab
Phosphate concentration[3]	µm/l	PO_4	Field/lab
Suspended solids concentration[3]	Milligrams/liter (mg/l)	None	Field/lab
BIOLOGICAL PARAMETERS			
BMI density	# per sq. meter (#/m^2)	None	Field/lab
Insect order diversity (field)	None	None	Field
Insect family diversity (field)	None	None	Field
Insect order diversity	None	None	Field/lab
Insect family diversity	None	None	Field/lab
Insect genera diversity	None	None	Field/lab
Ephemeroptera/Plecoptera/Tricoptera family diversity	None	EPT family diversity	Field/lab
Ephemeroptera/Plecoptera/Tricoptera genera diversity	None	EPT genera diversity	Field/lab
Percent Ephemeroptera/Plecoptera/Tricoptera	None	Percent EPT	Field/lab
Percent Plecoptera/Tricoptera	None	Percent PT	Field/lab
Biotic index score (family-level IDs)	None	Family biotic index score	Field/lab
Percent sensitive BMIs (family-level IDs)	None	Percent sensitive BMIs (family)	Field/lab
Percent tolerant BMIs (family-level IDs)	None	Percent tolerant BMIs (family)	Field/lab
Biotic index score (genera-level IDs)	None	Genera biotic index score	Field/lab
Percent sensitive BMIs (genera-level IDs)	None	Percent sensitive BMIs (genera)	Field/lab
Percent tolerant BMIs (genera-level IDs)	None	Percent tolerant BMIs (genera)	Field/lab
Percent collector-gatherers + scrapers + shredders	None	None	Field/lab
Percent omnivores + collector-filterers	None	None	Field/lab
Percent BMI predators	None	None	Field/lab
Abundances of individual BMI taxa (many)	# individuals/sample	None	Field/lab
Native aquatic vertebrate diversity	None	None	Field
Percent native riparian plant species	None	None	Field

[1] These physical parameters do not change for practical purposes, thus study reaches surveyed in more than one year have the same values in all years sampled.
[2] Calculated for 2000 and 2002 study reaches only.
[3] Calculated for 2000 study reaches only.
NA = Not applicable

- Stream discharge (Q) was estimated at a selected cross-section of the study reach. Q was estimated by multiplying the measured flow width times the average water depth and velocity, as measured at three to five equally spaced points along the cross-section. Velocity was measured using a Global Water FP101 flow probe.
- BMI samples were collected using a standardized method based on the "multi-habitat" approach described in the EPA's *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers* (1999). In 2000, one sample was collected per study reach. In 2001 and 2002, three samples were collected per 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. The 10 locations that constituted each sample were selected based on the relative coverage area of stream bottom features (i.e., riffles, pools, falls, etc.) 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 250 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 a defined 0.1-square meter area was scraped and stirred up for approximately 15 seconds using feet and hands. Dislodged BMIs were carried into the net by the stream current. In areas with little or no current (e.g., pools), stream bottom substrata 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 composite sample was collected, it was rinsed with water in a 250 μm sieve to wash out fine sediments, transferred to a plastic container and preserved in 70 percent ethanol for laboratory analysis.
- In 2002 only, the first BMI sample collected at each study reach was dumped into a plastic bucket with water and visually screened for five minutes. All aquatic insect orders and families observed were recorded.
- A semi-quantitative stream habitat assessment was conducted using the protocol provided in the EPA's *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers* (1999). 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 EPA protocol were used to guide scoring. An example of the EPA habitat assessment scoring sheet is provided in the Appendix.
- Photographs were taken of important features in the study reaches.

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. The field leader directed field surveys to insure consistency. The lone exception to this was the survey at AH-1 on June 1, 2001, which was conducted by PCW staff after they were thoroughly trained during 10 previous surveys.

B. Laboratory Analysis

Water samples collected during the 2000 field surveys were analyzed in the laboratory to determine concentrations of nutrients (NO_2, NO_3, NH_4, and PO_4) and suspended solids. Nutrient analysis was conducted at the UCSB Marine Science Laboratory using a LACHAT instruments model QuickChem 8000 analyzer. Suspended solid concentrations were determined by sieving 500 milliliter (mL) water samples through pre-weighed 40-micron cotton fiber filters to capture suspended solids, placing the filters in a drying oven for 24 hours, and re-weighing the filters to determine the net increase in weight created by captured suspended solids.

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 250-μm mesh sieve and washed with water to remove ethanol and fine sediments. The sample was then placed in a plastic tray marked with 25 equally-sized squares in a five by five grid pattern. The entire sample was spread out evenly across the 25 squares. Squares of material were randomly selected using a random number table, and sorted one at a time under a dissecting microscope until a specified number of BMIs were located and picked out. The proportion of the sample sorted was noted, and BMI density was estimated based on the one square meter sampling area and the number of specimens picked. 330 BMIs were picked out from each of the 2000 samples, when only one sample was collected per reach. Of the 330 specimens picked from each sample, 300 were randomly selected for identification. Starting in 2001, the sampling strategy was changed to allow the collection of replicate samples (three per study reach) without changing the total number of specimens picked and identified for each study reach. 110 specimens were picked out from each of the samples collected in 2001 and 2002 (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 under a dissecting microscope using standard taxonomic keys. As is the norm in professional-level rapid bioassessment studies, BMIs were typically identified to genus, with species names given for monotypic genera. Some non-insects (e.g., oligochaetes, ostracods, and copepods) were identified to coarser taxonomic levels (i.e., family, order, or class). Damaged specimens were identified to the finest taxonomic level possible. After processing and identification, sorted BMIs and unsorted remnant portions of the sample were bottled separately in 70 percent ethanol for storage.

Quality control (QC) measures were incorporated into the laboratory analysis to insure random selection and accurate, consistent enumeration and identification of BMIs. BMI sample processing methods were clearly established and strictly followed. Specimens from all of the taxa identified in the samples were sent to another taxonomist (Sheila Wiseman) for independent identification. Ecology's taxonomist (Jeff Brinkman) and Ms. Wiseman compared their results, and together resolved all inconsistencies in identification. All of the sample identifications were then re-examined, and necessary changes were made.

C. GIS Analysis

GIS Arcview software was used to calculate watershed area and watershed land use coverages for each study reach. The GIS analysis was completed by Mr. Ethan Inlander of the Conception Coast Project under contract with Ecology. Watershed area was calculated based on watershed boundaries generated in the GIS with a 30 meter digital elevation model using hydrologic processing tools in Arcview GIS 3.2. Watershed land use coverages for each study reach were calculated in the GIS 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 program contains a land use map for the region based on the following eight land cover categories: urban, agriculture, herbaceous, hardwood, shrub, conifer, water, and barren/other. Figure 10 provides an example of the land cover maps produced for the study reaches.

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 the fact that much of the herbaceous lands in the region are used for cattle grazing.

D. Review of Topographic Maps and Aerial Photographs

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 total stream length between the contours. Stream length was determined by tracing a map wheel over the mapped stream path. Quad maps were also used to check the accuracy of watershed boundaries determined for the study reaches by the GIS digital elevation model. Recent aerial photographs (1999) of the study area were reviewed to construct hand-drawn land use maps for the study area watersheds and check the accuracy of the GIS land use mapping layer. The GIS and hand-drawn land use maps were typically in very close agreement, and no major adjustments to the GIS calculations were necessary.

E. Calculation of Biological Parameters

Numerous BMI community parameters were calculated for each sample to reflect aspects of community structure including BMI density, diversity, composition (i.e., taxa present and relative abundances), and sensitivity to human disturbance. For 2001 and 2002 when three BMI samples were collected per study reach, a composite parameter for the study reach was calculated by combining the data from the three samples. This was not necessary for 2000, when only one BMI sample was collected.

Several of the BMI parameters are analogous (e.g., insect order diversity, insect family diversity, and insect genera diversity), but were calculated at different levels of taxonomic detail. This was done in an effort to evaluate the added benefit of identifying BMIs to finer taxonomic levels in detecting (1) differences in BMI parameters between study reach groups and (2) relationships between BMI parameters and physiochemical parameters.

BMI density (number of individuals per square meter) was calculated by dividing the number of specimens picked out of the sample by the sub sampled area. Diversity parameters were determined by counting the number of specified taxa (i.e., insect orders, EPT genera, etc.) identified in the sample. Functional feeding group parameters (i.e., percent collector-gatherers + scrapers + shredders, percent omnivores + collector-filterers, and percent BMI predators) were calculated using functional feeding group designations for individual taxa provided in Merritt and Cummins (1996).

Genera and family-level biotic index score, percent sensitive BMIs, and percent tolerant BMIs were calculated using disturbance tolerance values for individual BMI taxa (i.e., orders, families, genera, etc.) provided in CDFG's *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* (2002). BMIs have been assigned tolerance values of between 0 and 10 based on their observed 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. A BMI with a tolerance value of 10 is exceptionally tolerant of human disturbance. In this context, human disturbance includes both water pollution, which can cause physiological impairment, and physical perturbations (e.g., stream channelization, water impoundments and withdrawals, etc.) that alter or destroy stream habitat. In reality, disturbed streams are typically subjected to both water pollution and physical perturbations, thus the effects of different types of disturbance are often synergistic and difficult to separate.

Biotic index score is an average value of between 0 and 10 that indicates the overall tolerance of the BMI community to human disturbance. Family and genera biotic index score scores were calculated by adding the tolerance values for each BMI in the sample, and dividing by the total number of individuals. percent sensitive BMIs (family and genera) was calculated by adding the number of BMIs in the sample with a tolerance value of two (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 eight (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 biotic index score score, percent sensitive BMIs, and percent tolerant BMI taxa.

Abundances of selected BMI taxa (i.e., individual classes, orders, families, and genera) at each study reach were log (y+1) transformed and used as biological parameters. In addition to BMI parameters, native aquatic vertebrate species diversity and percent native riparian plant species were determined for each sampling point based on the species lists compiled during the field surveys.

E. Statistical Analysis Methods

Statistical methods including correlation analysis, multiple regressions, t-tests, and analysis of variance (ANOVA) were used to evaluate the data. Statistical tests were conducted in distinct phases, which are discussed below.

1. Multiple Regression Analysis of Undisturbed Study Reaches

Biological variables (response variables) and physiochemical variables (independent variables) were evaluated with multiple regression analysis using data from undisturbed reaches only (n=23). The purpose of this analysis was to determine the strength and nature of natural relationships (i.e., in the absence of human disturbance) among biological parameters and physiochemical parameters. Effort was made to sample a variety of undisturbed streams, from small mountain tributaries to large lowland rivers, so that wide ranges of physiochemical conditions (i.e., 1st order to 5th order, low gradient to high gradient, etc.) could be evaluated.

INSERT FIGURE 10: CARPINTERIA CREEK WATERSHED LAND USES

BACKSIDE OF FIGURE 10

A simple regression involves plotting data points for two variables on a two-dimensional axis (i.e., a response variable on the y-axis versus an independent variable on the x-axis), and determining the equation for the line that best represents the relationship between the two variables. Multiple regression analysis differs from this in that it evaluates and compares the effects of multiple independent variables, or regressors, on a single response variable simultaneously. 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 analysis, 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. P is given as a value between 0 and 1. As an example, a p of 0.05 indicates that there is a five percent probability there is no relationship between the response variable and the regressors, and there is a 95 percent probability that there is a relationship. A p of 0.05 or less is generally accepted as indicating a "statistically significant" relationship between the response variable and the regressors.

Before the multiple regression analysis was conducted, multi-variate correlation analysis was used to determine whether any of the physiochemical parameters were highly correlated among the undisturbed study reaches. High correlation among independent variables (regressors) is termed "collinearity". Strong collinearity among regressors causes multiple regression models to become unstable and sensitive to small changes in the data, thus highly collinear variables must be eliminated to yield reliable results. To accomplish this, where any two or more regressors had a correlation of 0.6 or greater, all but one were eliminated.

Physiochemical parameters with missing data for one or more of the study reaches (e.g., DO, suspended solids, and nutrients) were not used as regressors, as doing so would have eliminated study reaches with missing data from the analysis and reduced the sample size.

2. ANOVAs to Compare UNDIST, MOD DIST, DIST AG, and DIST URB Study Reach Groups

One-way analyses of variance (ANOVA) were used to compare mean values of physiochemical and biological parameters between the UNDIST, MOD DIST, DIST AG, DIST URB study reach groups. The purpose of this analysis was to determine the effects of varying levels and types of human disturbance on water chemistry and biological parameters. An ANOVA test compares the means and distributions of a given parameter among multiple sampling groups, and indicates the probability that the means for the groups are not different from each other. The probability that the means are not different is expressed as p, which again is between 0 and 1. The lower the p, the lower the probability is that the group means are not different. A p of 0.05 or less is generally accepted as indicating a statistically significant difference between group means.

3. T-tests to Compare Reference Study Reaches vs. Test Study Reaches within a Low-Moderate Elevation, Gradient, and Stream Order Classification

T-tests were used to compare mean values and distributions of physiochemical and biological parameters between two groups of study reaches, a "reference group" and "test group", within a low-moderate elevation (300 feet or less), gradient (0.04 or less), and stream order (2nd and

3rd order streams only) classification. 31 of the 65 sampling points fit into this classification. The reference group represented the less disturbed study reaches, including those categorized as UNDIST and MOD DIST. The test group represented the most disturbed study reaches, including those categorized as DIST AG and DIST URB. The purpose of this analysis was to minimize the natural influences of the independent variables (i.e., elevation, gradient, and order), and more clearly determine the effects of human disturbance on water chemistry and biological parameters.

4. T-tests to Compare Riffles and Pools

Separate riffle and pool samples were collected at nine of the study reaches in 2000: SO-1, AH-1, R-2, SJ-1, SJ-3, SA-1, AB-3, M-3, and M-4. T-tests were conducted to evaluate differences in BMI composition between the riffle and pool groups.

5. ANOVAs to Evaluate Year-to-Year Trends

ANOVAs were used to compare means for selected parameters in 2000, 2001, and 2002 among the nine study reaches (SO-2, AH-1, SJ-1, SJ-2, SJ-3, AB-2, AB-3, C-1, and C-3) that were surveyed in all three years of the study. The purpose of this analysis was to determine whether any selected parameters changed noticeably from year to year, possibly in response to variable climatic conditions. 2000 and 2001 were normal rainfall years, while 2002 was a relatively dry year. Selected parameters include BMI community parameters, native aquatic vertebrate diversity, stream temperature, water chemistry measurements, habitat assessment score, and Q. Variables such as elevation, stream order, gradient, and watershed area that are essentially constant were not evaluated.

V. Results

A. Data

Table A-1 in the Appendix presents physiochemical data for the individual study reaches. Parameter values generally ranged widely among the study reaches. Overall ranges and mean values among all of the study reaches are provided at the bottom of the table.

A total of 132 plant species were observed among all of the study reaches, including 91 native species and 41 introduced (i.e., non-native) species. Table A-2 provides a list of the plant species observed, and a breakdown of their occurrence by study reach. Table A-2 also indicates the number of native and introduced plant species observed at each study reach, and the percentage of native plant species. The number of years (i.e., 1, 2 or 3) each study reach was surveyed is provided at the top of the table. Plant observations were combined in the table for study reaches that were surveyed in multiple years.

A total of 100 vertebrate species (94 native and six introduced) were observed among all of the study reaches, including 11 aquatic and 89 terrestrial species, and four fish, five amphibians, 11 reptiles, 67 birds, and 13 mammals. Vertebrate species having special regulatory status (i.e., of concern, fully protected, rare, threatened, endangered, etc.) from the state and/or federal government that were observed include steelhead/rainbow trout, California newt, southwestern pond turtle, two-striped garter snake, coastal western whiptail lizard, coast horned lizard, yellow warbler, and Cooper's hawk. Table A-3 provides a list of observed vertebrate species, and a breakdown of their occurrence by study reach. The number of years each study reach was surveyed is provided at the top of the table. Vertebrate observations were combined in the table for study reaches surveyed in multiple years.

A total of 10 orders, 61 families, and 109 genera of aquatic insects (class Insecta) were collected and identified among all of the study reaches. Common aquatic insect orders included Ephemeroptera (mayflies, six families, 16 genera), Plecoptera (stoneflies, four families, four genera), Tricoptera (caddisflies, 14 families, 16 genera), Coleoptera (beetles, eight families, 17 genera), Diptera (true flies, 13 families, 33 genera), Hemiptera (true bugs, six families, eight genera), Odonata (dragonflies and damselflies, six families, 10 genera), and Megaloptera (Dobson flies and alder flies, two families, three genera). Two semi-aquatic insect orders, Collembola (springtails) and Hymenoptera (wasps), were found in small numbers. Non-insects found in the study reaches include Gastropoda (snails); several types of crustaceans including Ostracoda, Copepoda, Cladocera, Decapoda, and Isopoda; Acari (water mites); Turbellaria (flatworms); Oligochaeta (segmented worms); Hirudinea (leeches); and Nematomorpha (horsehair worms). Overall, non-insects composed a small proportion of the BMIs sampled.

Table A-4 provides a list of observed BMI taxa, and a breakdown of their occurrence and abundance by sample and study reach. BMI community parameters are also listed by sample and study reach. The table is organized by year.

B. Statistical Data Analyses

1. Analyses of Natural Relationships between Biological and Physiochemical Parameters at Undisturbed Study Reaches

Physiochemical parameters considered as potential regressors in the multiple regression analyses include stream order, elevation, gradient, wet stream width, Q, watershed area, stream temperature, pH, and specific conductivity. Table 3 summarizes the results of the physiochemical parameter correlation analysis. Based on the results of the correlation analysis, two physiochemical parameters were eliminated from further consideration due to high correlations (i.e., above 0.6) with other parameters:

- Watershed area: correlated with stream order (0.62), wet stream width (0.96), and Q (1.00).
- Wet stream width: correlated with stream order (0.72), Q (0.95), and watershed area (0.96).

After the elimination of these two physiochemical parameters, seven remained for use in the multiple regression analyses: order, elevation, gradient, Q, temperature, pH, and specific conductance. None of these parameters had correlations of 0.6 or higher among the undisturbed study reaches.

Table 3: Physiochemical Parameter Correlations at Undisturbed Study Reaches (N=23)

	Stream order	Elevation	Gradient	Wet width	Q	Watershed area	Temp.	pH	Sp. conduct.
Stream order	1.00	0.10	-0.49	**0.72**	0.58	**0.62**	0.48	0.45	0.18
Elevation	0.10	1.00	0.35	-0.01	-0.08	-0.04	0.24	-0.17	-0.21
Gradient	-0.49	0.35	1.00	-0.33	-0.36	-0.37	-0.24	-0.23	0.02
Wet width	**0.72**	-0.01	-0.33	1.00	**0.95**	**0.96**	0.32	0.56	0.28
Q	0.58	-0.08	-0.36	**0.95**	1.00	**1.00**	0.27	0.49	0.21
Watershed area	**0.62**	-0.04	-0.37	**0.96**	**1.00**	1.00	0.30	0.48	0.25
Temp.	0.48	0.24	-0.24	0.32	0.27	0.30	1.00	-0.05	0.09
pH	0.45	-0.17	-0.23	0.56	0.49	0.48	-0.05	1.00	0.38
Sp. conduct.	0.18	-0.21	0.02	0.28	0.21	0.25	0.09	0.38	1.00

Physiochemical parameters not measured at all study reaches included DO, suspended solids, PO_4, NO_3, NO_2, and NH_4. These parameters were not considered as regressors because if they were, study reaches where these parameters were not sampled would have to be dropped from the analyses, reducing the sample size for the regression analyses.

Biological parameters tested as response variables in the multiple regression analyses include all of the community parameters listed in Table 2, and BMI taxa that occurred in at least four of the 23 UNDIST reaches, and totaled at least 10 individuals in all UNDIST reach samples combined. A total of 69 individual taxa met these criteria.

Results of the multiple regression analyses are summarized in Table A-5 in the Appendix, which lists r^2 and p for each regression model, and equation coefficients for relationships between the biological parameters and each of the individual regressors. Significant values for the individual regressors are in **bold** and marginally significant values are in *italics*. Figures 11 and 12 provide graphical illustrations of multiple regression analyses for selected biological parameters.

Six of the 18 biological community parameters were significantly related to the physiochemical regressors, including # EPT (family), # EPT (genera), percent tolerant BMIs (family), genera biotic index score, percent tolerant BMIs (genera), and native aquatic vertebrate diversity. Four of the 18 biological community parameters were marginally significantly (i.e., $p<0.10$) related to the regressors, including insect order diversity, percent PT, percent sensitive BMIs (family), and percent sensitive BMIs (genera). Biological community parameters that did not have

Insert Figure 11: Multiple regressions of UNDIST reaches

Insert Figure 12: Multiple regressions of UNDIST reaches significant or marginally significant relationships with the whole model are BMI density, insect family diversity, insect genera diversity, percent EPT, Family biotic index score, percent collector-gatherers + scrapers + shredders, percent omnivores + collector-filterers, and percent BMI predators

28 of the 69 BMI taxa evaluated had significant or marginally significant relationships with the regressors. Most insect orders and several non-insect groups are represented in this group.

Stream temperature had significant or marginally significant relationships with 22 biological parameters, including 10 community parameters and 12 BMI taxa. Of these, variables that were negatively related to temperature included insect genera diversity, EPT family diversity, EPT genera diversity, percent PT, percent sensitive BMIs (family), percent sensitive BMIs (genera), Heptagenidae, Plecoptera, *Helicopsyche*, *Lepidostoma*, Psychodidae, *Pericoma/Telmatoscopus*, Libelullidae, and *Paltothemis*. Variables that were positively related to temperature are family biotic index score, genera biotic index score, percent tolerant BMIs (family), percent tolerant BMIs (genera), *Paracloeodes*, *Caloparyphus*, *Argia*, and Ostracoda.

pH had little relation to biological community parameters, with one significant positive relationship with percent tolerant BMIs (family), and a marginally significant positive relationship with percent collector-gatherers + scrapers + shredders. However, pH had significant or marginally significant relationships with 14 BMI taxa, including positive relationships with *Caenis*, Ephemerellidae, *Optioservus*, *Caloparyphus*, *Euparyphus*, and Ostracoda, and negative relationships with Leptophlebidae, *Paraleptophlebia*, *Malenka*, *Ordobrevia numbifera*, *Simulium*, Megaloptera, Corydalidae, and *Sialis*.

Specific conductance had a marginally significant positive relationship with percent PT, and significant or marginally significant relationships with 12 BMI taxa. This included positive relationships with *Leucrocuta/Nixe/Heptagenia*, *Lepidostoma*, *Eubrianax edwardsii*, Psychodidae, *Pericoma/Telmatoscopus*, and Gomphidae, and negative relationships with Ephemerellidae, *Wormaldia*, *Rhyacophila*, Dytiscidae, *Optioservus*, and *Euparyphus*.

Within the range studied, Q had little influence on biological community parameters, with only one marginally significant negative relationship with percent collector-gatherers + scrapers + shredders. Q had significant or marginally significant relationships with seven BMI taxa, including positive relationships with Leptophlebidae, Megaloptera, Corydalidae, and Gastropoda, and negative relationships with Heptagenidae, Caloparyphus, and Euparyphus. Although it was not particularly influential on the stream biota within the range of discharges (i.e., base flows) evaluated in this study, extreme discharges (i.e., no flow or scouring flood flows) can have major influences on the biota of local streams (Cooper et al., 1986).

Elevation had significant or marginally significant relationships with 19 biological parameters, including six community parameters and 13 individual taxa. This includes negative relationships with insect order diversity, percent omnivores + collector-filterers, percent BMI predators, native aquatic vertebrate diversity, and several disturbance-sensitive Ephemeroptera, Plecoptera, Tricoptera, and Coleoptera taxa, and positive relationships with genera biotic index score, percent tolerant BMIs (genera), Chironomidae, Gastropoda, and Ostracoda.

Stream order had significant or marginally significant relationships with 11 biological parameters, including three community parameters and eight individual taxa. This includes positive relationships with insect genera diversity, EPT family diversity, EPT genera diversity, *Fallceon quilleri*, *Tricorythodes*, *Hydropsyche/Ceratopsyche*, *Ochrotrichia*, *Ordobrevia numbifera*, and Corydalidae, and negative relationships with *Paraleptophlebia* and *Pericoma/Telmatoscopus*.

Gradient did not have any significant or marginally significant relationships with biological community parameters. Gradient did have significant or marginally significant relationships with five BMI taxa, including positive relationships with *Rhyacophila*, and *Eubrianax*, and negative relationships with *Wormaldia*, *Psychodidae*, and *Pericoma/Telmatoscopus*.

2. Comparisons of UNDIST, MOD DIST, DIST AG, and DIST URB Study Reach Groups

ANOVAs were used to evaluate differences in physical and biological parameters between the UNDIST, MOD DIST, DIST AG, and DIST URB study reach groups. ANOVA results are summarized in Appendix Table A-5, which lists group means and differences between group means for each parameter tested, as well as p. Significantly different values (i.e., where $p \leq 0.05$) are indicated in **bold**. Table A-5 also lists the total number of samples (i.e., "n") for each parameter, and for each individual group.

Physiochemical parameters evaluated in the ANOVAs include stream order, elevation, gradient, Q, stream temperature, pH, specific conductivity, DO, suspended solids, and nutrient concentrations. Habitat assessment score and percent watershed disturbed are also tested. Biological parameters evaluated included all of the community parameters, and individual BMI taxa that occurred in at least eight of the 65 sampling points, and totaled 25 or more individuals at all sampling points combined. A total of 82 BMI taxa met these criteria.

For most parameters, the total sample size was n=65 (i.e., all of the sampling point), with UNDIST (n=22), and DIST URB (n=23) having the most replicates, and the MOD DIST (n=12) and DIST AG (n=8) groups having fewer replicates. The sample size was smaller for DO, suspended solids, nutrients, insect order diversity (field), and insect family diversity (field), none of which were determined at all sampling points.

Figures 13 and 14 provide graphical illustrations of ANOVAs for selected parameters. The illustrations show the distributions (i.e., collection of data points) for each study reach group side by side. The top and bottom points of the diamonds shown for each study reach group indicate the 95 percent confidence limits for the group mean. The center of the diamond is the mean for the group.

Natural Physical Parameters

Given the regional pattern of undeveloped mountainous areas (upper watersheds) and highly developed coastal plains (lower watersheds), it is not surprising that there were significant differences among study reach groups with respect to natural physical parameters. Stream order ($p=0.0231$) was lowest in UNDIST reaches, and higher in more disturbed reaches. Gradient ($p<0.0001$) and elevation ($p<0.0001$) were highest in UNDIST reaches, and lower in more disturbed reaches. Q ($p=0.4616$) was not significantly different among the study reach groups.

Human Disturbance Parameters

There were highly significant differences in habitat assessment score ($p<0.0001$) and percent watershed disturbed ($p<0.0001$) among the study reach groups. This was to be expected, given that the study reaches were segregated into groups based on these parameters. Habitat assessment score declined with greater human disturbance from a high of 171.7 in the UNDIST reach group to a low of 81.0 in the DIST URB reach group. Mean values for all four groups

Insert Figure 13 Study Reach Group ANOVAs

Insert Figure 14 Study Reach Group ANOVAs were significantly different from one another. Conversely, percent watershed disturbed increased with greater human disturbance. The only groups not significantly different from one another for percent watershed disturbed were MOD DIST and DIST AG.

Water Quality Parameters

There were highly significant differences among the study reach groups in specific conductance ($p<0.0001$), which was lowest in UNDIST reaches (821.3 µS), and highest in DIST URB reaches (1,553.6 µS). The only combinations of groups not significantly different from one another were DIST URB vs. DIST AG and DIST AG vs. MOD DIST. Although the test results were not significant for stream temperature ($p=0.22$), mean values were lower at UNDIST (62.7 °F) and MOD DIST (64.1 °F) reaches compared to DIST URB (65.4 °F) and DIST AG (67.9 °F) reaches. pH, DO, and suspended solids were not significantly different among the study reach groups.

Evaluating differences in nutrient concentrations was problematic due to high variation in measured concentrations (particularly at DIST URB and DIST AG reaches) and a relatively small number of samples (i.e., n=30, 2000 surveys only). The ANOVA results were not significant for NO_3 ($p=0.11$), NO_2 ($p=0.11$), or NH_4 ($p=0.12$). However, concentrations of these nutrients were noticeably higher with greater human disturbance, particularly in the cases of NO_3 and NO_2. Mean NO_3 concentration was lowest in UNDIST reaches (2.2 mg/l) and highest in DIST URB reaches (430.1 mg/l), or a difference of nearly 200-fold. Mean NO_2 concentration was 0.05 mg/l in UNDIST reaches and 3.20 mg/l in DIST URB reaches, or a difference of more than 60-fold. NH_4 concentrations rose in much smaller increments with increasing levels of human disturbance from a low of 1.23 mg/l in UNDIST reaches to a high of 2.37 mg/l in DIST URB reaches. There was no clear pattern for PO_4 ($p=0.42$). Mean PO_4 concentration was relatively similar in UNDIST (0.23 mg/l), MOD DIST (0.34 mg/l) and DIST AG (0.25 mg/l) reaches, and considerably higher in DIST URB reaches (3.79 mg/l). The higher mean PO_4 concentration at the DIST URB reaches was greatly skewed by one especially high concentration at study reach F-1 (27.63 mg/l), which is known to be heavily polluted by greenhouse effluents (Page, 1999). If this outlier is removed, the DIST URB group mean is 0.38 mg/l, which is similar to the other groups.

Biological Parameters

The only biological community parameter that was not significantly different amongst the study reach groups was BMI density ($p=0.5088$). All other community parameters showed significant differences among the study reach groups. Interestingly, insect order diversity (field) ($p<0.0001$) and insect family diversity (field) ($p<0.0001$), both determined in the field, showed highly significant declines with greater human disturbance, despite a relatively small number of total sampling units (n=23). Other BMI community parameters that declined very significantly with greater human disturbance with $p<0.0001$ include insect family diversity, insect genera diversity, insect order diversity, EPT family diversity, EPT genera diversity, percent EPT, percent PT, percent sensitive BMIs (family), percent sensitive BMIs (genera), and percent BMI predators. Percent collector-gatherers + scrapers + shredders also declined significantly with greater human disturbance ($p=0.0002$). Also of interest is that native aquatic vertebrate diversity declined very significantly with greater human disturbance ($p<0.0001$).

Family biotic index score and genera biotic index score increased very significantly with greater human disturbance ($p<0.0001$). Other BMI community parameters that increased significantly with greater human disturbance include percent tolerant BMIs (family) ($p=0.0031$), percent tolerant BMIs (genera) ($p=0.0007$), and percent omnivores + collector-filterers ($p=0.0017$).

Most of the evaluated individual BMI taxa fit into one of the following patterns with respect to human disturbance:

- BMI taxa with highest densities in UNDIST reaches, and declining densities with greater human disturbance. These taxa appear to be particularly sensitive to human disturbance. As an example, the mayfly family Leptophlebidae declined significantly with greater human disturbance, with significant differences between all four study reach groups (p<0.0001) (see Figure 14). Other taxa that declined very significantly with greater human disturbance with p<0.0001 include *Paraleptophlebia*, Heptagenidae, *Leucrocuta/Nixe or Heptagenia*, Plecoptera, *Sweltsa*, *Malenka*, Tricoptera, *Lepidostoma*, *Rhyacophila*, Coleoptera, Elmidae, *Ordobrevia numbifera*, *Eubrianax edwardsii*, *Hexatoma*, Odonata, and Megaloptera. Others that declined significantly with greater human disturbance include *Calineuria californica* (p=0.0219), *Zaitzevia* or *Heterlimnius* (p=0.0019), Dixidae (p=0.0098), Tipulidae (p=0.0025), *Cordulegaster dorsalis* (p=0.0013), Gomphidae (p=0.0006), Corydalidae (p=0.0257), and *Sialis* (p=0.0011). *Diphetor hageni*, Ephemerellidae, *Eperous* (*Iron*), *Agapetus*, *Optioservus*, Psychodidae, *Pericoma/Telmatoscopus*, Libelullidae, and *Paltothemis lineatipes* declined noticeably with greater human disturbance, but test results were not significant. This was most likely due to the low overall abundances of these taxa.
- BMI taxa with similar densities in UNDIST, MOD DIST, and DIST AG reaches, and significantly lower densities in DIST URB reaches. These taxa are apparently able to withstand levels of human disturbance typical in MOD DIST and DIST AG study reaches, but not the heavier disturbance in DIST URB reaches. Ephemeroptera, Baetidae, and *Hydropsyche* or *Ceratopsyche* exemplify this pattern, all with p<0.0001 (see Figure 14). Other taxa showing this pattern with significant test results are *Micrasema* (p=0.0008) and *Helicopsyche* (p=0.0418).
- BMI taxa with highest densities in MOD DIST reaches, and lower densities in DIST AG, DIST URB, and UNDIST reaches. These taxa seem to thrive in low to moderate levels of human disturbance, but appear unable to withstand higher levels of human disturbance. *Caenis*, *Polycentropus*, *Tinodes*, and *Caloparyphus* exemplify this pattern, all with p<0.0001 (see Figure 14). Other taxa that showed this pattern with significant test results include *Tricorythodes* (p=0.0003), *Wormaldia* (p=0.0053), *Gumaga* (p=0.0002), *Agabus* (p=0.0393), Hemiptera (p=0.0089), *Abedus* (p=0.0002), *Microvelia* (p=0.0081), and *Archillestes* (p=0.0049). Taxa that showed this pattern with less than significant test results include *Paracloedes minutus*, *Graptocorixa* or *Neocorixa*, and Acari.
- BMI taxa that showed no relationship with human disturbance, with similar densities in all study reach groups. These taxa appear to be highly tolerant of human disturbance, but do not increase in density in degraded conditions. Ceratopogonidae is one of the best examples of this (p=0.8181) (see Figure 14). Other taxa that showed no obvious relationship with human disturbance include *Ochrotrichia* (p=0.784), Dytiscidae (p=0.4278), *Hydroporus* (p=0.4384), *Oreodytes* or *Nebrioporus/Stictotarsus* (p=0.6424), *Palpomyia/Bezzia* (p=0.9143), *Sphaeromias* (p=0.5443), Ephydridae (p=0.1558), *Simulium* (p=0.161), *Euparyphus* (p=0.3951), *Tipula* (p=0.1929), *Callicorixa* (p=0.4385), *Ambrysus* (p=0.4328), and *Argia* (p=0.2631).
- BMI taxa with highest densities in DIST URB and DIST AG reaches, and lower densities in MOD DIST and UNDIST reaches. These taxa appear to be highly tolerant of human disturbance, and are more prevalent in degraded conditions. Non-insects, Dipterans, and a few beetles make up this group, including *Peltodytes* (p=0.0067), *Hydrophilidae*

(p=0.0171), *Tropisternus* (p=0.0147), Diptera (p=0.0006), Chironomidae (p<0.0001), Gastropoda (p=0.0020), Ostracoda (p=0.0254), Copepoda (p=0.0031), Cladocera (p=0.0003), Oligochaeta (p=0.0424), and Hirudinea (p=0.0020). *Callibaetis* also showed this pattern, but with less than significant test results (r^2=0.08, p=0.1436).

Two taxa, *Baetis* (p=0.0006) and *Fallceon quilleri* (p=0.0049), were odd in that they showed significantly higher densities in UNDIST and DIST AG reaches than in MOD DIST and DIST URB reaches. There is no obvious explanation for this.

Percent native riparian plant species (p<0.0001) was significantly different between study reach groups. Percent native riparian plant species was highest in the UNDIST reach group (88.2 percent), and lowest in the DIST URB reach group (53.3 percent). Only MOD DIST and DIST AG were not significantly different from one another.

3. Comparisons of Reference Study Reaches vs. Test Study Reaches within a Low-Moderate Elevation, Gradient, and Stream Order Classification

T-tests were used to compare means and distributions of physiochemical and biological parameters between reference (i.e., less disturbed) and test (i.e., highly disturbed) groups within a low-moderate elevation, gradient, and stream order classification (n=31). The purpose of this analysis was to minimize the natural influences of the independent variables (i.e., elevation, gradient, and order), and more clearly determine the effects of human disturbance on water quality and the stream biota. As indicated in the multiple regression analysis of undisturbed study reaches, stream temperature, specific conductance, and pH also had significant natural relationships with many biological parameters. However, stream temperature, specific conductance, and pH can be influenced considerably by human disturbance, and thus were not considered as classification criteria.

Biological parameters selected for analysis included all of the community parameters and a total of 68 BMI taxa, all of which occurred in at least five of the 31 sampling sites, and totaled at least 10 individuals in all sampling sites combined. Results of the analyses are summarized in Appendix Table A-7. Figure 15 shows graphical illustrations of selected t-tests.

The results of this analysis with respect biological parameters were very similar to those of the ANOVAs of UNDIST, MOD DIST, DIST AG, and DIST URB groups (see 2. above). With the exception of BMI density (p=0.4092) and percent omnivores + collector-filterers (p=0.6964), all of the community parameters were noticeably different between the reference and test groups, and showed the same type of relationship (i.e., positive or negative) with human disturbance as in the ANOVA analyses. All BMI diversity parameters including insect orders, insect families, insect genera, EPT families, and EPT genera were significantly lower in the test sites with p<0.0001. Native aquatic vertebrate diversity was also significantly lower in the test sites (p=0.0044). Other community parameters that were significantly lower in the test sites include percent EPT (p=0.0037), percent PT (p=0.0005), percent sensitive BMIs (family) (p=0.0003), percent sensitive BMIs (genera) (p=0.0005), percent BMI predators (p<0.0001), and percent native riparian plant species (p=0.0003). Percent collector-gatherers + scrapers + shredders was lower in test sites, but not significantly (p=0.1009). Family biotic index score (p=0.0006) and genera biotic index score (p=0.0004) were both significantly higher in test sites, while percent tolerant BMIs (genera) was marginally significantly higher in test sites (p=0.0711). Percent tolerant BMIs (family) was also higher in test sites, but not significantly (p=0.1079).

Figure 15 Reference Group vs. Test Group T-Tests, Sites in a Low-Moderate Elevation, Gradient, and Stream Order Classification

The results of this analysis for individual BMI taxa densities were also similar to the ANOVAs of the UNDIST, MOD DIST, DIST AG, and DIST URB groups. BMI taxa that had significantly or marginally significantly higher density in the reference sites include Ephemeroptera, Baetidae, *Paracloedes minutus*, *Caenis*, Heptagenidae, *Leucrocuta/Nixe* or *Heptagenia*, *Paraleptophlebia*, Plecoptera, *Sweltsa*, *Malenka*, *Calineuria californica*, Tricoptera, *Hydropsyche* or *Ceratopsyche*, *Lepidostoma*, *Polycentropus*, *Rhyacophila*, *Gumaga*, Coleoptera, Elmidae, *Ordobrevia numbifera*, *Eubrianax edwardsii*, Dixidae, *Caloparyphus*, Tipulidae, *Hexatoma*, Hemiptera, *Graptocorixa* or *Neocorixa*, *Microvelia*, Odonata, Megaloptera, and *Sialis*. Taxa that had higher density at reference sites but without significant test results were *Tricorythodes* (p=0.1557), *Tinodes* (p=0.124), *Agabus* (p=0.1165), *Abedus* (p=0.1068), and *Cordulegaster dorsalis* (p=0.1472). Diptera (p=0.0922) and Chironomidae (0.0268) were the only BMI taxa that had significantly or marginally significantly higher density at the test sites. *Callibaetis* (p=0.1077), Gastropoda (p=0.2862), Ostracoda (p=0.248), and Copepoda (p=0.1241) also had higher density at the test sites, but the results of the analyses were not significant. BMI taxa that did not have notable differences in density between the reference and test sites include *Baetis*, *Fallceon quilleri*, *Micrasema*, *Ochrotrichia*, *Wormaldia*, Dytiscidae, *Hydroporus*, *Oreodytes* or *Nebrioporus/Stictotarsus*, *Optioservus*, *Peltodytes*, *Tropisternus*, Ceratopogonidae, *Palpomyia/Bezzia*, *Sphaeromias*, Ephydridae, Psychodidae, *Simulium*, *Euparyphus*, *Tipula*, *Argia*, *Archillestes*, Acari, Oligochaeta, and Hirudinea.

With respect to water quality, stream temperature (p=0.0423) and specific conductivity (p=0.0297) were both significantly higher in the test group. pH was not significantly different between groups (p=0.1884). Habitat assessment score and percent watershed disturbed were both significantly different between the groups (p<0.0001), with habitat assessment score higher in the reference group, and percent watershed higher in the test group. This was to be expected given that the study reaches were divided into the reference and test groups based on these two parameters.

Q was not significantly different between groups (p=0.9101). However, despite the classification criteria, there were significant differences between the reference and test groups in elevation (p=0.0005) and gradient (p<0.0001), which were both higher in the reference group, and stream order (p=0.0015), which was higher in the test group. Mean stream order was 2.5 for the reference group, and 2.9 for the test group. Mean elevations were 187 and 71 for reference and test groups, respectively. Mean gradients were 0.027 and 0.011 for the reference and test groups, respectively. There was much less variability in order, elevation, and gradient between the groups in this analysis compared with the ANOVAs of the UNDIST, MOD DIST, DIST AG, and DIST URB groups.

4. Comparisons of Riffles and Pools

T-tests were used to evaluate differences in BMI community parameters and the densities of selected BMI taxa between riffles and pools among nine study reaches where riffle and pool samples were collected separately in 2000. A total of 53 BMI taxa were selected for analysis, all of which occurred in at least four riffle and/or pool samples, with at least 10 individuals total in all samples combined. The results of the t-tests are summarized in Appendix Table A-8, which lists means for the riffle group and pool group and differences between the means, as well as p. Significantly different values are in **bold** and marginally significant values are in *italics*. Figure 16 provides graphical illustrations of t-test comparisons for selected parameters.

Figure 16 Riffle vs. Pool T-tests

Three of the 17 BMI community parameters tested were significantly or marginally significantly different between riffles and pools. Omnivores + collector-filterers was significantly higher in riffles (12.8 percent) compared to pools (0.3 percent) (p=0.0023). EPT genera diversity was marginally significantly higher (p=0.0807) in riffles (11.9 genera) compared to pools (8.8 genera). Percent tolerant taxa (genera) was marginally significantly higher (p=0.0799) in pools (9.1 percent) compared to riffles (2.7 percent). 14 of 17 BMI community parameters tested were not notably different between riffles and pools, including BMI density, insect order diversity, insect family diversity, insect genera diversity, EPT family diversity, percent EPT, percent PT, family biotic index score, percent sensitive BMIs (family), percent tolerant BMIs (family), genera biotic index score, percent sensitive BMIs (genera), percent collector-gatherers + scrapers + shredders, and percent BMI predators.

Of the 53 BMI taxa evaluated, 10 had significantly or marginally significantly higher density in riffles compared to pools, including Baetidae (p=0.0003), *Baetis* (p<0.0001), *Micrasema* (p=0.0021), *Hydropsyche* or *Ceratopsyche* (p<0.0001), *Rhyacophila* (p=0.0095), Psychodidae (p=0.0033), *Pericoma/Telmatoscopus* (p=0.0025), *Simulium* (p=0.0010), Stratiomyidae (p=0.0923), and *Caloparyphus* (p=0.078). Seven taxa had significantly or marginally significantly higher abundance in pools compared to riffles, including *Caenis* (p=0.092), *Tricorythodes* (p=0.0385), *Paraleptophlebia* (p=0.0088), *Lepidostoma* (p=0.038), *Gumaga* (p=0.0436), Odonata (p=0.0749), and Ostracoda (p=0.0590). The other 36 taxa tested did not have significant or marginally significant differences in density between riffles and pools.

5. Year-to-Year Trends Analyses

ANOVAs were used to compare selected physiochemical and biological parameters for 2000, 2001, and 2002 among the nine study reaches surveyed in all three years. The purpose of this analysis was to determine whether selected parameters changed noticeably from year to year. Results are summarized in Appendix Table A-9, which lists means for the 2000, 2001, and 2002, differences between the means from year to year, and p. Significantly different values are in **bold**, and marginally significant values are in *italics*. Figure 17 provides graphical illustrations of selected ANOVA results.

Stream temperature was significantly lower in 2002 (55.9 °F) than in 2000 (64.6 °F) and 2001 (62.2 °F) (p<0.0001), presumably because field surveys were conducted earlier in 2002 (i.e., March-May) than in 2000 and 2001 (i.e., May-July). Specific conductance was lower in 2001 (921.0 µS) than in 2000 (1,191.8 µS) and 2002 (1218.3 µS), but ANOVA results (p=0.1077) were not significant. Q, Habitat assessment score, and pH did not vary considerably among years.

Percent collector-gatherers + scrapers + shredders was significantly lower in 2001 (32.3 percent) than in 2000 (54.3 percent) and 2002 (51.1 percent) (p=0.0398). Percent tolerant BMIs (family) was significantly higher (p=0.0452) in 2002 (18.1 percent) than in 2001 (3.6 percent). Similarly, percent tolerant BMIs (genera) was marginally significantly higher (p=0.0573) in 2002 (17.3 percent) than in 2001 (3.6 percent). BMI density (p=0.1078) and percent omnivores + collector-filterers (p=0.1145) also varied among years, but ANOVA test results were not significant or marginally significant. All other biological parameters including insect order diversity, insect family diversity, insect genera diversity, EPT family diversity, EPT genera diversity, percent EPT, percent PT, family biotic index score, percent sensitive BMIs (family), genera biotic index score, percent sensitive BMIs (genera), percent BMI predators, and native aquatic vertebrate diversity did not vary considerably between years.

Figure 17: 2000, 2001, and 2002 ANOVAs

VI. DISCUSSION

It is important to note several limitations of this study that should be considered before interpreting and extrapolating the study results. First, this study was conducted within a limited geographic region. Geographic variation in stream ecosystems is well-documented (Rosenberg and Resh, 1993, Merritt and Cummins, 1996, Plotnikoff and Ehinger, 1997, Barbour, et al., 1999, Griffiths, 1999, Maxted et al., 2000). Although many of the findings of this study are similar to the conclusions of bioassessment studies conducted in other regions, they may not extrapolate well to all geographic areas. Second, this study involved the assessment of stream conditions in the spring and summer months over a three-year period. Since local stream biota is known to undergo succession in response to seasonal and year-to-year variability in rainfall and stream discharge (Cooper et al, 1986), study results may be different in other seasons (i.e., fall or winter) or over longer time periods. Another important limitation of this study and bioassessment studies in general is that they capture a "snapshot" of environmental conditions. This is particularly of concern for parameters such as stream discharge, temperature, water chemistry that can be highly variable even over short time periods. As an example, DO concentration typically fluctuates noticeably over a 24-hour period, with higher concentrations during the day when aquatic plants and algae are photosynthesizing (i.e., giving off O_2), and lower concentrations at night when plants are respiring (i.e., uptaking O_2). By sampling DO at only one point in time, this study did not represent daily DO variation or its potential influences on the stream biota. On the other hand, many physical variables such as watershed area, gradient, elevation, stream order, and human disturbance (e.g., percent watershed disturbed and habitat assessment score) are more constant through time. Snapshot measurements can provide good representations of these more constant environmental variables.

The following discusses the results of this study in the context of the Program goals presented in Section II. The Program goals identify information about local stream ecosystems that this study is intended to uncover. Discussion is provided in the context of the first three Program goals. The fourth goal deals with long-term responses of the stream biota to changing land use patterns and water quality/stream restoration efforts, which have not been studied thus far.

Determine the strength and nature of natural relationships between local stream biota and physiochemical parameters including stream temperature, water chemistry, stream discharge, microhabitat (e.g., riffles vs. pools), stream width, elevation, gradient, stream order, catchment area, and climatic trends.

About half of the biological community parameters and about 40 percent of the BMI taxa evaluated had significant or marginally significant natural relationships with physiochemical variables. This included a mix of community diversity and composition parameters and individual BMI taxa with representatives from several insect orders and non-insect groups. Of the seven physiochemical variables considered, stream temperature and elevation appeared to have the greatest influence on the stream biota, with moderate influence from stream order. Other recent stream studies have also found significant relationships between biological parameters and stream temperature, elevation, and order, as well as stream width and depth (Cooper and Herbst, 2001, Plotnikoff and Ehinger, 1997, Danehy, Ringler, and Ruby, 1999). Specific conductance and pH had little relation with most biological community parameters, but were significantly or marginally significantly related to several individual BMI taxa. Specific conductance and pH both had limited ranges among the undisturbed study reaches. Gradient and Q had little relationship to the biological community parameters, and few significant or marginally significant relationships with individual BMI taxa. As discussed previously, Q was at base flow conditions during the field surveys, thus the analyses did not provide information about relationships between extreme Qs and stream biota.

Natural relationships between stream temperature and biological parameters were of particular interest because they were similar in nature (i.e., positive or negative) to those of human disturbance. Relationships between stream temperature and biological parameters were generally weaker and applied to fewer biological parameters compared to those of human disturbance. Still, there could be some difficulty in separating out the respective influences of temperature and human disturbance. This is further complicated because elevated stream temperatures are a typical symptom of human disturbance associated with removal of overhanging riparian vegetation (i.e., loss of shade) and warmer surface water discharges from impervious surfaces.

Similar to temperature, elevation consistently showed negative relationships with disturbance-sensitive biological parameters, and positive relationships with disturbance-tolerant biological parameters. One would normally expect the opposite pattern, as many disturbance-sensitive taxa including various stoneflies, mayflies, and caddisflies are typically abundant in higher elevation, cold water mountain streams. The observed relationships between elevation and disturbance-sensitive and tolerant taxa is partly attributable to the influences of MA-1, MA-2, and M-5, which were unusual in that they were all at high elevations, but had high stream temperatures, presumably due to their open bedrock channel morphology. As indicated above, natural relationships between high stream temperature and many biological parameters were similar in nature to those of increased human disturbance. Thus, stream temperature may actually be the underlying cause of the perceived relationships between elevation and the stream biota.

While being a worthwhile exercise, the multiple regression analyses of undisturbed study reaches were confusing in some cases, particularly with respect to the influences of elevation. These analyses are based on a relatively small sample size (i.e., n=23). Statistical analyses of small sample sizes such as this can sometimes yield erroneous results due to random chance, or dominance by "outlier" data points that are not representative of the distribution (i.e., possibly MA-1, MA-2, and M-5 in the case of elevation). Analyses of a more robust data set may yield more definitive results regarding natural relationships between physiochemical and biological parameters.

In addition to the physiochemical differences discussed above, there were also subtle differences in BMI composition between streams in the easternmost portion of the study area (Matilija and Sespe Creeks) and streams located further west along the southern slopes of the Santa Ynez Mountains from Rincon Creek to Gaviota Creek. Most of the BMI taxa found in Sespe and Matilija Creeks also occurred in one or more of the study streams to the west. However, there were several taxa found only in Matilija Creek and/or Sespe Creek including the mayfly *Chloroterpes*, the caddisflies *Cheumatopsyche*, *Oxyethira*, and *Marilia flexuosa*, the true fly *Anopheles*, the true bug *Rhagovelia*, the dragonflies *Erpetogomphus* and *Brechomorphoga*, and the hellgrammite *Corydalus*. The absence of these taxa from the western study streams may indicate they reach the western edge of their range in the Santa Clara and Ventura River watersheds. This suggests a slight regional distinction between the Ventura County and Santa Barbara County streams.

Three of the 17 biological community parameters and about one-third (17 of 53) of the individual BMI taxa evaluated had significant or marginally significant differences between riffles and pools. This suggests that using a multi-habitat sampling approach (i.e., sampling riffles and pools) in local streams is important, assuming that one of the goals of bioassessment is to obtain as much information about the BMI community (i.e., the taxa present) as possible. Using a single habitat sampling protocol such as the California Stream Bioassessment Protocol, which involves sampling riffles only, would likely yield less information about the BMI community (i.e., pool-residing taxa) compared to the multi-habitat approach used in this study, despite a comparable investment of time and resources required to complete the sampling.

There was little year-to-year variability in most physiochemical and biological parameters among the nine study reaches surveyed in all three years, despite 2000 and 2001 being somewhat normal rainfall years and 2002 being a relatively dry year. Because this study was conducted over three years only, the influences of long-term climatic trends (i.e., extended wet and dry periods) have not been documented. Similarly, this study does not provide information on seasonal changes in stream biota, as field surveys have been conducted in roughly the same season each year.

Previous studies in Rattlesnake Creek, a tributary of Mission Creek, suggest that the local stream biota respond to seasonal and year-to-year variations in rainfall and Q (Cooper, et. al., 1986). In typical years, winter storm flows wash out stream substrata and many of the organisms that reside there. As flow levels and velocities recede, stream substrata are re-colonized by various diatoms and BMIs including Ephemerellidae, Baetidae, *Calineuria*, *Sweltsa*, *Malenka*, *Blepharicera*, *Simulium*, and *Paltothemis*. As Q diminishes into summer and fall, colonial algae increase in abundance, as do tadpoles (*Psuedacris spp.*), newt larvae (*Taricha torosa),* and BMIs including *Hydropsyche*, *Baetis*, Chironomidae, Hydroptilidae, *Archilestes*, Dytiscidae, *Tricorythodes*, and *Caenis*. Many taxa such as rainbow trout, *Notonecta*, *Baetis*, *Simulium*, *Abedus*, and *Paraleptophlebia* are fairly abundant year-round. In general, winter/spring taxa in Rattlesnake Creek persist into the summer in wet years, whereas summer/fall taxa appear earlier in the spring in dry years. Taxa that are aquatic throughout their lives such as rainbow trout, *Notonecta*, Gastropods, and Ostracods can be drastically reduced in number by extreme flood flows, and can take years to recover to their previous abundances. Organisms with terrestrial life stages such as newts, frogs, mayflies, caddisflies, stoneflies, true flies, etc. typically are able to recolonize and recover more quickly from scouring flows (Cooper, et. al., 1986). It is reasonable to assume that the patterns of biological succession documented in Rattlesnake Creek are similar to what occurs in streams throughout the study area. However, local streams do vary in physiochemical conditions and biotic composition. Gaining a more complete understanding of temporal patterns of biological succession in local streams would require long-term sampling at numerous study reaches, and sampling at different times of the year.

Determine the strength and nature of relationships between local stream ecosystem integrity and human disturbances including urban development, agricultural development, cattle grazing, physical habitat alterations (e.g., channelization), increased sedimentation, altered hydrology, and water pollution.

The exploratory statistical analyses (i.e., ANOVAs and t-tests) conducted in this study show that nearly all of the biological community parameters and many individual BMI taxa were significantly or marginally significantly related to human disturbance, with p well below 0.01 in many cases. In general, disturbed study reaches were degraded in terms of ecosystem integrity as evidenced by:

- Impaired water quality in the form of higher steam temperature, specific conductance, and nutrient levels;
- Lower diversity of BMIs and aquatic vertebrates;
- Lower composition of disturbance-sensitive BMIs, and;
- Higher biotic index score and composition of disturbance-tolerant BMIs.

The analysis indicates that urban-impacted sites (DIST URB) were typically more degraded in terms of water quality and biological parameters compared to agriculture-impacted sites (DIST AG). Differences between undisturbed (UNDIST) and lightly to moderately disturbed (MOD DIST) sites were in most cases slight and not statistically significant.

In general, the strong relationships between stream ecosystem integrity and human disturbance shown in this study echo the findings of several bioassessment studies conducted in other regions (e.g., Lin et. al., 2002; Cooper and Herbst, 2001; Maxted et. al., 2000; Mangum and Madrigal, 1999; Stevens and Cummins, 1999; Plotnikoff and Ehinger, 1997). In most cases, relationships between individual BMI taxa and human disturbance shown in this study are consistent with published tolerance values provided in CDFG's *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* (2002). Possible exceptions to this include *Paltothemis lineatipes*, *Agabus*, *Caloparyphus*, *Abedus*, *Archillestes*, and *Graptocorixa/Neocorixa*, which all appeared to be more sensitive to human disturbance in local streams compared to their listed tolerance values.

This study did not completely separate the natural influences of physiochemical parameters on the stream biota from those of human disturbance. However, the analyses of Reference vs. Test groups did show significant degradation of biological parameters with increasing human disturbance within a subset of study reaches having a fairly narrow range of stream order, elevation, and gradient. Also, relationships between the stream biota and human disturbance were generally much stronger and applied to more biological parameters compared with natural relationships between the stream biota and physiochemical parameters. Based on the exploratory analyses, it appears obvious that anthropogenic disturbance results in the degradation of local stream ecosystems.

Determine which biological parameters are the most reliable indicators of local stream ecosystem integrity.

This study identified more than 50 biological parameters showing significant or marginally significant relationships with human disturbance. These biological parameters, listed in Table 4, are all potential indicators of stream ecosystem integrity. The second column of Table 4 indicates the nature (i.e., positive or negative) and strength (i.e., significant or marginally significant) of each potential biological indicator's relationship with human disturbance. The remaining columns indicate the nature and strength of natural relationships of the potential biological indicators with physiochemical parameters. See the table notes for details. Table 4 is intended to provide guidance for determining the reliability and applicability of the biological indicators. The most reliable, widely-applicable biological indicators are those that have strong relationships with human disturbance, and do not have strong natural relationships with physiochemical parameters. Nine of the biological indicators identified in this study fit these criteria: insect family diversity, percent EPT, Tricoptera, Elmidae, Diptera, Tipulidae, *Hexatoma*, Odonata, and *Cordulegaster dorsalis*. These are highlighted in **bold** font in Table 4. The other biological indicators listed in Table 4 all had significant or marginally significant natural relationships with at lease one physiochemical parameter.

Table 4
Biological Indicators of Local Stream Ecosystem Integrity

Biological Indicator	**Relationship with Human Disturbance**	**Natural Relationships with Physiochemical Parameters**						
		Temp.	**pH**	**Sp. Conduct.**	**Q**	**Elev.**	**Order**	**Gradient**
COMMUNITY PARAMETERS								
Insect order diversity	**NEG**	NONE	NONE	NONE	NONE	**NEG**	NONE	NONE
Insect family diversity	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Insect genera diversity	**NEG**	NEG	NONE	NONE	NONE	NONE	POS	NONE
EPT family diversity	**NEG**	**NEG**	NONE	NONE	NONE	NONE	**POS**	NONE
EPT genera diversity	**NEG**	**NEG**	NONE	NONE	NONE	NONE	**POS**	NONE
Percent EPT	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Percent PT	**NEG**	**NEG**	NONE	POS	NONE	NONE	NONE	NONE
Family biotic index score	**POS**	**POS**	NONE	NONE	NONE	NONE	NONE	NONE
Percent sensitive BMIs (family)	**NEG**	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE
Percent tolerant BMIs (family)	**POS**	**POS**	**POS**	NONE	NONE	NONE	NONE	NONE
Genera biotic index score	**POS**	**POS**	NONE	NONE	NONE	**POS**	NONE	NONE
Percent sensitive BMIs (genera)	**NEG**	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE
Percent tolerant BMIs (genera)	**POS**	**POS**	NONE	NONE	NONE	**POS**	NONE	NONE
Percent collector-gatherers + scrapers + shredders	**NEG**	NONE	POS	NONE	NEG	NONE	NONE	NONE
Percent omnivores + collector-filterers	POS	NONE	NONE	NONE	NONE	**NEG**	NONE	NONE
Percent BMI predators	**NEG**	NONE	NONE	NONE	NONE	**NEG**	NONE	NONE
Native aquatic vertebrate diversity	**NEG**	NONE	NONE	NONE	NONE	**NEG**	NONE	NONE
INDIVIDUAL BMI TAXA								
Leptophlebidae	**NEG**	NONE	**NEG**	NONE	**POS**	NONE	NONE	NONE
Paraleptophlebia	**NEG**	NONE	NEG	NONE	NONE	NONE	**POS**	NONE
Heptagenidae	**NEG**	**NEG**	NONE	NONE	NEG	**NEG**	NONE	NONE
Leuc./Nixe or Hept.	**NEG**	NONE	NONE	**POS**	NONE	**NEG**	NONE	NONE
Plecoptera	**NEG**	NEG	NONE	NONE	NONE	**NEG**	NONE	NONE
Sweltsa	**NEG**	NONE	NONE	NONE	NONE	**NEG**	NONE	NONE
Malenka	**NEG**	NONE	**NEG**	NONE	NONE	NONE	NONE	NONE
Calineuria ca.	NEG	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Tricoptera	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Lepidostoma	**NEG**	**NEG**	NONE	**POS**	NONE	NONE	NONE	NONE
Rhyacophila	**NEG**	NONE	NONE	NEG	NONE	NEG	NONE	**POS**
Coleoptera	**NEG**	NONE	NONE	NONE	NONE	**NEG**	NONE	NONE
Elmidae	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Ordobrevia numb.	**NEG**	NONE	**NEG**	NONE	NONE	**NEG**	**POS**	NONE
Zaitz. or Heter.	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Peltodytes	**POS**	NONE	NONE	NONE	NONE	NONE	NONE	NONE

Table 4 **Biological Indicators of Local Stream Ecosystem Integrity**								
Biological Indicator	**Relationship with Human Disturbance**	**Natural Relationships with Physiochemical Parameters**						
		Temp.	**pH**	**Sp. Conduct.**	**Q**	**Elev.**	**Order**	**Gradient**
Hydrophilidae	**POS**	ND	ND	ND	ND	ND	ND	ND
Tropisternus	**POS**	ND	ND	ND	ND	ND	ND	ND
Eubrianax ed.	**NEG**	NONE	NONE	**POS**	NONE	**NEG**	NONE	**POS**
Diptera	**POS**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Chironomidae	**POS**	NONE	NONE	NONE	NONE	POS	NONE	NONE
Dixidae	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Tipulidae	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Hexatoma	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Odonata	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Cordulegaster dorsalis	**NEG**	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Gomphidae	**NEG**	NONE	NONE	POS	NONE	NONE	NONE	NONE
Megaloptera	**NEG**	NONE	**NEG**	NONE	POS	NONE	NONE	NONE
Corydalidae	**NEG**	NONE	NEG	NONE	POS	NONE	**POS**	NONE
Sialis	**NEG**	NONE	NEG	NONE	NONE	NONE	NONE	NONE
Gastropoda	**POS**	NONE	NONE	NONE	**POS**	**POS**	NONE	NONE
Ostracoda	**POS**	**POS**	**POS**	NONE	NONE	**POS**	NONE	NONE
Copepoda	**POS**	ND	ND	ND	ND	ND	ND	ND
Cladocera	**POS**	ND	ND	ND	ND	ND	ND	ND
Oligochaeta	POS	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Hirudinea	**POS**	ND	ND	ND	ND	ND	ND	ND

Notes:

1. "POS" = positive relationship, "NEG" = negative relationship, "NONE" = insignificant relationship, and "ND" = not determined due to insufficient data.
2. Strength of relationships with human disturbance and natural physiochemical parameters denoted in normal font for marginally significant ($0.1 \geq p > 0.05$) and **bold** font for significant ($p \leq 0.05$).
3. Indicators (first column) having significant relationships with human disturbance and insignificant natural relationships with all physiochemical parameters are denoted in **bold** font.

There should be many situations where biological indicators having strong relationships with one or more physiochemical parameters can be reliable. For example, percent BMI predators, which was shown to have a natural negative relationship with elevation, should be a reliable indicator for assessing the health of low elevation streams, since it is not naturally limited at low elevations. As another example, biotic index score, which was shown to have a natural positive relationship with stream temperature, should be a reliable indicator for assessing the integrity of cold-water streams.

The above examples aside, biological indicators that are naturally related to one or more physiochemical parameters should be used with caution to ensure that natural physiochemical influences are not confused with those of human disturbance. For example, using biotic index score to assess a naturally warm water stream would not be advised, unless a correction factor was used to account for the natural influences of high stream temperature. To illustrate this, consider the stream reaches SES-1, MAT-1, MA-2, and M-5, which are among the most pristine, least disturbed stream reaches studied. These stream reaches also have naturally high stream temperatures, presumably due to their open bedrock channels, which prevent riparian vegetation from shading most of channel, resulting in solar heating of the stream. These reaches all had high biotic index scores (genera and family) compared to the other undisturbed study reaches. In fact, biotic index scores at SES-1, MAT-1, MA-2, and M-5 were comparable to many of the highly disturbed study reaches, especially in the cases of MA-2 and M-5. Based solely on biotic index score, it could be erroneously concluded that these study reaches were unhealthy (i.e., degraded) because biotic index score had such a strong positive relationship with human disturbance among the study reaches as a whole. However, biotic index score also had a strong, positive natural relationship with stream temperature, which most likely explains the high scores for M-5, SES-1, MAT-1, and MA-2. Similarly, one should not interpret the absence or rarity of certain disturbance-sensitive taxa such as Heptagenidae, Plecoptera, and *Lepidostoma* at SES-1, MAT-1, MA-2, and M-5 to indicate that these streams are unhealthy, as these taxa are also naturally limited by high stream temperatures.

Another very important finding of the analyses is that analogous BMI community parameters based on genus-level and family-level identifications (e.g., insect genera diversity vs. insect family diversity, genera biotic index score vs. family biotic index score, etc.) provided almost identical overall ability to detect and indicate relationships between biological parameters, physiochemical variables, and human disturbance. A substantial amount of time equaling approximately 40 percent of the total laboratory BMI sorting/identification effort was dedicated to keying BMIs from family to genus. This accounted for approximately 15 percent of the total costs of the Program. Based on this, identifying BMIs to genus is neither necessary nor cost-effective to achieving the Program goals. This conclusion is supported by convincing statistical analyses based on a robust data set (i.e., n=65) collected over a three year period.

VII. Conclusions and Recommendations for Further Study

The three-year Program effort has already provided a great deal of insight regarding relationships between local stream biota, human disturbance, and natural physiochemical parameters. The study has also identified more than 50 biological indicators of local stream ecosystem health. There are however still questions posed by the Program Goals that remain partially or wholly unanswered. For one, sampling of more reference stream reaches in future years is needed to yield more solid conclusions regarding the influences of the natural ranges of physiochemical parameters on local stream biota. Second, it would be beneficial to more completely evaluate relationships between stream biota and specific human disturbances including urban and agricultural development, livestock grazing, increased sedimentation, hydrologic alterations, streambed and bank alterations, impacts to riparian and upland vegetation, and inputs of specific water pollutants. This could be accomplished by more closely studying sites affected by particular anthropogenic stressors, and possibly through experimental manipulations. Coordination of detailed water chemistry analysis with bioassessment efforts, possibly in combination with toxicity testing, could allow the effects of various water pollutants on the stream biota to be determined more rigorously. There are also the goals of monitoring long-term responses of the stream community to (1) climatic trends including prolonged wet and dry periods, and even global warming, and (2) existing and future human land uses, and stream restoration and water quality improvement efforts. More complete knowledge of geographic variation in stream biota would also be useful. These goals can only be met through continued, long-term monitoring of local streams.

Another goal that should be added to the Program scope is to develop a standardized tool known as an Index of Biotic Integrity (IBI). IBIs, popular among water resource agencies in the U.S., are multi-metric tools that provide a standardized, integrative, and readily understandable method for measuring the biological integrity of streams and other water bodies (Barbour, et al., 1999). The term "multi-metric" refers to the fact that an IBI is built by combining or compositing several individual biological parameters or "metrics". Selected "core" metrics all show distinct separation (i.e., are different) between minimally degraded "reference" sites, and degraded "test" sites. In addition, the core metrics of an IBI collectively represent multiple aspects of biological community structure including, at a minimum, richness and diversity, composition, disturbance tolerance, and trophic groups (Barbour, et al., 1999). Values for each core metric at a study site are "scored" on a dimensionless scale (e.g., from 1 to 5) in relation to the known distribution among a collection of reference and test sites. Higher scores (e.g., a 5) approach the conditions at the best reference sites, while lower scores indicate greater departure (i.e., degradation) from reference conditions. Scores assigned to the individual core metrics are equally weighted and combined into an overall score, or measure, of biological integrity for the study site. By translating complex biological data into an overall composite measure of biological integrity, an IBI score serves as a powerful tool for communicating the biological status of water resources to a wide audience, and an important basis of environmental management decisions (Barbour et al., 1999, Karr and Chu, 1999).

Because biological assemblages vary in response to physiochemical gradients that exist through geographic space, IBIs are calculated for specific regions with similar ecological characteristics. This minimizes the potential for confusion between natural physiochemical and anthropogenic influences. Further, separate IBIs are developed for different classes of water bodies, such as estuaries vs. lakes, lakes vs. streams, and, at a finer level, high elevation mountain streams vs. low elevation coastal streams. Another noteworthy aspect of IBIs is that although they combine several core biological metrics, they are developed for a single biological assemblage, typically BMIs, fish, amphibians, or algae. To provide a more complete assessment of the biological condition of water bodies, USEPA and others recommend developing IBIs for more than one assemblage (Barbour, et al., 1999). The various assemblages can respond differently to certain stressors and restoration activities. For example, Mount et al. (1984) found that benthic and fish assemblages responded differently to the same pollution inputs in the Ottawa River in Ohio. BMIs responded negatively to organic loading from a wastewater treatment plant, and exhibited no observable response to chemical input from industrial effluent. Conversely, fish exhibited no response to the organic inputs, and a negative response to metal concentrations in the water.

IBIs and similar multi-metric indexes are the most popular biological assessment models in U.S. Another approach known as the river invertebrate prediction and classification scheme (RIVPACs) and its derivatives are used extensively in England and Australia. RIVPACs is also being used in this country by the USGS. RIVPACs and its derivatives are empirical (statistical) models that predict what dominant BMI taxa should occur at a site in the absence of environmental stress based on the physiochemical attributes of the site (Barbour et al., 1999). RIVPACs models are developed for specific habitat types (e.g., riffles, pools, macrophyte stands, etc.) in streams within defined physiochemical classifications and geographic regions. Building a RIVPACs model requires the collection of data from a large set of randomly selected reference sites. RIVPACs models have been slow to gain acceptance in the U.S. Possible reasons for this include (1) the perception that RIVPACs models are intuitively more difficult to understand compared to IBIs; (2) RIVPACs models have not been developed thus far for any biological assemblages besides BMIs, and; (3) RIVPACs models have not been tested using multi-habitat BMI sampling approaches such as the protocol used in this Program (Barbour et al., 1999). In addition, RIVPACs models have not been demonstrated to be more effective than IBIs in measuring biological integrity. For these reasons, an IBI is considered more appropriate for development as part of this Program than is a RIVPACs model.

Based on the above, the following recommendations for further study are offered for the 2003 Program effort:

- Continue monitoring the established study reaches, and expand the number of study reaches as funding permits. Additional study reaches should be selected carefully to improve the range of physiochemical parameters and types of human disturbance collectively represented in the data set. Types of study reaches that are generally lacking from the current data set include (1) undisturbed lowland coastal streams and (2) disturbed higher elevation mountain streams. Adding more of these types of study reaches to the data set and subsequent analyses will provide more complete characterization of the relationships between biological parameters, physiochemical parameters, and human disturbance.
- As funding permits, combine bioassessment surveys with intensive water quality testing and/or bioassays. This will facilitate the characterization of relationships between individual water pollutants and biological parameters, and the identification of biological indicators for specific pollutants.
- Identify BMIs to the family level only. The analyses show that family-level and genus-level identifications of BMIs provide essentially the same ability to detect relationships between biological parameters, human disturbance, and physiochemical parameters. The money saved from not identifying BMIs from family to genus can be better spent

assessing additional study reaches or conducting more intensive water quality testing and/or bioassays.

- Develop a BMI-based IBI for local streams. After the 2003 field season, cumulative data collected through the Program should be sufficient to develop a fairly robust IBI. The analyses for the 2003 Program effort can be tailored to develop and test the IBI without increasing the total cost of the Program. In future years it would be advisable to develop IBIs for other biological assemblages, such as an aquatic vertebrate IBI.

Given the multitude of factors affecting stream ecosystems, it will probably never be possible to account for and totally separate all the natural and human influences. Still, the information gained from continuing this Program and other local stream assessment efforts is providing us with the ability to better recognize the effects of anthropogenic disturbances on local stream ecosystems, determine how water quality and stream ecosystems can be restored, and monitor the effectiveness of restoration efforts. Long-term stream monitoring will help advance the sciences of stream assessment and restoration, eventually leading to healthier streams.

VIII. REFERENCES

Allan, J.D. 1995. Stream Ecology. Kluwer Academic Press.

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. 1999. California Stream Bioassessment Procedure. May 1999.

______. 2002. List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort. Revised April 30, 2002.

Charbonneau, R. and V.H. Resh. 1992. Strawberry Creek on the University of California, Berkeley Campus: A Case History of Urban Creek Restoration. Aquatic Conservation: Marine and Freshwater Ecosystems, Vol. 2, 293-307 (1992).

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.

Cooper, S.D., and D.B. Herbst. 2001. Interim Report: First Phase of the Kings River Experimental Watershed Study, Survey Examining the Use of Stream Invertebrates in Monitoring Forest Management Practices.

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.

Danehy, R.J., Ringler, N.H., and R.J. Ruby. 1999. Hydraulic and Geomorphic Influence on Macroinvertebrate Distribution in the Headwaters of a Small Watershed. State University of New York, College of Environmental Sciences and Forestry. Journal of Freshwater Ecology. Volume 14, Number 1 – March 1999, pp. 79-91.

Griffiths, R.W. 1999. BioMAP: Bioassessment of Water Quality. The Centre for Environmental Training, Niagra College. Ontario, Canada.

Harrington, J., and M. Born. 2000. Measuring the Health of California Streams and Rivers. Sustainable Land Stewardship International Institute.

Hauer, R.F., and G.A. Lamberti. 1996. Methods in Stream Ecology. Academic Press.

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

Lin, C.J., Pedersen, R.F., Ambrose, R.F., and I.H. Suffet. 2002. Land Use Effects on Stream Ecology in a Mixed-Use Watershed in Mediterranean California. Environmental Science and Engineering Program, University of California, Los Angeles. Los Angeles, California.

Mangum, F.A. and J.L. Madrigal. 1999. Rotenone Effects on Aquatic Macroinvertebrates of the Strawberry River, Utah: A Five-Year Summary. Journal of Freshwater Ecology. Volume 14, Number 1 – March 1999, pp. 125-135.

Maxted, J.R., Barbour, M.T., Gerritsen, J., Poretti, V., Primrose, N., Silvia, A., Penrose, D., and R. Renfrow. 2000. Assessment framework for mid-Atlantic coastal plain streams using benthic macroinvertebrates. North American Benthological Society, 2000, 19(1):128-144.

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

McCafferty, P.W., and A.V. Provoshna. 1981. Aquatic Entomology. Jones and Bartlett Publishers.

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.

Needham, J.G. and P.R. 1962. A Guide to the Study of Freshwater Biology, Fifth Edition. Holden-Day, Inc. Oakland, California.

Padre Associates, Inc. 2001. Carpinteria Creeks Preservation Program, Public Review Draft. Prepared for the City of Carpinteria.

Page, Henry M. 1999. Nutrient Inputs into Carpinteria Salt Marsh Associated with Greenhouse Development in the Carpinteria Valley. Marine Science Institute, University of California, Santa Barbara.

Pennak, R.M. 1989. Freshwater Invertebrates of the United States (2^{nd} Edition). J. Wiley and Sons. New York.

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

Plotnikoff, R.W. and S.I. Ehinger. 1997. Using Invertebrate to Assess the Quality of Washington Streams and to Describe Biological Expectations. Washington State Department of Ecology. Olympia, Washington.

Project Clean Water, County of Santa Barbara. 2000. Rain Year 1999/2000 Water Quality Analysis Report. August 2000.

_____. 2001. Rain Year 2000/2001 Water Quality Analysis Report. September 2001.

_____. 2002. Rain Year 2001/2002 Water Quality Analysis Report. October 2002.

Rosenberg, D.M., and V.H. Resh. 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman and Hall.

Russo, R. and P. Olhausen. 1987. Pacific Coast Mammals.

Sibley, D.A. 2000. National Audubon Society: The Sibley Guide to Birds. Alfred A. Knopf, Inc. New York.

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

Stevens, M.H. and K.W. Cummins. 1999. Effects of Long-Term Disturbance on Riparian Vegetation and In-Stream Characteristics. Journal of Freshwater Ecology. Volume 14, Number 1 – March 1999, pp. 1-17.

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

Stone, R. 1999. Day Hikes Around Santa Barbara, California. Day Hike Books, Inc.

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

Usinger, R.L. (ed.) 1956. Aquatic Insects of California. University of California Press. Berkeley, California.

Wihlm, J.L. 1975. Biological Indicators of Pollution. River Ecology. University of California Press. Berkeley, California. pp. 375-402.

Zeiner D. C., Laurenslayer, W.F. Jr., Mayer K.E., and M. White, eds. 1990. California's Wildlife. Vol. I Amphibians and Reptiles, Vol. II Birds, and Vol. III Mammals. California Department of Fish and Game, Sacramento, California.