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BIOLOGICAL AND PHYSICAL/ HABITAT ASSESSMENT OF
CALIFORNIA WATER BODIES

California Regional Water Quality Control Board, San Diego Region 2002 Biological Assessment Report:

Results of May 2001 Reference Site Study and Preliminary Index of Biotic Integrity

California Department of Fish and Game
Office of Spill Prevention and Response
Water Pollution Control Laboratory
Aquatic Bioassessment Laboratory
2005 Nimbus Road
Rancho Cordova, CA. 95670
(916) 358-2862; jharring@ospr.dfg.ca.gov

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AUTHORS

Peter R. Ode, Andrew Rehn, James M. Harrington

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INTRODUCTION

Bioassessment in California

In order to add a biological component to its water quality monitoring programs as required under the federal Clean Water Act, the State of California began the initial stages of biocriteria development in 1993. These efforts have steadily increased over the last decade to the point that bioassessments are being used for a wide range of applications throughout the state and several regions have made considerable progress toward the goal of biocriteria implementation.

Because water quality regulatory authority in California is divided into nine autonomous Regional Water Quality Control Boards, the State of California has taken a regional approach to biocriteria development instead of the statewide approach common in other states. The California Department of Fish and Game (DFG) has helped to coordinate this approach by developing standard statewide procedures for collecting bioassessment data and by working with individual regions to apply appropriate bioassessment techniques to support water quality management decisions.

Bioassessments are typically based on fish (McCormick *et al.* 2001, Karr 1981), attached algae (Pan *et al.* 2000) or invertebrate communities (Resh and Jackson 1993, Kerans and Karr 1994), each having advantages and disadvantages. Like most states, California has adopted the use of invertebrate communities as its primary tool, however future programs in the state are likely to include other communities (especially algae). In 1995, DFG developed and distributed standardized sampling, laboratory and quality assurance procedures for invertebrate bioassessment (the California Stream Bioassessment Procedure [CSBP]).

The CSBP is a regional adaptation of the U.S. Environmental Protection Agency (EPA) Rapid Bioassessment Protocols (Barbour *et al.* 1999) and is recognized by the EPA as California's standardized bioassessment procedure (Davis *et al.* 1996). The CSBP is a cost-effective tool that utilizes measures of the stream's benthic macroinvertebrate (BMI) community and its physical/habitat structure. Because BMIs are sensitive in varying degrees to many environmental disturbances (Resh and Jackson 1993), they can provide considerable information regarding the biological condition of water bodies. Together, biological and physical assessments integrate the effects of water quality over time, are sensitive to multiple aspects of water and habitat quality, and provide the public with familiar expressions of ecological health (Gibson 1996, Yoder and Rankin 1998, Barbour *et al.* 1999).

Bioassessment in the San Diego Region

The California Regional Water Quality Control Board, San Diego Region [RWQCB (9)] has been a leader in the state's incorporation of biological information into its water quality monitoring programs. In 1997 and 1999 the RWQCB (9) contracted DFG's Aquatic Bioassessment Laboratory (ABL) to help them incorporate bioassessment into their ambient water quality monitoring program. The initial sampling strategy was designed to supplement existing water column chemistry and toxicity data with biological community data. As the program developed, emphasis was shifted toward gathering baseline information that would serve as a foundation for bioassessment in the San Diego region.

In April 2000, ABL first reported the results of bioassessments conducted in May 1998, September 1998, November 1998 and May 1999 at 48 locations spread throughout the San Diego region. Most of these initial sites were significantly impacted by human activities (Ode and Harrington 2000). Subsequent sampling events incorporated an increasing number of less disturbed sites (= reference sites) in addition to many of the original locations. A second ABL report contained the results of sampling events in November 1999, May 2000 and November 2000. In May 2001, a new set of sites was selected to explicitly characterize reference conditions in the San Diego region, increasing the number of sampling sites to 93 for all eight sampling events. The addition of data from many new reference sites allowed establishment of a framework for interpreting biotic condition for the San Diego region.

Interpretation of Biotic Condition: Multimetric vs. Mulitvariate Approaches

While there are many potential ways of evaluating biotic condition from community data, most approaches can be grouped into one of two categories: multimetric techniques and multivariate techniques. In multimetric techniques a set of biological measurements ("metrics"), each representing a different aspect of the community data, is taken at each site. An overall site score is calculated as the sum of individual metric scores. Sites are then ranked according to their scores and classified into groups with "good", "fair" and "poor" water quality. This system of scoring and ranking sites is referred to as an Index of Biotic Integrity (IBI) and is the end point of a multi-metric analytical approach recommended by the EPA for development of biocriteria (Davis and Simon 1995). The original IBI was created for assessment of fish communities (Karr 1981), but was subsequently adapted for BMI communities (Kerans and Karr 1994).

In multivariate techniques the response of biological communities to natural environmental gradients is evaluated either directly or indirectly. Community composition at test sites can then be predicted based on strongly correlated environmental variables. Overall site quality is estimated by comparing the observed biological community with the community expected based on key environmental variables (Wright *et al.* 1984, 1993).

Relative advantages of the two approaches have been debated extensively in the scientific literature (see summaries in Norris and Georges 1993, Norris 1995, Barbour *et al.* 1999). Both techniques are valid approaches to analysis of bioassessment data, and both types of analyses can be applied to the same dataset. Our recommendation is to use information from both approaches whenever possible in order to provide the most robust analysis of the data. Although a framework is not currently in place for the use of a multivariate approach, we expect to take advantage of ongoing work by the US Forest Service (Hawkins *et al.* 2000) and others to develop a model of expected conditions for California within the next few years.

Our initial strategy has been to develop IBIs for different regions of California; we are currently exploring several potentially appropriate ways to classify regions for unique IBI development (e.g. watershed-based IBIs, ecoregion-based IBIs and water management region-based IBIs). The first California regional IBI was successfully applied to the Russian River watershed in 1999 (Harrington 1999). Increased knowledge of how biological communities respond to environmental disturbance will lead toward a standardized approach to using IBIs throughout California.

In this report, the results of the May 2001 sampling event are presented in a format similar to previous reports and are combined with the results of earlier sampling events to construct and test a provisional IBI for the San Diego region. Two recent analyses of fish communities, one in the Willamette Valley of Oregon (Hughes *et al.* 1998) and one in the Middle Atlantic Highlands region of the eastern US (McCormick *et al.* 2001), developed a modified version of the original IBI. The IBI presented for the San Diego region combines the original Karr approach with these recent modifications.

Materials and Methods

May 2001 Sampling Event

Bioassessment data for the May 2001 sampling event were collected in the same manner described for the previous seven sampling events.

Monitoring Reach Delineation

Sampling reaches were delineated according to the methods described in the CSBP (Harrington 1999). Reaches normally consisted of a five-riffle stretch of stream in which all riffles had similar gradient and substrate characteristics. Three of the five riffles within a reach were then randomly selected for sampling. Occasionally, it was not possible to find 5 contiguous riffles of similar characteristics at a site in which case fewer riffles (3 or 4) were used. Monitoring reach descriptions are summarized in Table 1 and a map of sampling locations is presented in Figure 1. Monitoring activities occurred between May 15 and May 25, 2001.

BMI Sampling

Riffle length was measured for each of the three riffles, and a random number table was used to randomly establish a point along the upstream third of each riffle at which a transect was established perpendicular to stream flow. Starting with the riffle transect furthest downstream, the benthos within a 2 ft^2 area was sampled upstream of a 1 ft wide, 0.5 mm mesh D-frame kick-net. Sampling of the benthos was performed manually by rubbing cobble and boulder substrates in front of the net, followed by "kicking" the upper layers of substrate to dislodge any remaining invertebrates. The duration of sampling ranged from 60-120 seconds, depending on the amount of boulder and cobble-sized substrate that required rubbing by hand; more and larger substrates required more time to process. Three locations along each transect were sampled to represent habitat diversity within transects, and these were combined into a composite sample, representing a 6 ft^2 area for each transect and 18 ft^2 for the entire reach. Each composite sample was transferred into a 500 ml wide-mouth plastic jar containing approximately 200 ml of 95% ethanol. This technique was repeated for each of three riffles in each reach.

Physical Habitat Assessment (Reach Scale and Riffle Scale)

Physical habitat quality was assessed for the monitoring reaches using the visual scoring system described in the U.S. Environmental Protection Agency (EPA) Rapid Bioassessment Protocols (RBPs) (Barbour *et al.* 1999). Habitat quality assessments were recorded for each monitoring reach during each sampling event. Photographs were taken within each of the monitoring reaches to document overall riffle condition at the time of sampling. At a minimum, photographs were taken upstream and downstream through each reach sampled.

In addition to the physical habitat quality assessments for each entire reach, we recorded several additional measures of habitat characteristics within each riffle. The following measurements were taken in the vicinity of the BMI collection sites: GPS coordinates, elevation, riffle gradient, riffle width and depth, canopy cover, substrate complexity, substrate consolidation and the proportion of different substrate sizes (substrate composition).

Ambient Water Chemistry Recording

General Parameters

Ambient water chemistry was recorded at each site using a Yellow Springs Instruments (YSI 3800 or YSI 85) water quality meter. Recorded measurements included water temperature, dissolved oxygen concentration, specific conductance, salinity and pH.

Nitrogen and Phosphorus Series, TDS and Alkalinity

Additional chemistry measurements were collected at most of the May 2001 sites. Water samples were processed for the following analytes (Nitrogen-Nitrite, Nitrogen-Nitrate, Nitrogen-Kjeldahl, Nitrogen-Ammonia, Nitrogen-Total, Phosphorus-Orthophosphate, TDS, and Phosphorus-Total) by Environmental Engineering Laboratory (EEL) in San Diego. Alkalinity samples were processed at the DFG's Water Pollution Control Laboratory in Rancho Cordova.

BMI Laboratory Analysis

At the ABL laboratory, each sample was rinsed through a No. 35 standard testing sieve (0.5 mm brass mesh) and transferred into a tray marked with twenty, 25 cm^2 grids. All sample material was removed from one randomly selected grid at a time and placed in a petri dish for inspection under a stereomicroscope. All invertebrates from the grid were separated from the surrounding detritus and transferred to vials containing 70% ethanol and 5% glycerol. This process was continued until 300 organisms were removed from each sample. The material left from the processed grids was transferred into a jar with 70% ethanol and labeled as "remnant" material. Any remaining unprocessed sample from the tray was transferred back to the original sample container with 70% ethanol and archived. BMIs were then identified to a standard taxonomic level, typically genus level for insects and order or class for non-insects, using standard taxonomic keys (Brown 1972, Edmunds *et al.* 1976, Klemm 1985, Merritt and Cummins 1995, Pennak 1989, Stewart and Stark 1993, Thorp and Covich 2001, Usinger 1963, Wiederholm 1983, 1986, Wiggins 1996, Wold 1974).

Data Analysis

A taxonomic list of BMIs identified from the samples was entered into a Microsoft Excel® spreadsheet program. MS Excel® was used to calculate and summarize BMI community based metric values. A description of the metric values used to describe the community is shown in Table 2.

Table 1. Benthic macroinvertebrate sampling site information for sampling events between May 1998 and May 2001 in the San Diego region indicating site identification (ID), latitude and longitude and sampling dates. Reference sites are indicated in red.

WATERSHED NAME	LOCATION DESCRIPTION	SITE ID	LATITUDE/ LONGITUDE	Site No.	May 1998	Sept 1998	Nov 1998	May 1999	Nov 1999	May 2000	Nov 2000	May 2001
San Juan Hydrologic Unit	Aliso Creek: Reach consisted of 3 riffles upstream of Pacific Park Drive	AC-PPD	N33° 34' 30.6", W117° 42' 53.9"	1	x	x	x	x	x	-	-	x
San Juan Hydrologic Unit	Aliso Creek: Reach consisted of 5 riffles parallel to Country Club Road upstream of Hwy 1	AC-CCR	N33° 30' 51.2" W117° 44' 34.9"	2	x	x	x	x	x	x	x	-
San Juan Hydrologic Unit	Arroyo Trabuco Creek: Reach consisted of 5 riffles parallel to Country Club Road upstream of Highway 1	ATC-AP	N33° 35' 3.0" W117° 38' 9.0"	3	-	x	x	x	x	x	x	-
San Juan Hydrologic Unit	Bell Canyon Creek: Reach consisted of 5 riffles at Star Rise Trail in Casper's Wilderness Park	BCC-SRT	N33° 33' 51.2" W117° 33' 49.3"	4	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	Bell Canyon Creek: Reach consisted of 5 riffles at Bell Canyon Trail in Casper's Wilderness Park	BCC-BCT	N33° 34' 8.5" W117° 33' 54.3"	5	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	Arroyo Trabuco Creek: Reach consisted of 5 riffles in Trabuco Canyon	ATC-TC	N33° 40' 29.2" W117° 32' 49.5"	6	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	San Juan Creek: Reach consisted of 5 riffles upstream of Highway 74 bridge crossing	SJC-74	N33° 31' 9.0" W117° 37' 25.4"	7	-	x	x	x	-	x	x	-
San Juan Hydrologic Unit	Wood Creek: Reach consisted of 5 riffles at 2 mile marker	WC-2MM	N33° 33 56.6 W117° 44' 47.1"	8	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	Wood Creek: Reach consisted of 5 riffles at Coyote Run Trail	WC-CRT	N33° 34 05.0 W117" 44' 51.7"	9	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	Wood Creek: Reach consisted of 5 riffles at end of Wood Canyon Trail	WC-EOT	N33° 33 50.9 W117° 44' 41.2"	10	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	San Mateo Creek: San Mateo Canyon	SMC-SMC	N33° 32' 58.65" W117° 23' 46.23"	11	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	San Mateo Creek: Immediately upstream of confluence with Devil's Canyon Creek	SMC-DC	N33° 28' 22.0" W117° 27' 53.4"	12	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	San Mateo Creek: at San Mateo Road	SMC-SMR	N33° 25' 24.2" W117° 31' 52.9"	13	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	Devils Canyon Creek: Immediately upstream of confluence with San Mateo Cr.	DCC-DC	N33° 28' 15.9" W117° 27' 52.6"	14	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	Silverado Creek: Reach consisted o f 5 riffles near Ladd Canyon Road	SC-LCR	N33° 44 52.5 W117° 38' 28.5"	15	-	-	-	-	-	-	-	x
San Juan Hydrologic Unit	Silverado Creek: Reach consisted of 5 riffles above Silverado	SC-AS	N33° 44 49.1 W117° 36' 43.7"	16	-	-	-	-	-	-	-	x
Santa Margarita Hydrologic Unit	Santa Margarita River: Reach consisted of 5 riffles 2 miles upstream of Willow Glen Road	SMR-WGR	N33° 25' 49.3" W117° 11' 43.1"	17	x	x	x	x	x	x	x	x
Santa Margarita Hydrologic Unit	Santa Margarita River: Reach consisted of 5 riffles downstream of Sandia Road (near DeLuz/ Pico Road)	SMR-DP	N33° 24' 51.0" W117° 14' 26.3"	18	x	x	x	x	x	x	x	x

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WATERSHED NAME	LOCATION DESCRIPTION	SITE ID	LATITUDE/ LONGITUDE	Site No.	May 1998	Sept 1998	Nov 1998	May 1999	Nov 1999	May 2000	Nov 2000	May 2001
Santa Margarita Hydrologic Unit	Santa Margarita River: Reach consisted of 5 riffles upstream of DeLuz Rd. (downstream of confluence with Sandia Creek)	SMR-DLR	N33° 23' 56" W117° 15' 45"	19	-	-	-	-	-	-	-	x
Santa Margarita Hydrologic Unit	Santa Margarita River: Reach consisted of 5 riffles downstream of Santa Margarita Road, Camp Pendleton	SMR-CP	N33° 20' 22.1" W117° 19' 51.9"	20	x	x	x	x	x	x	x	x
Santa Margarita Hydrologic Unit	Santa Margarita River: Reach consisted of 5 riffles upstream of Stuart Mesa Blvd., Camp Pendleton	SMR-SMB	N33° 14' 12.1" W117° 23' 30.3"	21	x	-	-	x	-	-	-	-
Santa Margarita Hydrologic Unit	Murrieta Creek: Reach consisted of 5 riffles adjacent to USGS gauging station	MC-GS	N33° 28' 36.8" W117° 08' 25.5"	22	x	x	x	x	-	x	x	-
Santa Margarita Hydrologic Unit	Temecula Creek: Reach consisted of 5 riffles immediately downstream of I-15	TC-I-15	N33° 28' 27.9" W117° 08' 16.8"	23	x	x	x	x	x	x	x	-
Santa Margarita Hydrologic Unit	Rainbow Creek: Reach consisted of 3 riffles upstream of Willow Glen Road	RC-WGR	N33° 24' 26.1" W117° 11' 58.9"	24	x	x	x	x	x	x	x	-
Santa Margarita Hydrologic Unit	Murrieta Creek: Reach consisted of 3 riffles downstream of Calle del Oso Oro	MC-WB	N33° 34' 5.7" W117° 14' 21.2"	25	x	-	-	-	-	-	-	-
Santa Margarita Hydrologic Unit	Sandia Creek: Reach consisted of 5 riffles along Sandia Creek Drive, 0.7 miles upstream of Rock Mountain Road	SC-SCR	N33° 25' 27.3" W117° 14' 53.2"	26	x	x	x	x	x	x	x	x
Santa Margarita Hydrologic Unit	Sandia Creek: Reach consisted of 5 riffles upstream of DeLuz Rd.	SC-DLR	N33° 29' 31.9" W117° 14' 47.1"	27	-	-	-	-	-	x	x	x
Santa Margarita Hydrologic Unit	Roblar Creek: Reach consisted of 5 riffles upstream of confluence with De Luz Creek	ROB-DLZ	N33° 23' 13.65" W117° 19' 25.39"	28	-	-	-	-	-	-	-	x
Santa Margarita Hydrologic Unit	De Luz Creek: Reach consisted of 5 riffles upstream of DeLuz-Murrieta Road	DLC-DLM	N33° 27' 34.5" W117° 17' 25.9"	29	-	-	-	-	-	-	x	x
San Luis Rey Hydrologic Unit	Keys Creek: Reach consisted of 5 riffles upstream and downstream of Lilac Road	KC-LR	N33° 17' 38.1" W117° 05' 10.3"	30	x	x	x	x	x	x	x	x
San Luis Rey Hydrologic Unit	Pauma Creek: Site is located downstream of Doque Trail at Palomar Mountain Park	PC-PMP	N33° 20' 55.7" W116° 54' 48.2"	31	-	-	-	-	-	-	x	-
San Luis Rey Hydrologic Unit	San Luis Rey River: Reach consisted of 5 riffles about 50 meters upstream of pullout opposite Outdoor Education School on Hwy 76	SLRR-PG	N33° 15' 44.5" W116° 48' 29.5"	32	x	x	x	x	x	x	x	x
San Luis Rey Hydrologic Unit	San Luis Rey River: Reach consisted of 3 riffles downstream of old Hwy 395 and I-15	SLRR-395	N33° 19' 27.8" W117° 09' 28.2"	33	x	x	x	x	x	x	-	x
San Luis Rey Hydrologic Unit	San Luis Rey River: Reach consisted of 3 riffles upstream of Mission Road	SLRR-MR	N33° 15' 41.6" W117° 14' 06.1"	34	x	x	x	x	x	x	x	-
San Luis Rey Hydrologic Unit	San Luis Rey River: Reach consisted of five riffles upstream of Fousat Road crossing	SLRR-FR	N33° 13' 34.3" W117° 20' 39.2"	35	x	x	x	x	x	-	-	-
San Luis Rey Hydrologic Unit	French Creek: Reach consisted of 5 riffles in Palomar State Park	FC-PSP	N33° 21' 01" W116° 54' 42"	36	-	-	-	-	-	-	-	x

WATERSHED NAME	LOCATION DESCRIPTION	SITE ID	LATITUDE/ LONGITUDE	Site No.	May 1998	Sept 1998	Nov 1998	May 1999	Nov 1999	May 2000	Nov 2000	May 2001
San Luis Rey Hydrologic Unit	Fry Creek: Fry Creek Campground	FC-FCC	N33° 20′ 39″ W116° 52′ 49″	37	-	-	-	-	-	-	-	x
Carlsbad Hydrologic Unit	Loma Alta Creek: Reach consisted of 5 riffles downstream of College Blvd.	LAC-CB	N33° 12' 18.0" W117° 17' 13.4"	38	x	x	x	x	x	-	-	-
Carlsbad Hydrologic Unit	Loma Alta Creek: Reach consisted of 5 riffles downstream of El Camino Real	LAC-ECR	N33° 11' 57.6" W117° 19' 48.2"	39	x	x	x	x	-	x	x	-
Carlsbad Hydrologic Unit	Buena Vista Creek: Reach consisted of 5 riffles downstream of Santa Fe Avenue	BVR-ED	N33° 11' 57.9" W117° 14' 35.1"	40	x	x	x	x	x	-	-	-
Carlsbad Hydrologic Unit	Buena Vista Creek: Reach consisted of 5 riffles upstream of South Vista Way	BVR-SVW	N33° 10' 48.7" W117° 19' 41.1"	41	x	x	x	x	x	x	x	-
Carlsbad Hydrologic Unit	Agua Hedionda Creek: Reach consisted of 5 riffles downstream of Sycamore Avenue	AHC-SA	N33° 09' 22.5" W117° 13' 34.0"	42	x	x	-	-	-	-	-	-
Carlsbad Hydrologic Unit	Agua Hedionda Creek: Reach consisted of 5 riffles downstream of El Camino Real	AHC-ECR	N33° 08' 57.0" W117° 17' 46.9"	43	x	x	x	x	x	x	x	x
Carlsbad Hydrologic Unit	San Marcos Creek: Reach consisted of 5 riffles 50 m upstream of Mc Mahr Road intersection	SMC-M	N33° 07' 47.8" W117° 11' 29.0"	44	x	x	x	x	x	x	x	-
Carlsbad Hydrologic Unit	San Marcos Creek: Reach consisted of 5 riffles downstream of Santar Place	SMC-SP	N33° 08' 37.0" W117° 08' 54.2"	45	x	x	x	x	x	-	-	-
Carlsbad Hydrologic Unit	San Marcos Creek: Reach consisted of 5 riffles 50 m upstream of Mc Mahr Road intersection	SMC-RSFR	N33° 06' 12.9" W117° 13' 33.6"	46	x	x	x	x	x	-	x	-
Carlsbad Hydrologic Unit	San Marcos Creek: Reach consisted of 5 riffles downstream of Rancho Santa Fe Road	SMC-LCCC	N33° 05' 18.7" W117° 14' 43.6"	47	x	x	x	x	x	x	x	-
Carlsbad Hydrologic Unit	Encinitas Creek: Reach consisted of 5 riffles downstream of Green Valley Rd	ENC-GVR	N33° 04' 17.5" W117° 15' 43.8"	48	x	x	x	x	x	x	-	-
Carlsbad Hydrologic Unit	Encinitas Creek: Reach consisted of minimal riffle habitat, large pool was sampled using lentic procedures in May 2000	ENC-RSFR	N33° 04′ 4.2″ W117° 14′ 42.1″	49	-	-	-	-	-	x	-	-
Carlsbad Hydrologic Unit	Chicarita Creek: Site consisted of 5 riffles downstream of Evening Creek Road	CC-ECR	N32° 57′ 43.5″ W117° 05′ 36.2″	50	-	-	-	-	-	x	x	-
Carlsbad Hydrologic Unit	Escondido Creek: Reach consisted of 5 riffles downstream of Harmony Grove bridge	EC-HRB	N33° 06' 31.6" W117° 06' 41.2"	51	x	x	x	x	x	-	-	-
Carlsbad Hydrologic Unit	Escondido Creek: Reach consisted of 5 riffles downstream of Elfin Forest Resort	EC-EF	N33° 04' 17.6" W117° 09' 52.0"	52	x	x	x	x	x	x	-	-
Carlsbad Hydrologic Unit	Escondido Creek: Reach consisted of 5 riffles upstream of Elfin Forest on Harmony Grove Rd.	EC-HG	N33 04' 35.2″ W117 09' 33.3″	53	-	-	-	-	-	-	x	-
Carlsbad Hydrologic Unit	Escondido Creek: Reach consisted of 5 riffles upstream of Rancho Santa Fe Road	EC-RSFR	N33° 02' 10.2" W117° 14' 6.1"	54	x	-	-	-	-	-	-	-

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WATERSHED NAME	LOCATION DESCRIPTION	SITE ID	LATITUDE/ LONGITUDE	Site No.	May 1998	Sept 1998	Nov 1998	May 1999	Nov 1999	May 2000	Nov 2000	May 2001
San Dieguito Hydrologic Unit	Black Mountain Creek: Upstream of Santa Ysabel Creek	BMC-CG	N33° 07' 37.4" W116° 48' 13.0"	55	-	-	-	-	-	-	-	x
San Dieguito Hydrologic Unit	Boden Canyon Creek: Reach consisted of 5 riffles ~0.5 mile upstream of Santa Ysabel Creek	BCN-1	N33° 06' 19" W116° 53' 35"	56	-	-	-	-	-	-	-	x
San Dieguito Hydrologic Unit	Boden Canyon Creek: just above confluence with Santa Ysabel Creek	BCN-2	N33° 05' 33" W116° 53' 45"	57	-	-	-	-	-	-	-	x
San Dieguito Hydrologic Unit	Santa Ysabel Creek: Reach consisted of 5 riffles above and below Highway 79 crossing	SYC-H79	N33° 07' 18" W116° 40' 39"	58	-	-	-	-	-	x	x	x
San Dieguito Hydrologic Unit	Santa Ysabel Creek: at North Trail on Hwy. 78	SYC-NT	N33° 05" 10 .1" W116° 55' 0.2"	59	-	-	-	-	-	-	-	x
San Dieguito Hydrologic Unit	Kit Carson Creek: Reach consisted of 5 riffles above/below Sunset Drive crossing	KCC-SD	N33° 04' 3.2" W117° 03' 57.8"	60	-	-	-	-	-	-	x	-
San Dieguito Hydrologic Unit	Green Valley Creek: Reach consisted of 5 riffles just below West Bernardo Road	GVC-WB	N33° 02' 38" W117° 04' 36.5"	61	-	-	-	-	-	-	x	-
Los Peñasquitos Hydrologic Unit	Rattlesnake Creek: Reach consisted of 5 riffles adjacent to Hillary Park	RC-HP	N32° 57' 36.0" W117° 02' 31.2"	62	x	x	x	x	-	x	-	-
Los Peñasquitos Hydrologic Unit	Los Peñasquitos Creek: Reach consisted of 5 riffles upstream of Cobblestone Creek Road	LPC-CCR	N32° 56' 55.9" W117° 04' 06.6"	63	x	x	x	x	x	-	-	-
Los Peñasquitos Hydrologic Unit	Los Peñasquitos Creek: Reach consisted of 5 riffles upstream of Black Mountain Road	LPC-BMR	N32°56' 24.8" W117° 07' 36.5"	64	x	x	x	x	x	-	x	x
Los Peñasquitos Hydrologic Unit	Carroll Canyon Creek: Reach consisted of 5 riffles near Interstate 805	CCC-805	N32° 53' 30.3" W117° 12' 53.9"	65	-	x	x	x	x	x	x	-
San Diego Hydrologic Unit	Tecolote Creek: Reach consisted of 5 riffles in the Tecolote Creek Nature Preserve	TC-TCNP	N32° 46' 30.6" W117° 11' 15.5"	66	-	-	x	x	x	x	x	-
San Diego Hydrologic Unit	Boulder Creek: Reach consisted of 5 riffles upstream of Boulder Creek Road	BC-BCR	N32° 57' 48.2" W116° 39' 50.2"	67	-	-	-	-	-	-	-	x
San Diego Hydrologic Unit	Cedar Creek: Reach consisted of 5 riffles upstream of Cedar Creek Road	CC-CCR	N33° 0' 8" W116° 42' 32"	68	-	-	-	-	-	-	-	x
San Diego Hydrologic Unit	Conejos Creek: Reach consisted of 5 riffles upstream of El Capitan Reservoir	CON-ECR	N32° 53' 25" W116° 45' 47"	69	-	-	-	-	-	-	-	x
San Diego Hydrologic Unit	San Vicente Creek: Site consisted of 5 riffles just downstream of Wildcat Canyon road crossing	SV-WCR	N32° 59' 46.9" W116° 50' 38.5"	70	-	-	-	-	-	-	x	-
San Diego Hydrologic Unit	San Diego River: Reach consisted of 5 riffles upstream of Mission Dam	SDR-MD	N32° 50' 25.8" W117° 02' 20.7"	71	x	x	x	x	x	-	-	-
San Diego Hydrologic Unit	San Diego River: Reach consisted of 5 riffles at the downstream boundary of Mission Trails Regional Park	SDR-MT	N32° 49' 06.9" W117° 03' 55.1"	72	x	x	x	x	x	x	x	-
San Diego Hydrologic Unit	San Diego River: Reach consisted of 5 riffles adjacent to the River Valley golf course	SDR-1	N32° 45' 53.9" W117° 11' 28.9"	73	x	x	x	x	x	-	-	-

WATERSHED NAME	LOCATION DESCRIPTION	SITE ID	LATITUDE/ LONGITUDE	Site No.	May 1998	Sept 1998	Nov 1998	May 1999	Nov 1999	May 2000	Nov 2000	May 2001
Sweetwater Hydrologic Unit	Cold Creek: Reach consisted of 5 riffles in Cuyamaca State Park	CC-CSP	N32° 56′ 24.1″ W116° 33′ 52″	74	-	-	-	-	-	-	-	x
Sweetwater Hydrologic Unit	Sweetwater River: Reach consisted of 5 riffles downstream of Highway 79 at Cuyamaca State Park	SWR-CSPD	N32° 54′ 33.9″ W116° 34′ 34.8″	75	-	-	-	-	-	-	-	x
Sweetwater Hydrologic Unit	Sweetwater River: Reach consisted of 5 riffles upstream of Highway 79 at Cuyamaca State Park	SWR-CSPU	N32° 54′ 32.0″ W116° 34′ 16.2″	76	-	-	-	-	-	-	-	x
Sweetwater Hydrologic Unit	Sweetwater River: Reach consisted of 5 riffles downstream of Riverside Drive near I-8	SWR-79	N32° 50′ 20.8″ W116° 36′ 51.2″	77	x	x	x	x	x	-	x	x
Sweetwater Hydrologic Unit	Sweetwater River: Reach consisted of 5 riffles directly upstream of Hwy 94	SWR-94	N32° 43′ 59.9″ W116° 56′ 19.0″	78	x	x	x	x	x	-	x	-
Sweetwater Hydrologic Unit	Sweetwater River: Reach consisted of 5 riffles directly downstream of Sweetwater Road	SWR-WS	N32° 39′ 29.1″ W117° 02′ 36.4″	79	x	x	x	x	x	-	-	-
Otay Hydrologic Unit	Jamul Creek: Reach consisted of 5 riffles located directly upstream of Otay Lakes Road	JC-OLR	N32° 38′ 13.1″ W116° 53′ 3.7″	80	-	-	-	-	-	-	x	x
Otay Hydrologic Unit	Jamul Creek: Reach consisted of 5 riffles at USGS gauging station	JC-GS	N32° 38′ 1.0″ W116° 53′ 9.7″	81	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	Kitchen Creek: Reach consisted of 5 riffles upstream of Kitchen Creek Road	KC-KCR	N32° 47′ 14.9″ W116° 27′ 03.8″	82	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	Kitchen Creek: Reach consisted of 5 riffles below Cibbets Flat Campground	KC-BCF	N32° 45′ 38.2″ W116° 27′ 05.7″	83	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	Long Canyon Creek: Reach consisted of 5 riffles at Cibbets Flat Campground	LCC-CFC	N32° 46′ 42″ W116° 26′ 42″	84	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	Noble Creek: Reach consisted of 5 riffles directly upstream of Pine Creek Road	NC-PCR	N32° 51′ 49.6″ W116° 31′ 02.5″	85	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	North Pine Creek: Reach consisted of 5 riffles directly upstream of Noble Creek	NPC-NC	N32° 51′ 54.6″ W116° 31′ 05.8″	86	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	Troy Canyon Creek: Reach located above Kitchen Creek Road, site at trail crossing.	TCC-TC	N32° 48′ 28″ W116° 26′ 24″	87	-	-	-	-	-	x	x	x
Tijuana Hydrologic Unit	Wilson Creek: Reach consisted of 5 riffles upstream of Barrett Lake	WLC-ABL	N32° 41′ 37″ W116° 41′ 43″	88	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	Middle Cottonwood Creek: Reach consisted of 5 riffles below Morena Lake	MCC-BML	N32° 40′ 33″ W116° 34′ 59″	89	-	-	-	-	-	-	-	x
Tijuana Hydrologic Unit	Pine Creek: Reach consisted of 5 riffles just upstream of Old HWY 80 crossing.	PC-H80	N32° 50′ 13.9″ W116° 32′ 10.9″	90	-	-	-	-	-	x	x	x

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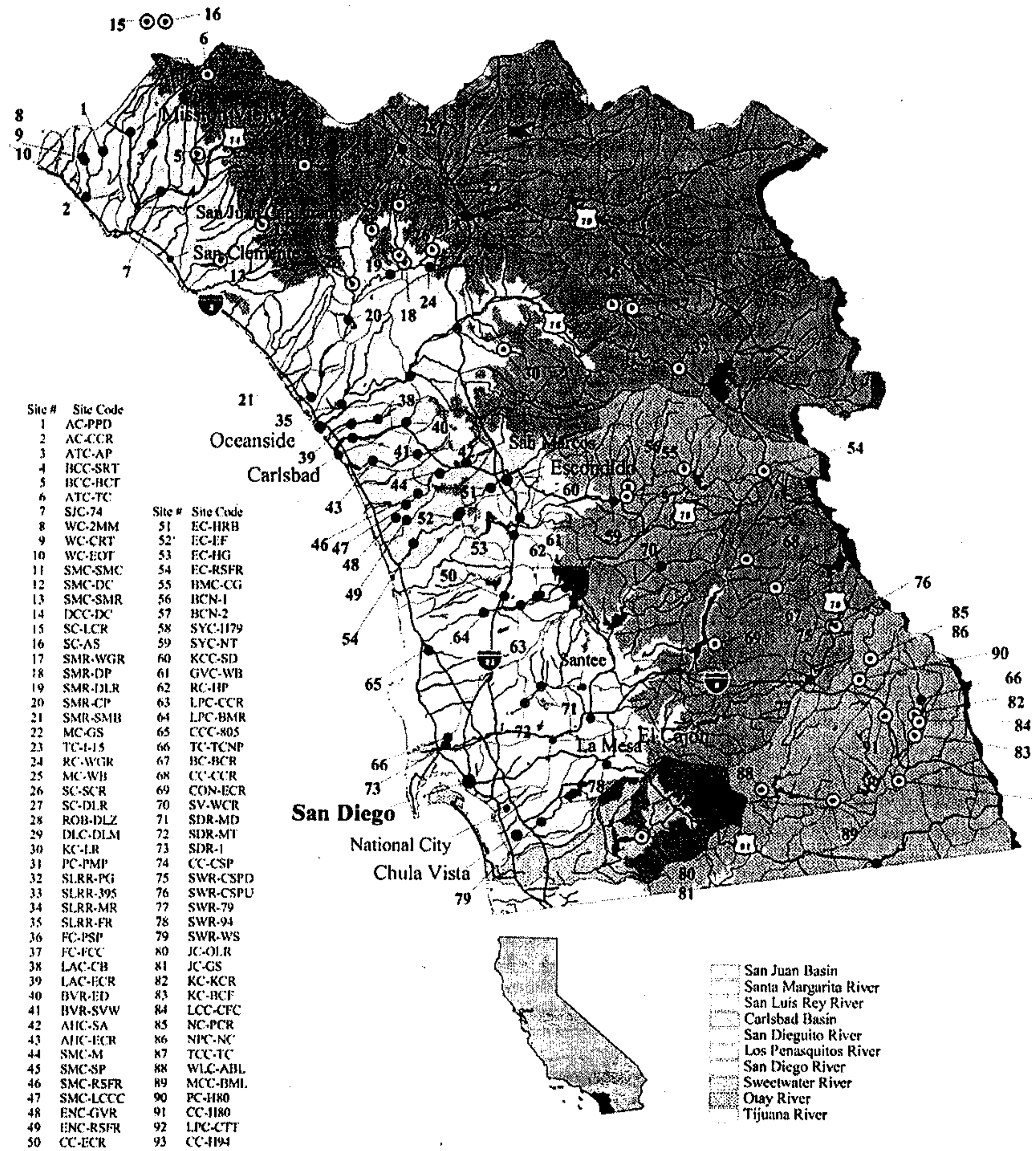
WATERSHED NAME	LOCATION DESCRIPTION	SITE ID	LATITUDE/ LONGITUDE	Site No.	May 1998	Sept 1998	Nov 1998	May 1999	Nov 1999	May 2000	Nov 2000	May 2001
Tijuana Hydrologic Unit	Cottonwood Creek: Reach consisted of 5 riffles directly downstream of Old HWY 80 crossing.	CC-H80	N32° 47′ 16.9″ W116° 29′ 51.4″	91	-	-	-	-	-	x	x	x
Tijuana Hydrologic Unit	La Posta Creek: Reach consisted of 5 riffles located in The Narrows between Cameron Truck Trail and Buckman Springs Road.	LPC-CTT	N32° 41′ 59.7″ W116° 28′ 44.9″	92	-	-	-	-	-	-	x	x
Tijuana Hydrologic Unit	Campo Creek: Reach consisted of 5 riffles just upstream of HWY 94 Gauging Station.	CC-H94	N32° 35′ 21.4″ W116° 31′ 04.7″	93	-	-	-	-	-	-	x	x



Site #	Site Code	Site #	Site Code
1	AC-PPD	51	EC-HRB
2	AC-CCR	52	EC-EF
3	ATC-AP	53	EC-HG
4	BCC-SRT	54	EC-RSFR
5	BCC-BCT	55	BMC-CG
6	ATC-TC	56	BCN-1
7	SJC-74	57	BCN-2
8	WC-2MM	58	SYC-1179
9	WC-CRT	59	SYC-NT
10	WC-EOT	60	KCC-SD
11	SMC-SMC	61	GVC-WB
12	SMC-DC	62	RC-HP
13	SMC-SMR	63	LPC-CCR
14	DCC-DC	64	LPC-BMR
15	SC-LCR	65	CCC-805
16	SC-AS	66	TC-TCNP
17	SMR-WGR	67	BC-BCR
18	SMR-DP	68	CC-CCR
19	SMR-DLR	69	CON-ECR
20	SMR-CP	70	SV-WCR
21	SMR-SMB	71	SDR-MD
22	MC-GS	72	SDR-MT
23	TC-I-15	73	SDR-1
24	RC-WGR	74	CC-CSP
25	MC-WB	75	SWR-CSPD
26	SC-SCR	76	SWR-CSPU
27	SC-DLR	77	SWR-79
28	ROB-DLZ	78	SWR-94
29	DLC-DLM	79	SWR-WS
30	KC-LR	80	JC-OLR
31	PC-PMP	81	JC-GS
32	SLRR-PG	82	KC-KCR
33	SLRR-395	83	KC-BCF
34	SLRR-MR	84	LCC-CFC
35	SLRR-FR	85	NC-PCR
36	FC-PSP	86	NPC-NC
37	FC-FCC	87	TCC-TC
38	LAC-CB	88	WLC-ABL
39	LAC-ECR	89	MCC-BML
40	BVR-ED	90	PC-H80
41	BVR-SVW	91	CC-I180
42	AHC-SA	92	LPC-CTT
43	AHC-ECR	93	CC-I194
44	SMC-M		
45	SMC-SP		
46	SMC-RSFR		
47	SMC-LCCC		
48	ENC-GVR		
49	ENC-RSFR		
50	CC-ECR		

Figure 1. Benthic macroinvertebrate sites sampled in May 1998, September 1998, November 1998, May 1999, November 1999, May 2000, November 2000 and May 2001. Sampling dates for sites are indicated in the legend. Reference sites are indicated by yellow points and non-reference sites are indicated by red points.

Table 2. Bioassessment metrics used to describe characteristics of the benthic macroinvertebrate (BMI) community at sampling reaches within the San Diego region.

BMI Metric	Description	Response to Impairment
Richness Measures		
Taxa Richness	Average number of individual taxa at each site	decrease
EPT Taxa	Average number of taxa in the Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) insect orders	decrease
Cumulative Taxa	Total number of taxa at each site	decrease
Cumulative EPT Taxa	Total number of EPT taxa at each site	decrease
Dipteran Taxa	Number of taxa in the insect order (Diptera," true flies")	increase
Non-Insect Taxa	Number of non-insect taxa	increase
Composition Measures		
EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae	decrease
Sensitive EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae with tolerance values between 0 and 3	decrease
Shannon Diversity Index	General measure of sample diversity that incorporates richness and evenness (Shannon and Weaver 1963)	decrease
Tolerance/Intolerance Measures		
Tolerance Value	Weighted average value (0-10) of individuals designated as pollution tolerant (high values) or intolerant (low values)	increase
Percent Dominant Taxa	Percent composition of the single most abundant taxon	increase
Percent Chironomidae	Percent composition of the tolerant dipteran family Chironomidae	increase
Percent Intolerant Organisms	Percent of organisms in sample that are highly intolerant to impairment as indicated by a tolerance value of 0, 1 or 2	decrease
Percent Tolerant Organisms	Percent of organisms in sample that are highly tolerant to impairment as indicated by a tolerance value of 8, 9 or 10	increase
Functional Feeding Groups (FFG)		
Percent Collectors	Percent of macrobenthos that collect or gather fine particulate matter	increase
Percent Filterers	Percent of macrobenthos that filter fine particulate matter	increase
Percent Grazers	Percent of macrobenthos that graze upon periphyton	variable
Percent Predators	Percent of macrobenthos that feed on other organisms	variable
Percent Shredders	Percent of macrobenthos that shreds coarse particulate matter	decrease
Abundance		
Estimated Abundance	Estimated number of benthic macroinvertebrates in sample calculated by extrapolating from the proportion of organisms in the subsample	variable

RESULTS

Results of May 2001 Sampling Event

To facilitate comparison of data from the May 2001 sampling event with data from earlier sampling events, May 2001 data are presented in the same format used in our previous two reports. The data are presented in tables, figures and appendices as listed below:

- Table 3 presents a list of top five most abundant taxa identified from each site sampled during the May 2001 sampling event
- Figure 2 presents BMI ranking scores for macroinvertebrate monitoring sites sampled in May 2001
- Appendices A, B and C contain the complete May 2001 taxonomic lists, transect metrics and site metric summaries, respectively

This report utilizes the newly established ranking criteria based on the IBI described herein. Since this method integrates multiple components of biological community data, no attempt is made in this report to interpret general trends in abundance or community composition based on visual assessment of the May 2001 data tables as was done in previous bioassessment reports for RWQCB (9) (Ode and Harrington 1999).

Table 3. The top five most abundant taxa identified at each site sampled during the May 2001 sampling event (percent contribution in parentheses).

StationID	Top Five Most Abundant Taxa at Each Site				
	1	2	3	4	5
San Juan Hydrologic Unit					
AC-PPD	*Fallceon quilleri* (36.7)	*Baetis* (28.2)	*Simulium* (12.4)	Orthocladiinae (7.6)	Cyclopoida (5.2)
BCC-SRT	*Physa/ Physella* (23.6)	Naididae (21.9)	*Baetis* (20.5)	*Simulium* (8.1)	Orthocladiinae (8.1)
BCC-BCT	*Physa/ Physella* (32.9)	*Baetis* (16.4)	Naididae (11.9)	Tanytarsini (9.3)	*Fossaria* (7.9)
ATC-TC	Orthocladiinae (33.8)	*Physa/ Physella* (16.3)	*Serratella* (12.6)	*Baetis* (9.7)	Tanytarsini (6.9)
WC-2MM	*Simulium* (56.6)	Orthocladiinae (26.0)	Naididae (7.5)	*Baetis* (7.0)	Megadrili (1.4)
WC-CRT	*Simulium* (42.7)	Orthocladiinae (23.1)	*Baetis* (16.1)	Naididae (14.9)	Tanytarsini (1.9)
WC-EOT	Tanytarsini (34.5)	Orthocladiinae (22.1)	Nematoda (14.2)	*Simulium* (11.2)	Planariidae (7.1)
SMC-SMC	Tanytarsini (26.7)	Orthocladiinae (20.8)	Naididae (10.4)	*Simulium* (9.3)	*Serratella* (7.8)
SMC-DC	Orthocladiinae (20.5)	*Baetis* (11.2)	*Wormaldia* (10.9)	*Amiocentrus* (8.6)	Tanytarsini (6.9)
SMC-SMR	*Physa/ Physella* (28.8)	*Fossaria* (14.6)	Naididae (9.6)	*Helisoma* (7.1)	*Baetis* (6.8)
DCC-DC	*Physa/ Physella* (15.7)	Orthocladiinae (12.7)	Tanytarsini (9.4)	*Baetis* (7.3)	Naididae (6.6)
SC-LCR	Orthocladiinae (47.8)	Tanytarsini (20.2)	*Baetis* (10.3)	*Physa/ Physella* (8.2)	Hygrobatidae (2.4)
SC-AS	Orthocladiinae (21.4)	Amiocentrus (20.6)	*Physa/ Physella* (19.2)	*Baetis* (17.3)	Tanytarsini (4.7)
Santa Margarita Hydrologic Unit					
SMR-WGR	*Simulium* (35.0)	*Baetis* (13.2)	Orthocladiinae (10.8)	Chironomini (8.4)	Chironominae (5.5)
SMR-DP	*Baetis* (25.3)	*Hydropsyche* (14.4)	*Tricorythodes* (13.9)	Orthocladiinae (9.9)	*Amiocentrus* (7.7)
SMR-DLR	*Tricorythodes* (35.6)	Orthocladiinae (15.8)	*Corbicula* (14.4)	*Falleeon quilleri* (9.8)	*Baetis* (6.4)
SMR-CP	*Fallceon quilleri* (28.6)	*Centroptilum/ Procloeon* (12.8)	Orthocladiinae (11.5)	*Tricorythodes* (9.4)	*Corbicula fluminea* (8.7)
SC-SCR	Baetis (31.5)	Orthocladiinae (12.9)	Chironominae (10.9)	*Simulium* (10.9)	*Micrasema* (3.9)
SC-DLR	*Baetis* (15.0)	*Physa/ Physella* (14.6)	Orthocladiinae (13.2)	*Prosimulium* (8.9)	*Simulium* (6.5)
ROB-DLZ	*Gyraulus* (32.2)	Tanytarsini (14.3)	Orthocladiinae (11.3)	*Cheumatopsyche* (6.7)	Naididae (6.6)
DLC-DLM	*Baetis* (25.1)	*Hydropsyche* (11.3)	Orthocladiinae (10.4)	*Zaitzevia* (9.0)	*Amiocentrus* (7.1)

San Luis Rey Hydrologic Unit					
KC-LR	Orthocladiinae (33.0)	*Baetis* (16.6)	*Simulium* (10.3)	*Hydropsyche* (9.3)	Tanytarsini (6.6)
SLRR-PG	*Baetis* (33.2)	*Simulium* (25.8)	Orthocladiinae (10.4)	Tanytarsini (7.6)	Naididae (7.6)
SLRR-395	*Gammarus* (36.6)	*Corbicula* (32.0)	Orthocladiinae (16.2)	Tanytarsini (6.1)	*Simulium* (4.2)
FC-PSP	Chironomini (17.7)	*Simulium* (16.4)	Orthocladiinae (12.7)	*Caenis* (10.1)	*Argia* (7.2)
FC-FCC	Orthocladiinae (31.4)	Tanytarsini (16.0)	*Serratella* (7.8)	*Hydraena* (7.5)	Tanypodinae (6.6)
Carlsbad Hydrologic Unit					
AHC-ECR	*Baetis* (27.8)	*Simulium* (26.2)	*Fallceon quilleri* (14.7)	Cyprididae (6.8)	Tanytarsini (4.5)
San Dieguito Hydrologic Unit					
BMC-CG	Orthocladiinae (26.0)	Chironomini (11.5)	Tanytarsini (8.2)	*Wormaldia* (7.1)	*Hydropsyche* (6.4)
BCN-1	Orthocladiinae (15.2)	*Wormaldia* (14.8)	Tanytarsini (13.4)	*Zaitzevia* (9.3)	Chironomini (7.2)
BCN-2	Tanytarsini (29.5)	Cyprididae (24.5)	Orthocladiinae (18.2)	*Physa/ Physella* (6.0)	*Wormaldia* (4.1)
SYC-H79	*Physa/ Physella* (57.1)	*Agapetus* (10.5)	Tanytarsini (7.9)	*Baetis* (5.1)	*Simulium* (3.6)
SYC-NT	Orthocladiinae (50.1)	Tanytarsini (22.4)	*Serratella* (4.7)	*Wormaldia* (4.6)	*Isoperla* (2.6)
Los Peñasquitos Hydrologic Unit					
LPC-BMR	*Simulium* (77.0)	*Fallceon quilleri* (5.5)	*Corbicula* (3.3)	*Baetis* (2.6)	*Hyalella azteca* (2.6)
San Diego Hydrologic Unit					
BC-BCR	Orthocladiinae (25.7)	Tanytarsini (24.8)	*Simulium* (17.1)	Chironomini (11.9)	Tanypodinae (6.8)
CC-CCR	*Serratella* (13.0)	Orthocladiinae (12.4)	*Wormaldia* (11.2)	Tanytarsini (10.9)	Chironomini (6.4)
CON-ECR	Tanytarsini (44.8)	Naididae (21.5)	Orthocladiinae (13.6)	*Physa/ Physella* (8.0)	*Hydroptila* (3.1)
Sweetwater Hydrologic Unit					
CC-CSP	Tanytarsini (27.2)	Nematoda (24.5)	Orthocladiinae (22.5)	*Ameletus* (3.6)	*Optioservus* (2.8)
SWR-CSPD	Orthocladiinae (16.0)	Tanytarsini (13.1)	*Hyalella azteca* (10.8)	*Pisidium* (7.7)	Chironomini (5.4)
SWR-CSPU	Orthocladiinae (31.9)	*Simulium* (11.6)	Tanytarsini (11.6)	*Baetis* (8.2)	Chironomini (4.7)
SWR-79	Tanytarsini (30.4)	*Physa/ Physella* (28.8)	Orthocladiinae (19.1)	Megadrili (6.3)	*Baetis* (3.3)

Otay Hydrologic Unit					
JC-OLR	*Baetis* (39.4)	Tanytarsini (15.1)	*Hydropsyche* (11.0)	*Amiocentrus* (10.8)	Orthocladiinae (4.9)
JC-GS	Tanytarsini (38.1)	*Baetis* (15.8)	*Hydropsyche* (13.0)	*Amiocentrus* (7.8)	Orthocladiinae (5.0)
Tijuana Hydrologic Unit					
KC-KCR	Orthocladiinae (42.0)	Tanypodinae (18.8)	Tanytarsini (8.5)	*Serratella* (4.3)	Nematoda (3.8)
KC-BCF	Orthocladiinae (36.5)	Nematoda (19.5)	Tanytarsini (16.1)	*Isoperla* (6.7)	*Serratella* (4.1)
LCC-CFC	Orthocladiinae (40.4)	Tanytarsini (29.3)	*Baetis* (8.4)	*Isoperla* (7.9)	Enchytraeidae (4.4)
NC-PCR	Orthocladiinae (33.4)	Nematoda (29.0)	Tanytarsini (11.8)	Enchytraeidae (5.9)	Naididae (4.2)
NPC-NC	Orthocladiinae (22.6)	*Serratella* (15.4)	Tanytarsini (14.1)	*Physa/ Physella* (9.3)	*Metrichia* (6.2)
TCC-TC	Orthocladiinae (37.0)	*Hyalella azteca* (13.7)	Cyprididae (9.9)	Tanypodinae (7.7)	Tanytarsini (5.6)
WLC-ABL	Tanytarsini (26.9)	Orthocladiinae (24.1)	*Baetis* (14.9)	*Physa/ Physella* (5.2)	*Hyalella azteca* (5.1)
MCC-BML	Tanytarsini (33.1)	Orthocladiinae (24.4)	*Simulium* (19.7)	Enchytraeidae (6.5)	Chironomini (4.8)
PC-H80	Orthocladiinae (33.7)	*Baetis* (13.2)	*Simulium* (11.5)	Tanytarsini (10.4)	Chironomini (4.9)
CC-H80	Hydrobiidae (31.7)	Orthocladiinae (20.5)	*Microcylloepus* (10.9)	*Pisidium* (3.9)	Sphaeriidae (3.4)
LPC-CTT	Orthocladiinae (31.8)	*Hyalella azteca* (11.7)	*Baetis* (10.4)	Cyprididae (6.7)	Tubificidae (6.1)
CC-H94	Orthocladiinae (42.8)	Tanytarsini (24.6)	Chironomini (5.2)	*Hyalella azteca* (3.7)	*Fallceon quilleri* (3.4)

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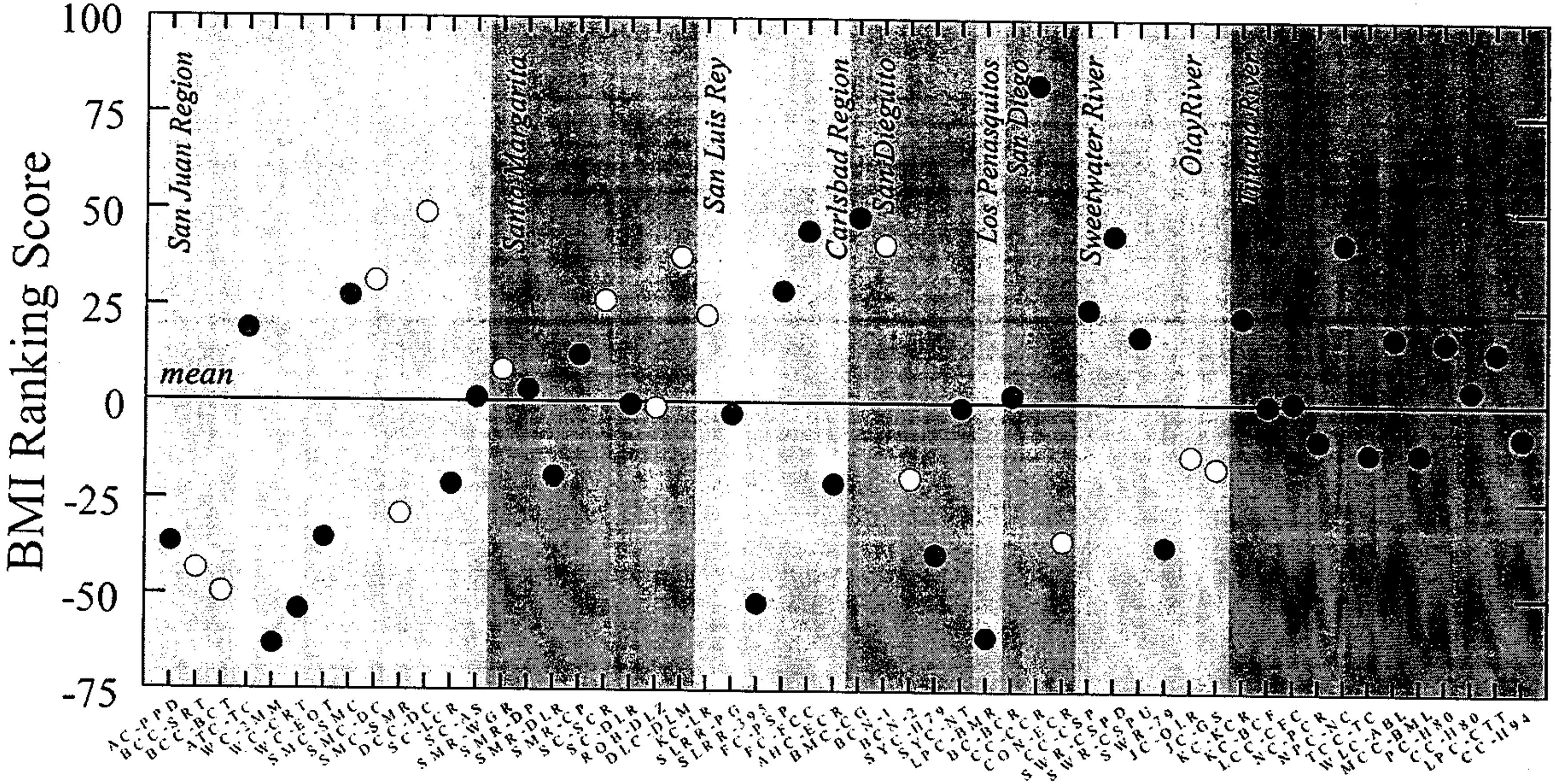

Figure 2. BMI ranking scores for macroinvertebrate monitoring sites sampled in May 2001. Red points indicate reference sites above 1000 feet elevation, white points represent reference sites below 1000 feet elevation, and black points indicate non-reference sites.

IBI Methodology

General Steps for Creating an Index of Biotic Integrity (IBI)

Barbour *et al.* (1999) identify 6 general steps involved in the development of an IBI; each step can be modified based on the needs of the region or availability of research tools. We discuss here some of the major conceptual issues involved in each step and describe specifically the methods that we used to create the San Diego IBI. Topics for future development are also discussed.

I. Classify stream types into classes and select reference sites
II. Select potential metrics
III. Evaluate metrics to select most robust ones
IV. Score metrics and combine scores into IBI
V. Assign rating categories to IBI score ranges
VI. Evaluate IBI and refine

Step I. Stream Type Classification and Reference Site Selection

General Theory
Reference sites are sections of streams that represent the desired state of stream health (*sensu* Meyer 1997) for a region of interest. Since natural stream communities vary both spatially and temporally, it is natural that measures of biotic integrity also should be expected to vary. Once candidate reference reaches have been identified, these are used to characterize the range of biotic conditions expected for minimally disturbed sites. Deviation from this range can then be used as an indication that test sites may be impaired.

Variation is fundamental to biological communities. Although this variation poses challenges to the interpretation of water quality, sound scientific approaches for interpreting impairment in the context of natural variation have been and continue to be developed for both multivariate and multimetric analytical techniques (Wright et al. 1993, Barbour *et al.* 1999, Karr and Chu 1999, Hawkins *et al.* 2000). The objective of a sound IBI is to identify potential sources of variation and control for this variation by classifying stream types and using IBI metrics that are less susceptible to natural variation (Karr and Chu 1999, Barbour *et al.* 1999).

Techniques for the selection of reference sites have been discussed extensively (Hughes and Larsen 1988, Hughes 1995, Stoddard unpublished ms). There are many definitions of the term "reference condition" ranging from the pristine, undisturbed state of a stream, to merely the "best available" or "best attainable" conditions in a region. Since practical considerations limit our ability to find minimally disturbed sites, most reference condition approaches seek to identify a compromise, the "least disturbed condition" in region. In some regions, particularly those that have been severely impacted by human activity, it is necessary to select sites that represent the "best attainable" condition given best management practices in a manipulated ecosystem.

(SNARL) Reference Site Selection Approach
To date, most of the bioassessment projects/ programs in California that have attempted to include information about minimally impacted conditions have used either "control sites" or a few "reference" sites to supplement data collected at test sites, but this has rarely been done in a systematic manner. Almost all programs have used the subjective technique of "best professional judgement" for selecting sites.

In May 2000, the DFG and Sierra Nevada Aquatic Research Laboratory (SNARL) collaborated to develop a quantitative approach to selecting reference sites in California. The basic approach combines landscape analysis tools (geographic information system,GIS) with ground-truthing to identify a pool of reference sites that can be subsampled to define the range of variability in benthic communities in relatively undisturbed portions of a region of interest. The procedure consists of the following steps:

1. *Identification of the Region of Interest and Classes of Streams to be Evaluated–*
   a. The region of interest will be defined by the scale of the questions and the entity asking the questions. It could be based on regulatory or other political boundaries, bioregions or ecoregions, watersheds or other groupings.
   b. Classification of streams into different categories serves as the basis for dividing the natural variation into classes of similar stream types. Ecoregions are the most commonly used unit for grouping reference streams, but many other partitions may be equally useful: stream order, stream gradient, watershed area, elevation zones, prior beneficial use designations, etc. Note that there is no *a priori* reason to avoid combinations of classification schemes might be used in an attempt to partition natural variation and many of these factors may be interrelated.

2. *Within the Region of Interest, Identify Areas to be used as Units of Analysis*
   a. Because they integrate all upstream landuse activities, watersheds are the logical choice for analysis areas. Ideally this would mean using the smallest watersheds (defined by first order streams) as the basic unit of analysis, but adequate watershed areas are not currently available for GIS analysis.
   b. Existing CalWater Watershed Planning Areas (WPAs) can serve as the basic analysis unit. However, because they often do not match true watershed boundaries at the smallest scales, their use limits analysis to larger scale watershed boundaries. This is acceptable for coarse screening of target areas, but will need to be resolved before GIS can be used at a finer scale.

3. *Develop a List of Land Use Disturbances of Interest*
   a. Assemble a list of major impacts that have the potential to affect stream condition.
   b. Landuse categories and measures of human activities in the watershed are available in GIS formats from various state and federal agencies.
   c. Additional factors affecting stream condition include the presence of dams and other diversion structures, presence of mining activity, previous history of pollution events, etc.

4. *Use GIS tools to Summarize Potential Land Use Impacts for each Area*
    a. This is the quantitative step in the process. Using GIS tools like the USEPA's Analytical Tools for Landscape Analysis (ATtILA) extension, landuse data layers are analyzed to calculate impact scores for each impact identified in Step 3 (e.g. percent impervious surface in each target unit).
    b. At present, available GIS tools are limited to analysis of land use and related measures (e.g. road density, percentages of different landuse activities, estimates of nitrogen and phosphorous loading). Additional criteria (e.g. presence of dams and other diversion structures, presence of mining activity, previous history of pollution events) can be scored the same way by hand using other datasets and maps to supplement the GIS data. Ultimately, important additional factors can be integrated into ATtILA to provide a unified tool for analysis.

5. *Use Statistical Properties of the Distributions to Score Impacts*
    a. Frequency histograms of impact intensity are used to set criteria for eliminating sites from consideration as having candidate reference streams.
    b. This can be done visually by looking for "natural breaks" in distributions (which may indicate impact thresholds) or by using statistical properties of the distributions to select cutoffs (e.g. eliminate all sites having road densities >1 standard deviation above the mean for the region)

6. *Use Impact Scores to Identify Regions with Minimal Disturbance: Target Areas*
    a. Using scoring criteria, progressively eliminate all target areas that do not meet all of the criteria established in Step 5.
    b. This may require modification of the scoring criteria if too many or too few candidate areas are selected.
    c. This stage can be further modified to emphasize specific impact types based on *a priori* or *a posteriori* decisions about the relative importance of these factors.

7. *Ground Truthing*
    a. *Stage I– Rapid Reconnaissance.* Once areas with potential for containing candidate reference sites are identified, field crews drive through the area to identify stream reaches that meet basic criteria for bioassessment sampling (e.g. adequate flow, practical access). Preliminary screening of streams within each target areas will identify regions that need to be eliminated based on information not available through GIS tools.
    b. *Stage II–Identify Ownership and Obtain Access Permission.* It is usually desirable to select sampling locations that occur on publicly owned land or land with easy access. However, since it is important to sample streams from a truly representative set of sites within an area, it is often necessary to sample from reaches running through privately owned land. Reasonable efforts should be taken to obtain permission from landowners before rejecting candidate sites.
    c. *Stage III–Intensive Habitat Scoring and Selection of Reference Sites for Sampling.* Sites that make it through Stage I reconnaissance and for which legal access is obtained are evaluated using an intensive physical habitat scoring procedure that emphasizes quantitative physical measurements.

8. *Sampling of Biotic Communities*
    a. A subsample of the pool of reference sites is sampled for benthic invertebrates and the data are analyzed to define the range of biological metric values in the pool of reference sites.
    b. Reference sites may be sampled for other measures of stream or riparian health (e.g. fish or algal communities, water column chemistry, toxicity, etc)

9. *Refinement of the Reference Pool*
    a. The reference site pool is further refined based on biological, chemical and physical habitat data collected at each site.
    b. Some candidate reference sites will be eliminated as land use changes occur, while others may be added if conditions improve.

Between Fall 2000 and Fall 2001, DFG has applied a test of this procedure to the Sierra Nevada Foothills Ecoregion (SNFE) of the Sacramento River Watershed Program (SRWP). As this methodology is developed we will apply these techniques to the San Diego Region. Although most of these techniques were not applied to the selection of reference sites in the current IBI, we expect to use these techniques extensively in the future refinement phase of the IBI.

Application to San Diego IBI

Most reference sites in the San Diego region were selected by David Gibson between 1991 and 1999, with a few additional sites selected by DFG in April 2001. The approach used in the selection process represents a combination of objective and subjective criteria. Sites were selected on the following criteria:

1. Relatively Easy Access: Legal, reliable access that minimized foot travel time. David Gibson made an effort in 1995-1997 to sample stream reaches that were significant distances from roads, impoundments, and public access, but found that the effort to reach the sites usually did not result in locating sites that were significantly better candidates for reference conditions.

2. Base Flow Stream Chemistry:
- low nitrates (<0.25 ppm)
- low nitrites(<0.005 ppm)
- low orthophosphate (<0.25 ppm)
- low turbidity (<0.75 NTU)
- low manganese (<0.3 ppm)
- low iron (<0.5 ppm)
- non-detect ammonia (<0.01 ppm)
- non-detect copper(<0.01ppm)
- non-detect aluminum (<0.01 ppm)
- non-detect chromium, (<0.01 ppm)
- REC-1 bacteria levels
(Total Coliform <1000MPN, Fecal Coliform <400CFU, and Enterococcus <104 CFU).

3. Absence of Grazing: (or minimal grazing) during the previous 5 years. Minimal grazing meant that few livestock were observed and little or no impact on the stream was observed during site visits. Grazing pressure has recently been increasing in parts of the

Cleveland National Forest as privately owned grazing rangelands have come off the lease market, so some of these sites are now more impacted than previously.

4. Residential Land Use: Areas without residential land use or where residential land use was minimal. In particular, we tried to avoid areas with dense septic tank fields, hobby agriculture, extensive groundwater pumping, and road networks (paved or dirt).

5. Stream Flow Status:
    a. Perennial streams 1st Order
    b. Perennial streams 2^{nd} –3rd Order
    c. Intermittent streams (1^{st} –2^{nd} Order) with at least 3-4 months of reliable flow (typically March - June).

6. Additional Criteria:
    a. Upstream of road crossings and recreational areas (campgrounds, picnic grounds, popular road side visitation areas).
    b. Upstream of impoundments or on drainages without impoundments.
    c. If upstream impoundments were present, site was located at least 5 stream-miles downstream of the impoundments.
    d. Presence of mature riparian habitat and an otherwise high RBP physical habitat score.

7. Professional Judgement: Additional experience of RWQCB Environmental Scientist David Gibson (based on at least 1 annual visit to the area around the site over several years) indicating that the stream reach was minimally impacted by land use upstream or that the impact was mitigated.

8. Elevation: Considerable effort was taken to identify reference sites from different parts of the area covered by the San Diego RWQCB (9). We were especially careful to select a comparable number of sites above and below 1000 feet elevation so that we could evaluate minimally disturbed sites in both regions.

Rejection of Candidate Reference Sites

After the initial screening criteria were used to identify potential reference sites for the San Diego Region, we eliminated a few sites from consideration based on their physical habitat scores. To do so, we calculated a Physical Ranking Score (PRS) for each of the May 2001 sites

(Figure 3, Figure 4). The PRS was calculated in the same manner as the BMI Ranking Score that we have described in previous San Diego reports. We used 8 physical habitat metrics, representing both reach and riffle scale measures of physical habitat integrity. These metrics are defined in the CSBP (Harrington 1999) and were selected on the basis of their responsiveness to physical condition:

1. Epifaunal Substrate
2. Riffle Embeddedness
3. Sediment Deposition
4. Bank Vegetation
5. Canopy Cover
6. Substrate Consolidation
7. Percent Fines
8. Specific Conductance

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Physical Rank Scores were calculated using the following formula:

$$Score = \sum (x_i - \bar{x}) / sem_i$$

where: x_i = site value for the *i*-th metric; x bar = overall mean for the *i*-th metric; sem_i = standard error of the mean for the *i*-th metric. An overall score of "0" is the average for all sites.

For a methods comparison, we also calculated an Index of Physical Integrity (using methodologies similar to those used for calculating the Karr style IBI (Karr 1981). However, the PRS scores provided a better means of discriminating between sites.

On the basis of PRS scores we eliminated several sites from consideration as reference sites (sites removed from the reference pool include: WC-2MM, WC-CRT, WC-EOT, SMR-DP, SYC-NT, TCC-TC, and SWR-79). Final reference sites used in the IBI are identified in red in the site description table (Table 1).

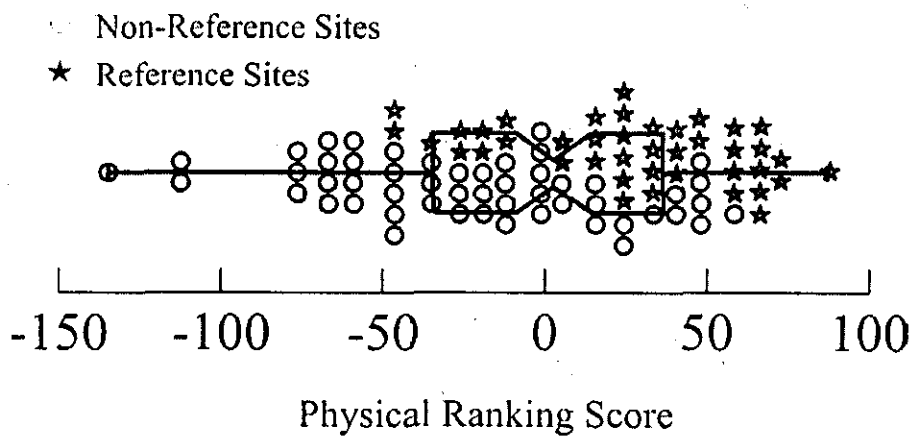

Figure 3. Distribution plot of physical ranking scores for all sites. The box represents 25th and 75th percentiles, the constriction in the plot represents the median value and the lines represent 95% confidence limits. References sites are indicated by blue stars.

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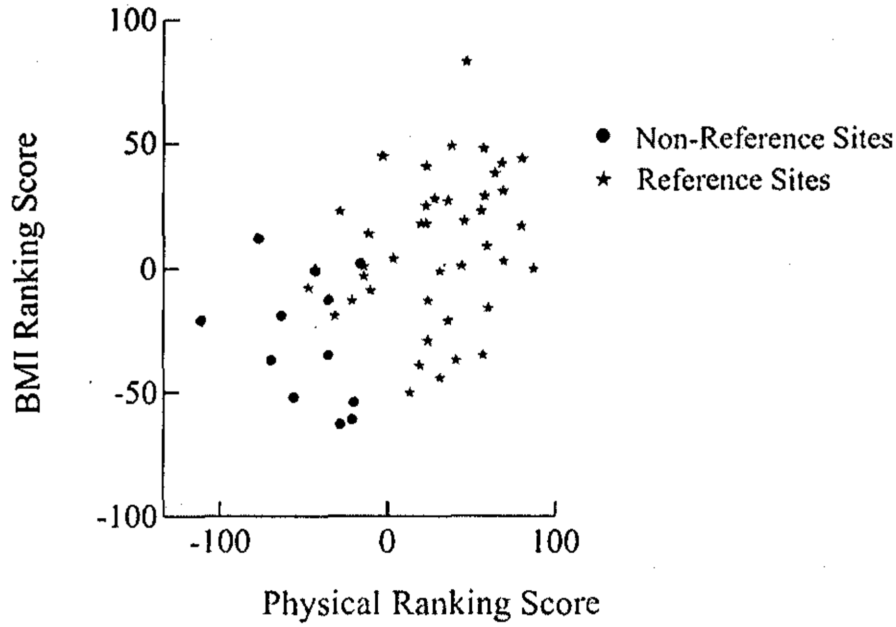

Figure 4. Relationship between physical ranking score and the BMI ranking score for the May 2001 sampling event.

<u>Steps II and III. Metrics Screening and Selection for Use in IBI</u>

Selection of the most appropriate bioassessment metrics for an IBI is a critical phase in the creation of an IBI and typically undergoes the most revision in subsequent refinement of the IBI. According to Barbour *et al.* (1999), a metric is "a measure of the biota that changes in a predictable way with increased human influence". Ideal metrics differ from region to region (hence the need for regional IBIs), but share common characteristics. Most critically, "core" metrics should be able to discriminate between known reference condition sites and known impaired condition sites Barbour *et al.* (1999).

We used a series of techniques to select appropriate metrics following the United States Environmental Protection Agency's (EPA) recommendations (Barbour *et al.* 1999, Hughes *et al.* 1998, McCormick *et al.* 2001). We screened approximately 20 metrics, first by testing their discriminatory power and then by evaluating their relationship with an independent measure of human impact. In a prior report, we used a measure of land use activity (percent developed land) to screen metrics. Metrics used in this IBI were selected on the basis of their responsiveness to the Gibson Score, a measure developed by RWQCB staff David Gibson to integrate multiple aspects of land use impairment in a site. The measure is a quantification of many of the criteria that were used to select reference sites. In addition to these criteria, Karr (1986) and the EPA (Barbour *et al.* 1999) recommend selecting metrics from all of the different metrics categories (richness measures, composition measures, tolerance measures and trophic/ habitat measures). Figures 5 and 6 present examples of how these two techniques are used to screen metrics. Figure 5 compares the distribution of metric values for references sites and non-reference sites; Figure 5a demonstrates a metric with good separation between reference sites and non-reference sites, 5b demonstrates a metric with poor separation between reference and non-reference sites. Figure 6 compares the relationship between two metrics and a measure of human influence; Figure 6a demonstrates a strong relationship between the Gibson Score and Cumulative EPT Taxa, while

6b demonstrates a weak relationship between the Gibson Score and Percent Chironomidae. On the basis of these screening techniques, we selected the following 7 "core" metrics to use in the San Diego IBI:

1. Cumulative Taxa
2. Cumulative EPT Taxa
3. Percent Sensitive EPT
4. Percent Dominant Taxon
5. Shannon Diversity
6. Intolerant Taxa
7. Percent Grazers.

Other approaches used in creating IBIs include measurement of signal: noise ratios (good metrics have a high degree of precision in repeat measurements) and tests for independence of measurement, which are sometimes called "redundancy" or "orthogonality" tests (see discussion in Barbour *et al.* 1999 and Hughes *et al.* 1998). There were insufficient reference sites with repeat site visits to adequately apply these tests, but both are approaches that should be used in future refinement of the IBI.

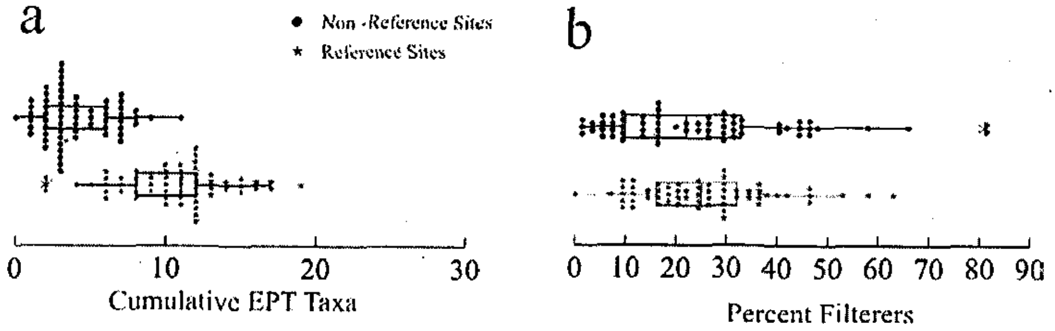

Figure 5. Boxplots describing the distribution of site values for a) Cumulative EPT Taxa and b) Percent Filterers.

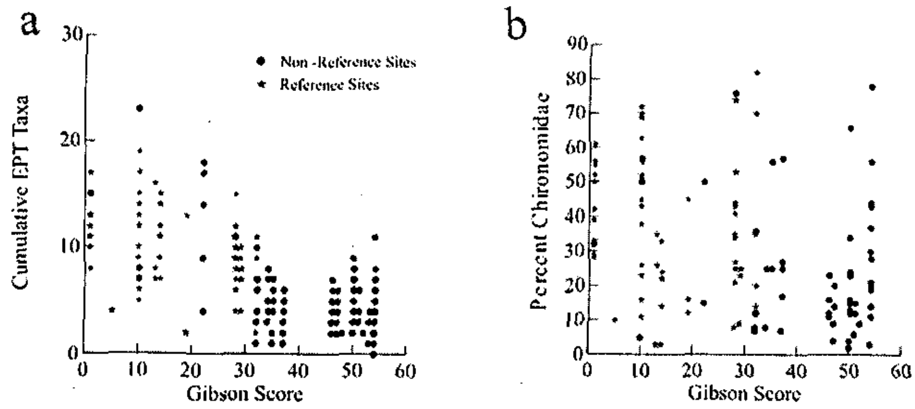

Figure 6. Scatterplots describing the relationship between the Gibson Score values and a) Cumulative EPT Taxa and b) Percent Chironomidae.

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Step IV. Defining Scoring Ranges of Core Metrics

Scoring ranges were defined using techniques described in Hughes *et al.* (1998) and McCormick *et al.* (2001). Statistical properties of the distribution of metric scores for both reference sites and non-reference sites were used to define cutoffs using the following criteria: 1) any site with a metric value of less than the 5th percentile of the non-reference sites was assigned a "0" score, 2) any site with a metric value of greater than the 50th percentile of the reference sites was assigned a "10" score. The range between these values was divided into 9 equal portions and assigned values between 1 and 9 (Figure 7). Scoring ranges were calculated for all core metrics based on the data from the last three sampling events (May 2000, November 2000 and May 2001) and are listed in Table 4.

The cutoffs that define the ranges for each metric (here: 5% and 50%) are arbitrary and can be adjusted if necessary to better describe the range of variability in scores. We investigated the use of other cutoffs to see if other values would result in more optimal distribution of the final IBI scores. We also used a Karr –style IBI scoring methodology (Barbour *et al.* 1999) in which 95% of the complete range is divided into 3 (=trisection) or 4 (=quadrisection) equal ranges. This approach was used in the creation of the Russian River IBI (Harrington 1999). A comparison of the three alternatives indicated that the Hughes/ McCormick methodology provided the best discrimination of site quality.

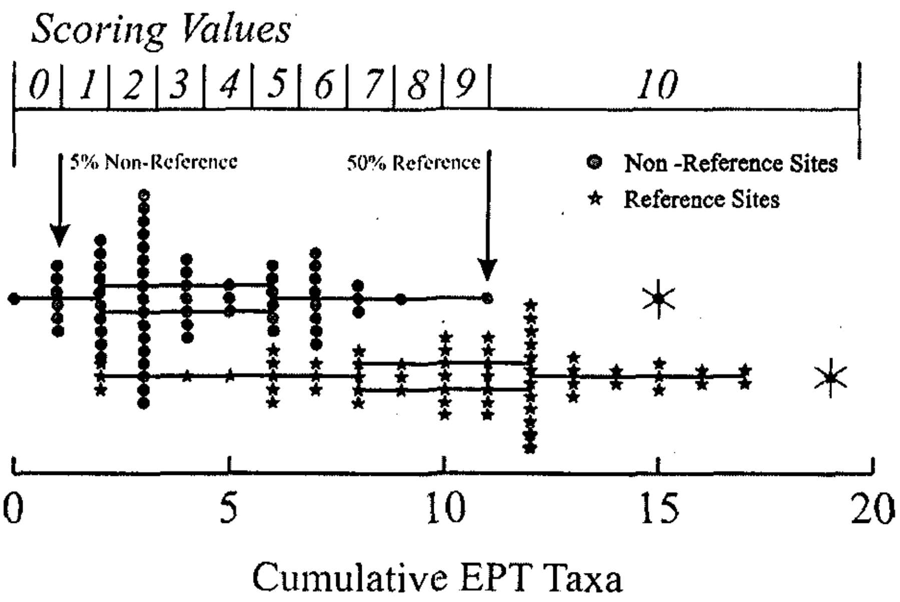

Figure 7. Example of methodology for setting scoring ranges for the core metrics. See text for full description of scoring methodology.

Step V. Calculation of the IBI

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After the core metrics have all been assigned scoring ranges (Table 4), the IBI score for each site is calculated by summing the component metric scores. The distribution of resulting IBI scores for all the sites is then divided into ranges that define thresholds of biotic condition (Table 4). Ranking ranges for the San Diego IBI were established by using the 25th percentile of reference sites (again using only the last three sampling events which included a substantial number of reference sites) to set the boundary between the "Good" and "Fair" scoring ranges. Then the top end of the scale was divided into two equal sections ("Good" and "Very Good") and the bottom end of the scale was divided into three equal sections ("Fair", "Poor" and "Very Poor"). A distribution plot of the site IBI scores used to establish the rating thresholds for the San Diego IBI is presented in Figure 8.

Table 4. Scoring ranges for the seven metrics included in the San Diego IBI and the IBI values

	Metric Scoring Ranges for San Diego IBI						
Score	**Cumulative Taxa**	**Dominant Taxon**	**Sensitive EPT Index**	**Cumulative EPT Taxa**	**Shannon Diversity**	**Intolerant Taxa**	**Percent Grazers**
0	**0-16**	**>56**	**0-0.6**	**0-1**	**0-1.31**	**0-.5**	**0-0.6**
1	**17-19**	**54-56**	**0.7-1.3**	**2**	**1.31-1.4**	**0.6-1.0**	**0.7-1.3**
2	**20-21**	**51-53**	**1.4-2.0**	**3**	**1.41-1.49**	**1.1-1.6**	**1.4-2.0**
3	**22-23**	**49-50**	**2.1-2.7**	**4**	**1.5-1.58**	**1.7-2.1**	**2.1-2.7**
4	**24-25**	**47-48**	**2.8-3.3**	**5**	**1.59-1.67**	**2.2-2.7**	**2.8-3.4**
5	**26-27**	**45-46**	**3.4-4**	**6**	**1.68-1.76**	**2.8-3.2**	**3.5-4.1**
6	**28-29**	**42-44**	**4.1-4.6**	**7**	**1.77-1.84**	**3.3-3.8**	**4.2-4.8**
7	**30-31**	**40-41**	**4.7-5.3**	**8**	**1.85-1.93**	**3.9-4.3**	**4.9-5.5**
8	**32-33**	**37-39**	**5.4-6**	**9**	**1.94-2.02**	**4.4-4.9**	**5.6-6.2**
9	**34-35**	**34-36**	**6.1-6.9**	**10**	**2.03-2.11**	**5.0-5.4**	**6.3-7**
10	**>35**	**0-33**	**>6.9**	**11**	**>2.11**	**>5.4**	**>7**
IBI Score	Very Poor [illegible]	Poor [illegible]		Fair [illegible]	Good [illegible]		Very Good [illegible]

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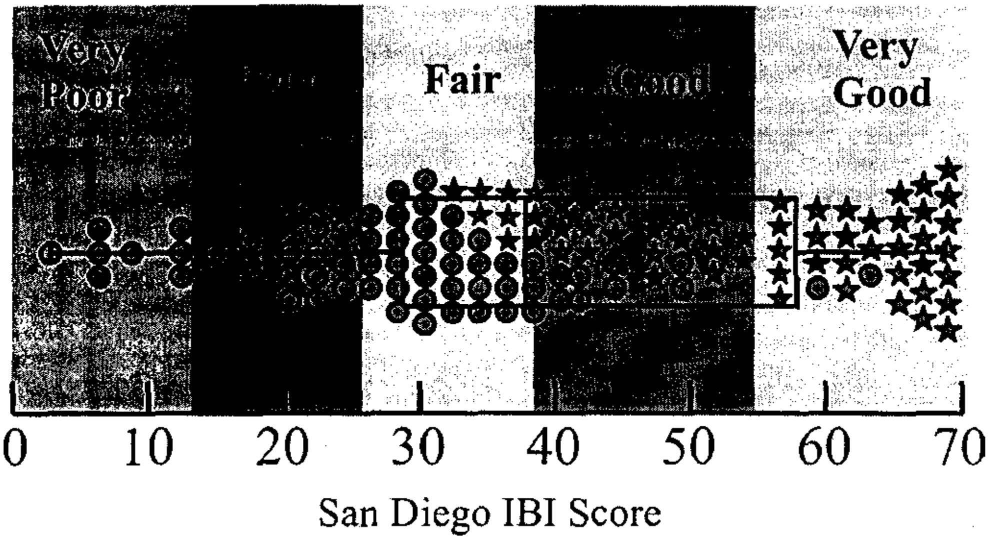

Figure 8. Distribution of IBI scores for May 2000, November 2000 and May 2001 sampling events with range cutoffs for assignment of index thresholds. Reference sites are indicated by red stars, while non-reference sites are indicated by gray circles.

Step VI: Testing and Refining the IBI

After IBI ranges are established, the final step in IBI development is to test the performance of the IBI and make adjustments as necessary to refine the scoring ranges. IBI development is an iterative process: "setting scoring criteria is an iterative process and should be revisited as regional databases and biological knowledge expand" (Karr and Chu 1999).

The first step is to test the IBI to see if it discriminates sites as expected. Some sites designated as "reference" or "non-reference" should be re-evaluated for reassignment to the appropriate class (see commentary in Barbour *et al.* 1999, sections 9-12). Reasons for eliminating reference sites based on data include: 1) unusually high degrees of natural variability at a site, 2) evidence of impairment from stressors not measured in the reference site selection phase (see Step I above), and 3) evidence that a site is not representative of its class.

IBI scoring ranges are presented in Figure 9 for all sites and all 8 sampling events. Scoring values in the May 1998 and May 1999 sampling events were abnormally low for many sites (see Figure 12), obscuring patterns in the data. To make it easier to see patterns we have removed data from these two sampling events in Figure 10.

On the basis of the distribution of IBI scores, several sites appear to be good candidates for status review. At least three sites classified as non-reference sites should be considered for re-classification as reference sites (PC-PMP, SYC-NT, and TCC-TC). Interestingly, these were sites that were removed from the reference pool based on their physical condition. In contrast, at least one site (SLRR-PG) should be dropped from the reference site pool as an outlier on the basis of its performance here. All of the reference sites sampled for the first time in May 2001 will need additional sampling events before their suitability can be confirmed. Several sites that scored in the fair range in the May 2001 event should receive carefully review: CON-ECR, BCC-SRT, BCC-BCT, SMC-SMR, SC-LCR, BC-BCR, JC-GS, NC-PCR, and MCC-BML.

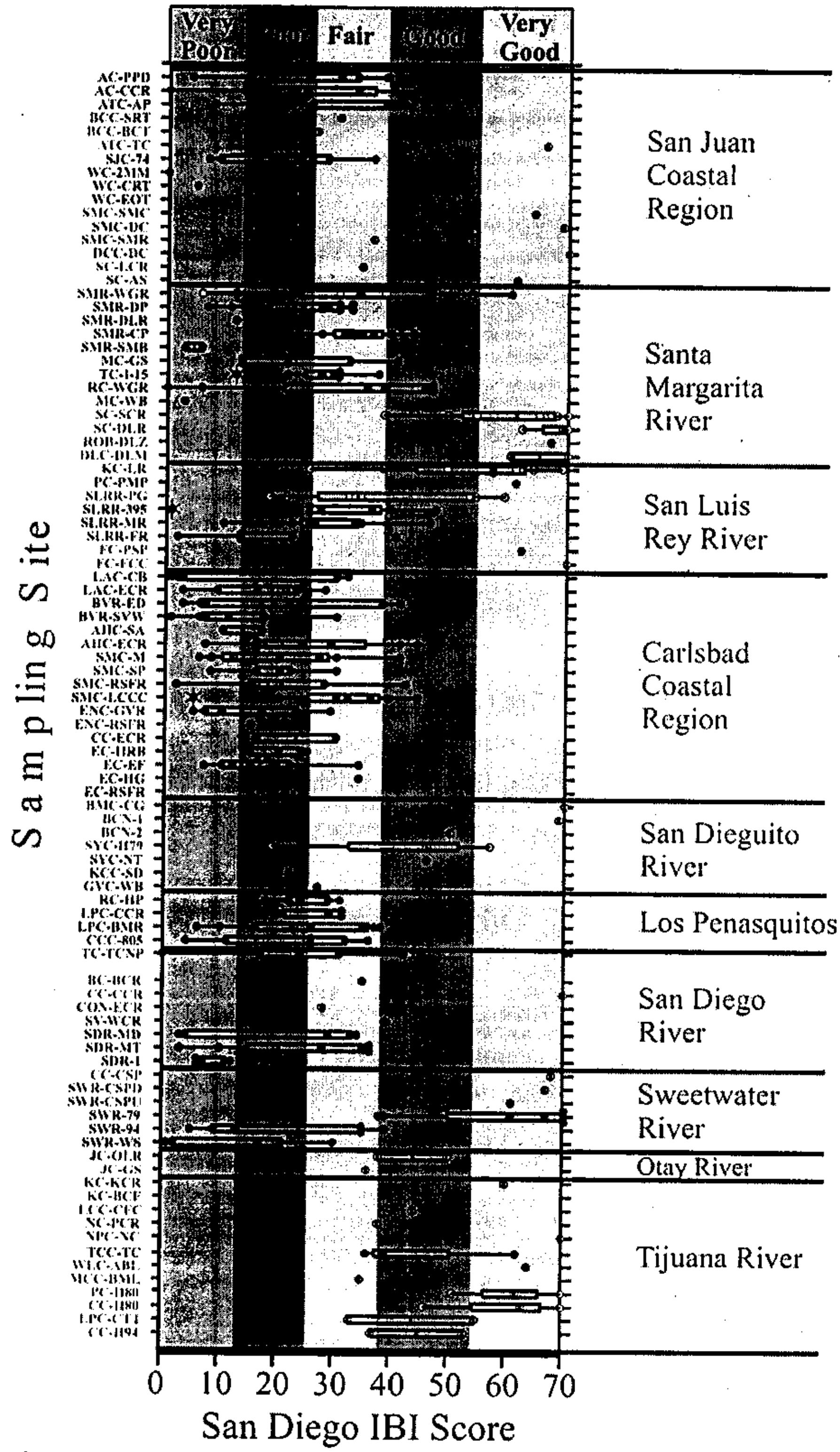

Figure 9. Boxplots demonstrating the range of IBI scores calculated for all sites sampled in the San Diego Region between 1998 and 2001. Values for individual sampling events are indicated by the separate points, reference sites are indicated by yellow points and red text site codes.

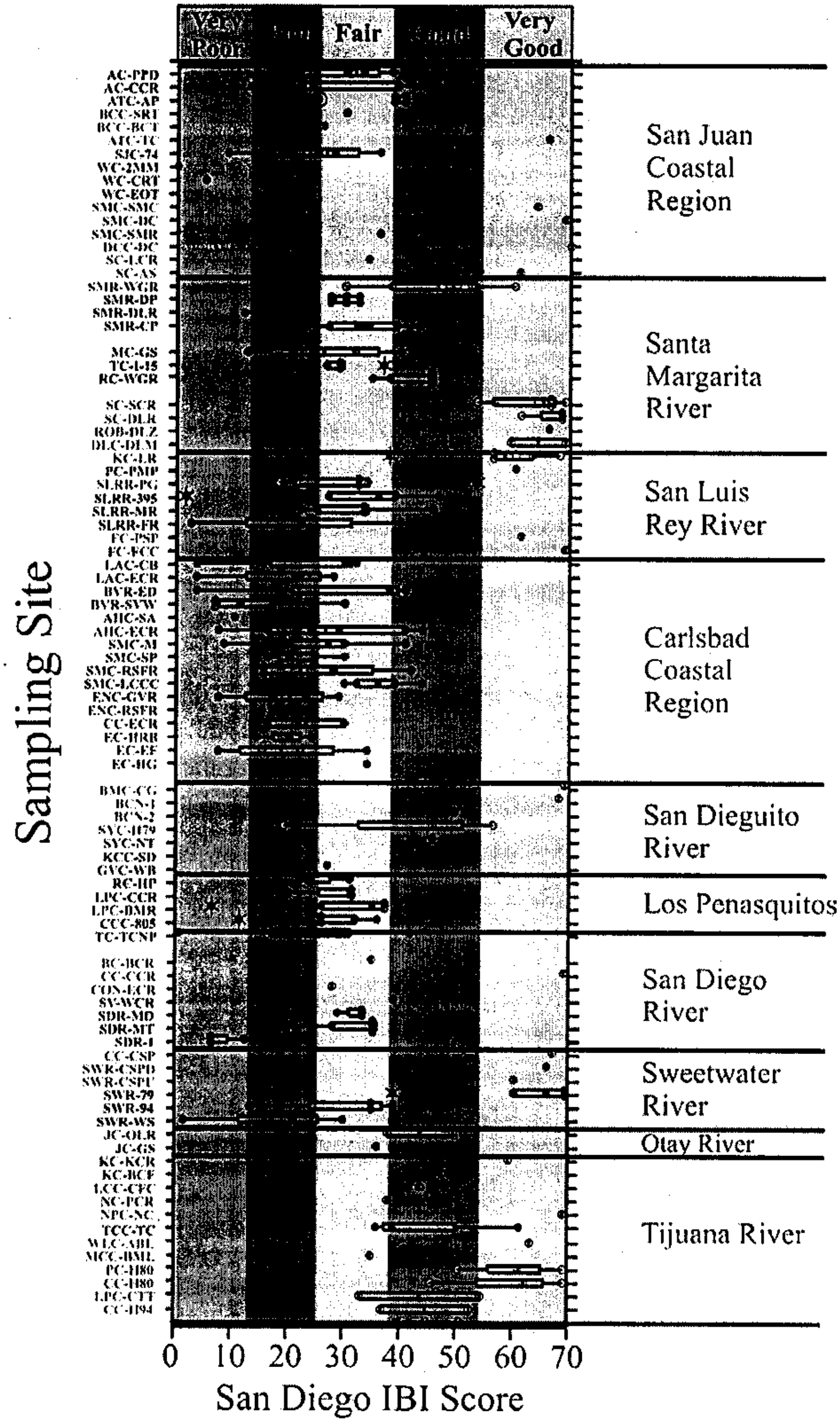

Figure 10. Boxplots demonstrating the range of IBI scores calculated for all sites sampled in the San Diego Region between 1998 and 2001. **Sampling points from May 1998 and May 1999 are removed.** Values for individual sampling events are indicated by the separate points, reference sites are indicated by yellow points and red text site codes.

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Additional Considerations: Reviewing the need to classify stream types

One of the fundamental challenges of bioassessment is the fact that stream communities naturally vary spatially and temporally. In order for bioassessment to provide meaningful guidance for water quality managers, it is critical that this variation be managed so that signals (evidence of impairment) can be detected over the noise of variation.

One of the most common ways that multimetric approaches (e.g. IBI) deal with natural variation is by partitioning that variation into natural classes of streams or natural classes of stream sites. The assumption inherent to this approach is that streams (or sites) of similar types (based on stream order, underlying geology, elevation zones, ecoregion or subecoregion) have relatively similar aquatic communities in their natural state. However, there is a trade-off between the advantage gained by partitioning variation into multiple classes and the decreased efficiency caused by creating and maintaining multiple IBIs for a region. In theoretical terms, the ideal number of classes is the smallest one that provides adequate power to detect impairment.

For the San Diego IBI we considered several ways of partitioning variation. Our initial year of sampling suggested that bioassessment data collected in spring samples had lower biotic condition scores than those collected from the same sites in fall. We therefore continued to sample in May and November in subsequent years. Because we expected stream condition to vary with elevation, we were careful to select a similar distribution of reference sites upstream and downstream of 1000 ft. We did not address stream order in this study because there was little variation in stream size compared to what we have seen in other regions. However, we have not fully explored this factor and intend to investigate it in future iterations.

Figures 11 and 12 demonstrate the relationship between two of these factors, elevation and sampling season. Site elevation did not appear to have any influence on IBI scores for the last three sampling events (Figure 11). Although lower elevation sites appear to have lower IBI scores when all sites are considered (Figure 11a), this appears to be an artifact of the fact that most of the impaired (non-reference) sites in the May 2000 sampling event were also low elevation sites (this is apparent in Figure 11b). Seasonality, which appeared to strongly influence metric scores in the first set of samples (May 1998 through May 1999), was not a consistent factor in IBI scores (Figure 12). This was especially true for reference sites, which did not show the same reduction in IBI scores in the May 1998 and May 1999 sampling events.

To further investigate the need for stratification into elevation or season, we compared the patterns we saw in the IBI scores to patterns derived from measures of the community composition at each site. To do this we used multivariate ordination techniques designed for analysis of community data.

Use of Multivariate Statistics in Bioassessment

Multivariate statistics are often used in community ecology to determine which environmental variables, out of many that might be measured, best explain observed species distributions. Ordination is one set of multivariate techniques used to arrange sites along axes based on their species composition. Sites that are plotted closely together are similar in species composition and sites that are dissimilar are plotted farther apart. When environmental data is lacking or not included the ordination is unconstrained, and sites are plotted along theoretical axes that represent a combination of variables that best explain the variance in the species data. Resulting scatter plots can then be interpreted *post-hoc* by calculating correlation coefficients between environmental variables and ordination axes. An advantage of unconstrained ordination is that it can show whether important environmental variables have been overlooked (ter Braak 1995). When environmental data is available, ordination can be constrained so that the ordination axes must be a linear combination of environmental variables; this approach has a direct environmental basis, and ordination axes appear in order of the degree to which each explains variance in the species data.

In the field of bioassessment, multivariate techniques have been employed extensively in the development of predictive models (Wright *et al.* 1984, Moss *et al.* 1987). This type of modeling is used in the River Invertebrate Prediction and Classification (RIvPACS) approach (Wright *et al.* 1993) and its derivative Australian River Assessment System (AusRivAS, Norris 1995), and is considered to be the main alternative to multi-metric (IBI) methods (Barbour *et al.* 1999). In these methods, reference sites are ordinated on the basis of species composition, groups of similar reference sites are defined with some type of clustering algorithm, and then those groups are described in terms of their environmental variables using discriminant function analysis. Measurement of the same environmental variables at a test site allows estimation of reference group membership, and therefore allows prediction of the expected community at the test site. Test sites can be placed into impairment categories based on the ratio of taxa observed to taxa expected.

Use of multivariate techniques, including ordination, is not limited to generation of predictive models and can be used in many stages of IBI development including setting reference condition criteria, screening metrics and defining stream or site classifications (ter Braak 1986, Barbour *et al.* 1999). In addition to ordination of sites based on species composition, multiple regression can be used to express metrics as a function of several environmental variables at once, which is important when environmental variables are correlated or when they show interaction (the value of one variable depends on the value of another variable). Alternatively, ordination can be performed on chemical and physical variables alone, a technique that allows identification of the primary gradients that might determine organismal distributions. Finally, canonical ordination is an approach that combines ordination with regression and expresses the main relationships between species and each environmental variable (Jongman *et al.* 1995, Legendre and Legendre 1998).

Use of Multivariate Methods in San Diego IBI

To determine if a separate IBI was needed for fall and spring index periods or for low and high elevations, and to explore differences in reference and non-reference communities, detrended correspondence analysis (DCA), a type of unconstrained ordination, was used in analysis of all years of the San Diego data set. Ordination plots showed whether variance in species composition across sites was best explained by sampling season, site elevation or site classification as reference vs. non-reference. Sites did not cluster by elevation category (< 1000 ft = "low"; > 1000 ft = "high", Figure 13b) or by reference status (Figure 13c), but did show clustering based on whether they were sampled in the spring or fall (Figure 13a); this effect was particularly noticeable in the last three sampling events, upon which our IBI is based, but was also present when we looked at all sampling events.

Site Classification: Elevation and Seasonality

There was no evidence from either multi-metric or ordination techniques that elevation had a strong influence on stream invertebrate communities. Although most non-reference sites were located in the lower elevation band (due to management decisions for water quality testing) we attempted to find reference sites across a range of elevations (Figure 14). Non-reference sites had higher IBI scores in higher elevation sites, but the lack of relationship between elevation and IBI scores at reference sites indicates that this was due to higher degrees of impairment at lower non-reference sites rather than differences in biotic community composition at different elevation bands. This is further supported by the distribution of IBI scores by elevation categories (Figure 11) and ordination results (Figure 13c).

In spite of evidence that the taxonomic composition of spring communities differs from fall communities (Figure 13a), metric scoring was not affected by seasonal differences in community composition, and it was determined that a separate IBI for spring and fall index periods was unnecessary. Although community composition differs greatly from spring to fall in terms of which taxa are present, biological metrics used in the present IBI (e.g., cumulative taxa richness, cumulative EPT taxa) are not greatly affected by the seasonal turnover.

One possible explanation for the difference between the ordination and IBI result is that the taxonomic richness may be lower in the non-reference sites, resulting in lower IBI scores. However, reference and non-reference sites may cluster together on the basis of a few common (and abundant) taxa. Thus this may be in part an artifact of the way clustering techniques score similarity as a function of the abundance of individual taxa.

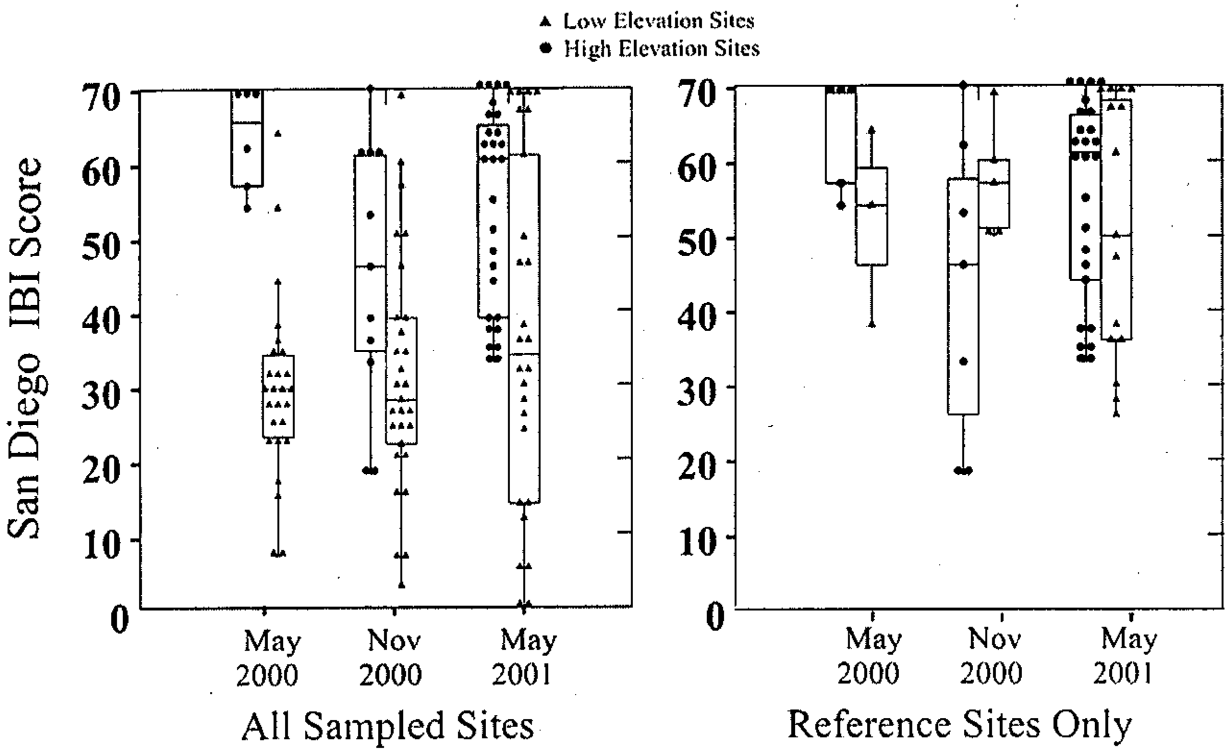

Figure 11. Distribution box plots of IBI scores v. elevation categories for the last three sampling events. Blue boxplots with blue triangular points indicate sites less than 1000' elevation, while black boxplots with black circular points represent sites greater than 1000' elevation.

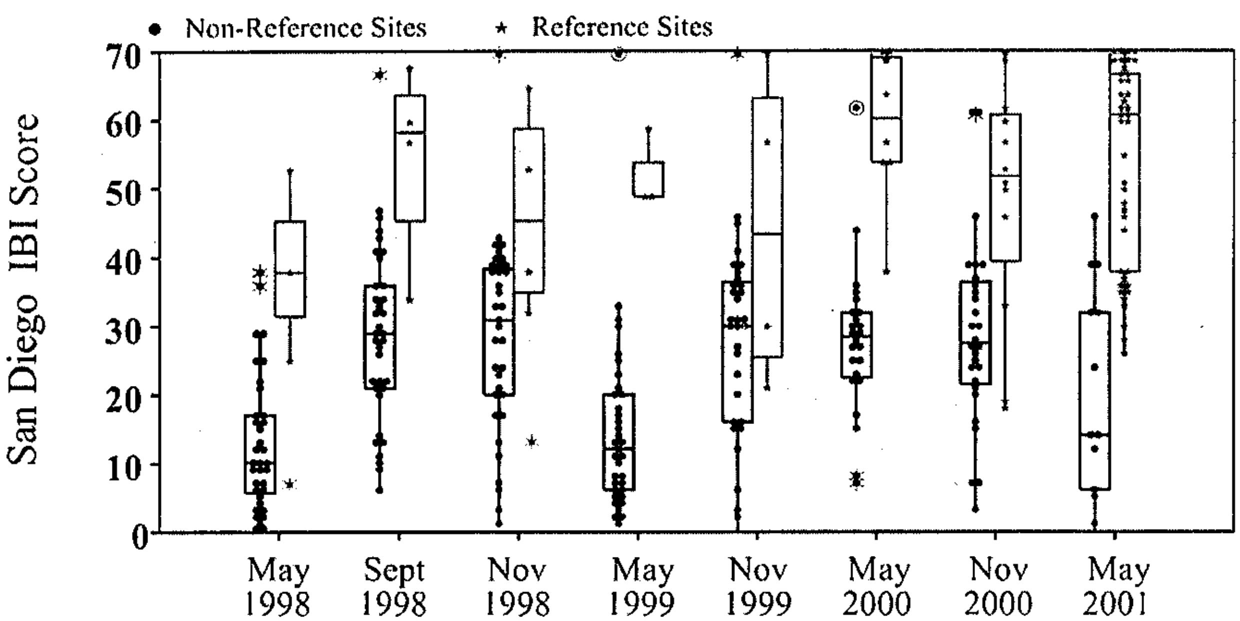

Figure 12. Distribution box plots of IBI scores for each of the eight sampling events, with separate plots for reference sites and non-reference sites. The number of sites in each sampling event are indicated by the separate points superimposed on the boxplots.

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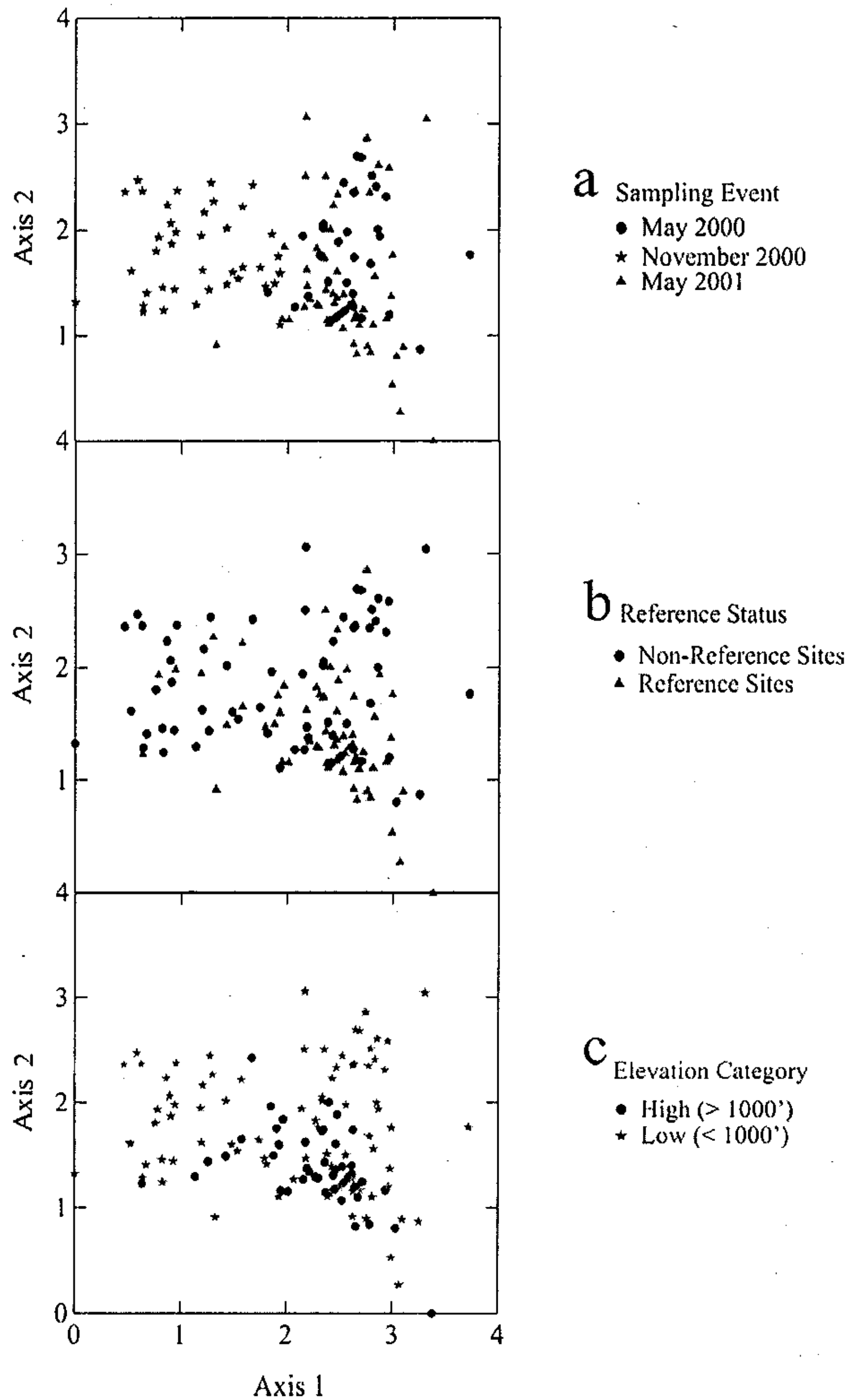

Figure 13. Multivariate ordination plots comparing communities at each site sampled in the last three sampling events (May 2000, November 2000 and May 2001). See text for interpretation of axes and explanation of the ordination techniques.

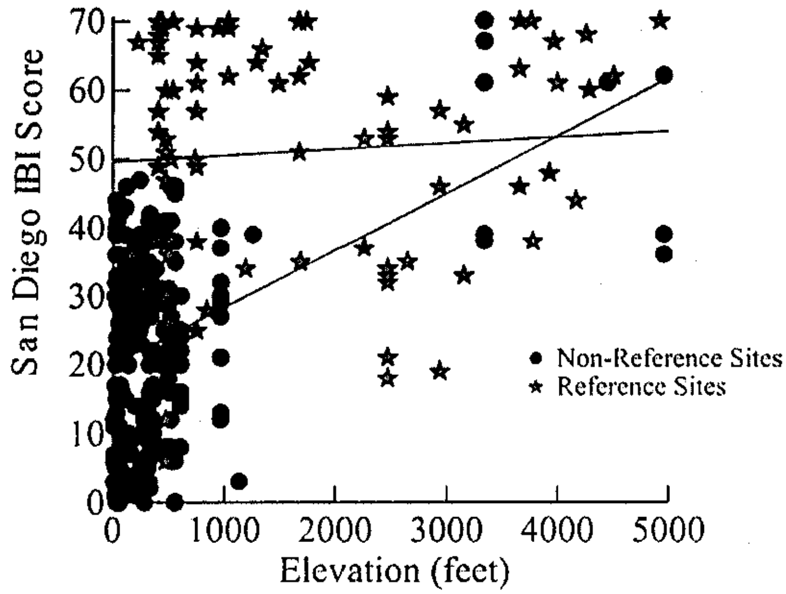

Figure 14. Distribution of IBI scores at different elevations. Reference sites are indicated by red stars and non-reference sites are indicated by black dots.

DISCUSSION

This report presents a preliminary IBI that provides the first context for assessing biotic condition from benthic macroinvertebrate assemblages in the San Diego region. Use of this IBI may extend beyond the boundaries of the San Diego RWQCB, but should be done so with caution since all of the data used to create the IBI were collected within the region's boundaries.

There was a considerable amount of within site variation in IBI score, and many sites ranked across two or three of the five rating categories in different sampling events. Therefore, we recommend that sites should be sampled at least twice before the current San Diego IBI is used to assign rating categories. Nonetheless, the IBI is clearly able to discriminate between major classes of site quality, especially when multiple sampling points are available. For example, all sites in the Carlsbad and the Peñasquitos hydrologic units consistently scored in the lower half of the range, while several sites in the Santa Margarita and Tijuana hydrologic units consistently scored in the upper half of the range. Variation in biotic condition has itself been noted as an indicator of stressed environments (see multiple papers in JNABS volume 19, no.3), but we do not have enough repeat visits at most reference sites to evaluate reference site variability versus non-reference site variability.

The number of water quality ranks established in an IBI can affect perceived variability in site rank because fewer categories reduce within site variation in IBI assignment of ranges. The current San Diego IBI has five rating categories. Based on the ranges of sites scores we found, the IBI seems to reliably assign three categories of biotic condition. The objective of future work on this IBI should be focused on decreasing the measured variability and thus increasing the ability of the IBI to discriminate more tightly defined classes.

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There are several potential sources of this variation in site scoring; these can be roughly grouped into two classes: 1) differences in site health (increased or decreased impairment) in the different sampling events and 2) natural variation in bioassessment metrics at these sites. The next step in applying bioassessment to regional assessments is therefore to refine the IBI in order to reduce the portion of variation that is due to natural causes so that impairment signals can be detected. Most of the techniques involved in this step involve one of two strategies: 1) partitioning natural variation into different classes of streams and 2) investigating metrics that are least influenced by this natural variation.

IBI Partitioning

Since IBI development is an iterative process, the partitioning of stream classes can be investigated at any stage in the IBI development. Our initial investigation into the influence of sampling season and site elevation and found at most weak relationships between these factors and IBI scores, but there may be other environmental variables for which we have not accounted.

There is also reason to investigate possible seasonality in metric scores further. Although the strong seasonal component to biological metrics that we noted in the first sampling year was not apparent in later years, the taxonomic composition of biological communities in this region appears to be very much influenced by seasonality and sampling timing. This suggests that there may be some metrics (not captured in the IBI) that are affected by sampling season. We should, therefore, consider the possibility that exploration of new metrics might necessitate the need to revisit the question of partitioning by season. Although there was not enough evidence to justify creation of seasonal IBIs at this stage, the data warrant further investigation.

Metrics Improvement and Correlation with Physio-chemical Variables

Improvement of the core metric pool that makes up the IBI has the greatest potential for reducing the natural variability that is measured in the IBI and should be the greatest focus for future efforts. One promising direction for future research is multivariate analysis of the major physical and chemical factors driving community composition. It will be very important to continue to monitor intensive quantitative physical and chemical monitoring at all biomonitoring sites (test sites and reference sites). This data will be critical to refinement of the IBI because it will allow for the identification of physio-chemical factors of key influence to natural community variation.

Summary and Recommendations

1. This report establishes a preliminary IBI for the San Diego Region (Table 4) which provides the first context available for interpreting aquatic macroinvertebrate data in the San Diego Region.

2. Initial evidence suggests that there is no need to create separate seasonal IBIs or separate IBIs based on elevation. However, we recommend further investigation of this with expanded datasets from surrounding regions.

3. The San Diego Region IBI is appropriate for use in screening test sites for further analysis, but we recommend that sites should be evaluated at more than one sampling event before assigning a rating category to them.

4. We recommend that the RWQCB (9) continue to develop and refine the IBI with special emphasis on supporting metrics evaluation with the goal of improving IBI precision.
    a. We recommend establishing a program for continued monitoring of sites that includes more intensive quantitative physical and chemical monitoring at all biomonitoring sites (test sites and reference sites). This data will be critical to refinement of the IBI because it will allow for the identification of physio-chemical factors of key influence to natural community variation. This could be a portion (~ 15-20 sites) of the sites identified here.
    b. The influence of seasonality should continue to be evaluated. This could be evaluated with a smaller set of reference and non-reference sites.
    c. We recommend quantification of IBI performance so that IBI scores can be assigned a degree of estimated precision. This could be done by taking 3 samples (9 transects) from10-20 sites and using iterative techniques like bootstrapping to calculate error rates.
    d. We recommend continuing efforts to identify reference sites, including efforts to adapt the new DFG/ SNARL reference site selection methodology to the San Diego region.

5. Currently, the RWQCB (9) has assigned responsibility for ongoing sampling of many suspected impaired locations to various co-permittees in the region.
    a. We recommend establishing a plan to integrate data collected from these co-permittees along with data collected by the RWCBQ (9) into a common database.
    b. This should be done on an on-going basis and include continuing evaluation of reference sites.
    c. The quality assurance/ quality control (QA/QC) program already in place should be maintained to ensure compatibility among datasets from the various entities.

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Appendix A (56 pp.)

Taxonomic list of benthic macroinvertebrates identified from samples collected in the San Diego Region in May 2001

Appendix B (8pp.)

Bioassessment metrics calculated from benthic macroinvertebrate samples collected in the San Diego region in May 2001

Appendix C (6 pp.)

Summary statistics (means and coefficients of variation) calculated for bioassessment metrics for samples collected in the San Diego region in May 2001

Appendix D (18 pp.)

General data matrix for physical habitat measures and water chemistry measure collected at bioassessment collection sites in the San Diego region over eight sampling events between May 1998 and May 2001. Physical habitat measures are the most recent available for a site and most chemistry measures are only available for the May 2001 sampling event.