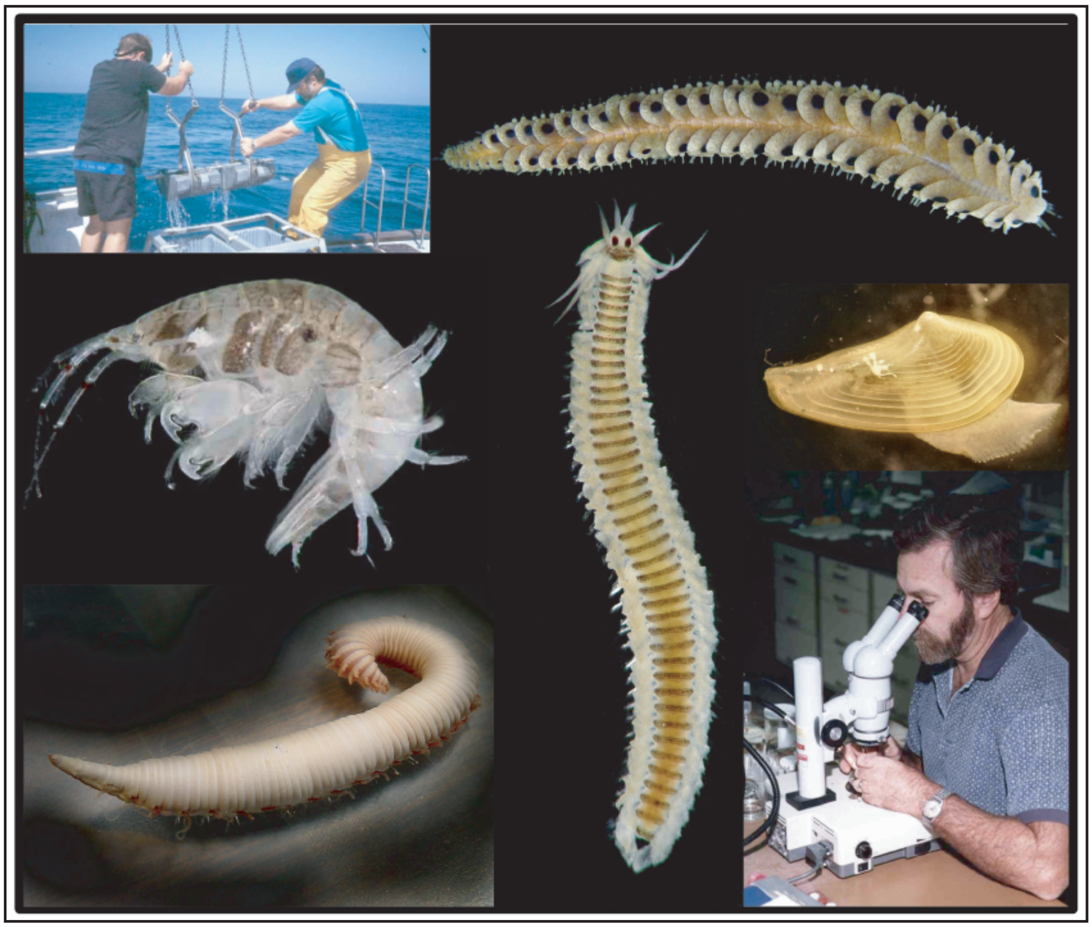
BIGHT'03

Benthic Macrofauna



Southern California Bight
2003 Regional Monitoring
Program
Vol. III

Descriptions and Sources of Photographs on Cover

Clockwise from upper left: (1) Benthic sediment sampling with tandem-rigged Van Veen grab; LACSD Ocean Monitoring & Research Group. (2) The polynoid polychaete *Arctonoe pulchra* (Johnson 1897); L. Harris, Los Angeles County Natural History Museum. (3) The nuculid bivalve *Nuculana;* B. Power; LACSD Ocean Monitoring & Research Group. (4) Bight'03 taxonomist T. Parker identifying benthic macrofauna; LACSD Ocean Monitoring & Research Group. (5) An undescribed species of phyllodocid polychaete *Pterocirrus*; L. Harris, Los Angeles County Natural History Museum. (6) The opheliid polychaete *Travisia gigas* Hartman 1938; R. Rowe, City of San Diego Metropolitan Wastewater Dept. (7) The isaeid amphipod *Photis brevipes* J.L. Barnard 1962; L. Harris, Los Angeles County Natural History Museum.

Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna

May 2007

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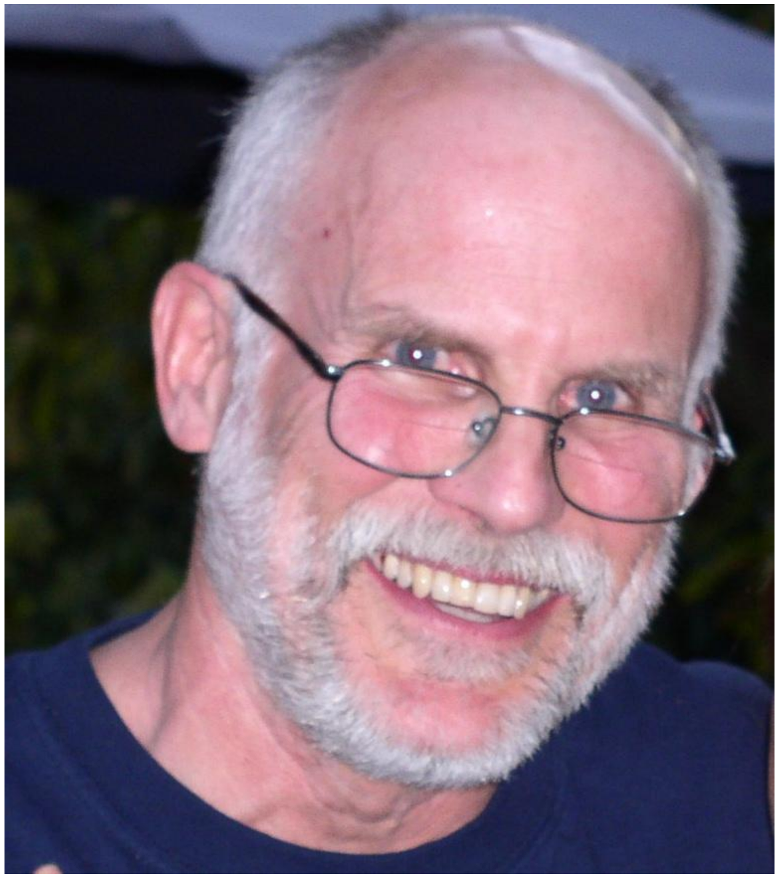
DEDICATION



Robert W. Smith, Ph.D.
March 21, 1943 - December 29, 2005

Ph.D. Marine Biology, University of Southern California - 1976
B.S. Oceanography, University of Washington - 1969
B.A. Psychology, University of California, Berkeley - 1966

This report is dedicated to the memory of Bob Smith. Bob was an ecologist and statistician with a long and close association with benthic monitoring in the Southern California Bight. As a USC student in the early 70's, he developed an appreciation for using benthic organisms to measure the effects of wastewater discharges; he was still actively solving challenges in interpreting benthic abundance data at the time of his death. The Benthic Response Index (BRI) used to assess benthic condition in this report was his conceptual creation. The approach was eventually extended to assess trawl-caught fish and invertebrates. Bob invented the way marine and estuarine assessments are conducted in southern California. He was a unique, productive and kind person with varied interests. Those of us who were fortunate enough to know him sorely miss him.

THE BIGHT'03 BENTHIC MACROFAUNA WORKING GROUP

Much of the success of the Southern California Bight Regional Monitoring Program is its consensus-based management structure. A Project Steering Committee comprised of environmental managers from each of the participating agencies provides design, oversight, and approval, while most of the technical work is accomplished through Working Groups for each discipline. The Benthic Macrofauna Working Group was charged with implementing much of the work presented in this report. The members of the Benthic Macrofauna Working Group include:

Member	Affiliation
Jeff Armstrong	Orange County Sanitation District
Arthur M. Barnett	Southern California Coastal Water Research Project
Chris Beegan	State Water Resources Control Board
Cheryl Brantley	Sanitation Districts of Los Angeles County
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Stephen B. Weisberg	Southern California Coastal Water Research Project

FOREWORD

The Southern California Bight (SCB) is a 100,000-square-mile body of water and submerged continental shelf that extends from Point Conception, California, in the north to Cabo Colnett, Baja California, Mexico in the south. This area is a unique and important ecological and economic resource in southern California that includes diverse habitats for a broad range of marine life including more than 2,000 species of invertebrates, 500 species of fish, and many marine mammals and birds.

The coastal region along the SCB is one of the most densely populated coastlines in the U.S. and the world. The activities of this dense human population stress the coastal marine environment by introducing pollutants from point and non-point sources, modifying natural habitats and increasing fishing pressure.

Over $10 million is spent annually to monitor coastal environmental quality in the SCB. These monitoring programs provide important site-specific information about the impacts of individual waste discharges, but do not assess the condition of the SCB as a whole. The assessment of environmental quality on a more regional scale is needed to help environmental regulators and resource managers understand the consequences of pollution beyond the immediate vicinity of discharge pipes.

The 2003 Southern California Bight Regional Monitoring Program (Bight'03) is an effort to provide an integrated assessment of the SCB through cooperative region-scale monitoring. Bight’03 is a continuation of regional surveys conducted in 1994 and 1998, and represents the joint effort of 58 organizations. Bight'03 is organized into three technical components: (1) Coastal Ecology, (2) Shoreline Microbiology, and (3) Water Quality. This report presents the results of the benthic macrofauna studies of Bight'03, which is a part of the Coastal Ecology component. Other Coastal Ecology components include sediment toxicity, sediment chemistry, and demersal fish and megabenthic invertebrates. Copies of this and other Bight'03 guidance manuals, data, and reports are available for download at www.sccwrp.org.

The proper citation for this report is: Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. 2007. Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

ACKNOWLEDGEMENTS

This report is the product of the dedication and hard work of many individuals who share a common goal of improving our understanding of the environmental quality of the Southern California Bight. The authors thank all of those who contributed to this report. While space limitations do not allow us to acknowledge all contributors by name, we are grateful to the following people and agencies whose efforts were crucial to our success.

The members of the Bight'03 Steering Committee provided the impetus, vision, and resources that guided and fueled our efforts. The Coastal Ecology Committee coordinated our efforts with other disciplines; their critical and timely reviews improved this document.

The field teams collected our samples with efficiency and care. The captains, crew and scientists on the Alguita, Portunus and Shearwater (MBC Applied Environmental Sciences), JB and inflatables for lagoon sampling (Weston Solutions, formerly MEC Analytical Systems Inc.), Earlybird (Sea Ventures), Enchanter IV (Orange County Sanitation District), Hey Jude (Aquatic Bioassay and Consulting Laboratories), La Mer and Marine Surveyor (City of Los Angeles), Monitor III and Metro (City of San Diego), MacArthur II (Channel Islands National Marine Sanctuary), Ocean Sentinel (County Sanitation Districts of Los Angeles County), and a 17-ft Boston Whaler (Kinetic Laboratories) were responsible for field collection and processing. They contributed to our success in no small measure.

The Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) provides a mechanism for standardizing the names of organisms in southern California and promotes communication among taxonomists. They were an integral part of this effort and conducted workshops to prepare taxonomists for organisms in habitats that were sampled in a regional survey for the first time.

We appreciate the efforts and expertise of the taxonomists who produced the primary data on which this report was built. Kelvin Barwick, Cheryl Brantley, John Byrne, Don Cadien, Douglas Diener, Leslie Harris, Kathy Langan, Megan Lilly, John Ljubenkov, Lawrence Lovell, Ricardo Martinez-Lara, John Miller, Eric Nestler, Thomas Parker, Dean Pasko, Tony Phillips, William Power, James Roney, Rick Rowe, Timothy Stebbins, and Ron Velarde identified and counted every one of the 245,917 organisms from 1,664 taxa that were collected. Special thanks are due to Dave Montagne, who coordinated the data generation process; his efforts ranged from training and auditing field crews to holding meetings to ensure that every taxonomist used each taxon name in the same way.

Specialty taxonomists identified and counted groups of animals that were previously not consistently and reliably identified bightwide by taxonomists, and prepared documentation and training materials to improve the state of the science. John Ljubenkov was specialty taxonomist for Anthozoa, Tony Phillips for Polycladida, and Don Cadien and Kelvin Barwick for Aplacophora.

The Benthic Macrofauna Working Group Committee worked cooperatively on all aspects of data collection, sample processing, data analysis, and report preparation. Discussions were open and thoughtful, and the synergy of different perspectives resulted in new and productive ideas.

The California State Water Resources Control Board supported development of the measure used to assess the condition of benthic communities in bays and estuaries through the effort to develop Sediment Quality Objectives. We appreciate the assistance.

We are grateful to Shelly Moore for making the maps, Shelly Moore and Bruce Bealer for maintaining the database and writing computer programs, Paul Smith for solving many computing issues and distributing data and documents across the Internet, Dave Montagne for coordinating acquisition of the cover photographs and arranging their layout and Valerie Raco-Rands for layout of the cover. The efforts of these individuals made many complicated tasks seem easy.

Participating Benthic Laboratories

Aquatic Bioassay and Consulting Laboratories, Inc.
City of Los Angeles, Environmental Monitoring Division
City of San Diego, Marine Biology Laboratory
Sanitation Districts of Los Angeles County
Weston Solutions, Inc. (formerly MEC Analytical Systems, Inc.)

EXECUTIVE SUMMARY

Organisms that live in sediments beneath bodies of water (benthic organisms) have many characteristics that make them useful as indicators of environmental stress for monitoring programs. Benthic organisms have limited mobility, respond to many different types of environmental stress, and integrate the effects of environmental conditions at a place over time. Benthic organisms are also more relevant measures of environmental condition than some other indicators, such as sediment chemistry, because they represent the biological resources that are the focus of many environmental laws and regulations. Most benthic monitoring in the Southern California Bight (SCB) is conducted to evaluate the effect of discharges from individual sources such as wastewater outfalls, thermal and industrial outfalls, dredged material, and drilling mud. The low proportion of the SCB monitored by these programs and the differences in methodology between them impede the interpretation of the local patterns and trends measured by each program in a regional perspective. Recognizing the value of regional assessment, 12 agencies joined in a cooperative effort to assess the health of southern California's mainland shelf in 1994. This study was called the Southern California Bight Pilot Project (SCBPP). Based on the success of this regional monitoring survey, a second cooperative regional survey known as Bight`98 was conducted in 1998 by 62 organizations. Bight'98 expanded the spatial scope of the SCBPP in three ways: (a) sampling extended inshore to assess the condition of bays, harbors, and ports (embayments); (b) coastal sampling extended southward to include Mexican waters as far south as Ensenada; and (c) coastal sampling extended westward to include the island shelves. In 2003, a third cooperative survey, known as Bight'03, was conducted by 58 organizations. The spatial scope expanded again in 2003, this time in two ways: (a) shoreward to include estuaries (including lagoons), and (b) off the mainland and island shelves down slopes and basins to a depth of 1,000 meters.

Benthic macrofauna were successfully collected and processed from 388 sites between Point Conception, California, and the United States-Mexican border. Sites were selected using two designs. A random tessellation stratified (RTS) design was used to estimate the extent and magnitude of benthic condition in the SCB. The RTS designs are stratified random designs where samples are distributed more evenly across space, avoiding the "clumping" of sites that often occurs in spatially random designs. The RTS design was used to select 351 sites in areas from 3-1000 m deep stratified on habitats and potential sources of pollution. The second design sampled 37 sites at predetermined locations, for other purposes such as assisting scientists to develop assessment tools for benthic macrofauna. At each site, samples were collected with a 0.1m^2 Van Veen grab, sieved through a 1 mm mesh screen, placed in a relaxant solution for at least 30 minutes and fixed in buffered 10% formalin. In the laboratory, samples were sorted into major animal groups and the specimens in each group were identified to the lowest practical taxon, most often species, and counted.

Extensive quality assurance and quality control measures were implemented. Manuals specifying the field, laboratory, and data submission procedures were prepared. All participating vessels and field crews passed audits to ensure they were capable of carrying out the planned fieldwork. Efforts to ensure consistency among the five taxonomic laboratories that processed samples significantly reduced the number of unexpected taxonomic problems in comparison to the 1998 and 1994 regional monitoring efforts. The mean sorting efficiency was 97.7% and quality control reanalysis of 6% of the samples identified mean error rates of 2.0%, 2.7%, and 4.3% in abundance, number of taxa, and identification accuracy, respectively. These results meet or surpass the performance of any other national benthic program that quantifies data quality. This high level of quality assurance is due, in part, to activities of the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) who focused on resolving problems associated with sample processing, taxonomic keys, aids to standardization, and identification of especially difficult taxa.

Assessment tool development was necessary to achieve the benthic regional monitoring program objectives of assessing the extent and magnitude of altered benthic communities. In Bight'03, two assessment tools were used. The first was the Benthic Response Index (BRI) that was developed in 1994 (Smith *et al.* 2001). The BRI is a multivariate measure that was used to assess the mainland and island shelf from 5 to 200 m. The second assessment tool was the SQO26, which was developed for marine bays and estuaries as part of Bight'03. mThe SQO26 is a combination of multivariate and multimetric biointegrity indices that correctly identified benthic condition for 94.3% of the independent samples used for performance evaluation. This performance surpasses the status classification rates achieved by many previous benthic biointegrity index development efforts. Both indices were developed and validated to yield a result on the same four-category response level scale from Reference to Response Level 3; Response Levels 2 and 3 were clear evidence of disturbed benthic communities, while Reference and Response Level 1 were not.

Overall, the SCB benthos were in good condition during 2003. Our estimates indicated that benthic macrofauna in 98.4% of the SCB were in reference condition or deviated only marginally from reference. There was no evidence of disturbance on the island shelf, near small POTWs, and virtually none on the mainland shelf. Areas near large POTWs did not differ substantially from other areas at similar depths on the coastal mainland shelf. Macrofaunal communities in bays and estuaries, on the other hand, were more frequently disturbed. Nearly 13% of the area in these embayments contained clearly disturbed benthos, with the greatest frequency occurring in estuaries and marinas. The most altered benthic communities (Response Level 3) were only observed in bay and estuarine habitats. Benthic communities in poor condition occupied more than half (55.2%) the area of Los Angeles County estuaries, nearly half (42.5%) of other estuaries in southern California, and one quarter (25.0%) of the area in marinas.

The condition of benthos on the SCB mainland shelf is not changing rapidly. Results from the current study in 2003 were similar to the estimates from regional studies in 1994 and 1998. The area of the coastal shelf in poor benthic condition has remained between 1.6 and 2.8% over the 9-year time span. This temporal assessment of benthic condition is limited, however, to the inner and middle coastal shelf strata that were sampled in all three surveys. Trend information for other habitats of interest such as estuaries and the upper slope, which were only sampled in 2003, cannot be assessed at this time.

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I. INTRODUCTION

Benthic macrofauna are often used as indicators of the condition of marine (Pearson and Rosenberg 1978, Smith *et al.* 2001, Borja *et al.* 2003, Ranasinghe *et al.* 2003, Rosenberg *et al.* 2004) and estuarine (Tapp *et al.* 1993, Engle *et al.* 1994, Wilson and Jeffrey 1994, Alden *et al.* 1997, Dauer 1997, Engle and Summers 1999, Van Dolah *et al.* 1999, Paul *et al.* 2001, Llansó *et al.* 2002, Thompson and Lowe 2004) environments. They include a diverse mixture of organisms with a wide range of physiological tolerances, and are well suited for use as indicators because they respond to many different types of environmental stress. Their responses also integrate environmental conditions over time because they have limited mobility and cannot avoid adverse conditions.

Most benthic macrofaunal monitoring in the Southern California Bight (SCB) is conducted to evaluate the effect of discharges from individual sources, such as municipal wastewater outfalls (Stull *et al.* 1986, Zmarzly *et al.* 1994, Diener *et al.* 1995, Dorsey *et al.* 1995, City of San Diego 2006, Los Angeles County Sanitation Districts 2006, Orange County Sanitation District 2006), thermal and industrial outfalls (Barnett *et al.* 1987, Southern California Edison Company 1997), disposal of dredged material and drilling mud (U.S. Environmental Protection Agency 1987), and stormwater runoff (Bay and Schiff 1997, MEC Analytical Systems Inc and Weston Solutions Inc 2005, Weston Solutions Inc 2005). The University of Southern California conducted regional studies between 1956 and 1959 (Allan Hancock Foundation 1959, Barnard and Hartman 1959, Barnard and Ziesenhenne 1960, Stevenson 1961, Allan Hancock Foundation 1965, Jones 1969). However, these data were not used for environmental assessment. The Southern California Coastal Water Research Project (SCCWRP) also conducted regional surveys in 1977, 1985, and 1990 (Word and Mearns 1979, Thompson *et al.* 1987, Thompson *et al.* 1993), but their objective was to describe reference conditions rather than assessing the condition of the entire SCB benthic environment.

The spatial limitations of these programs and the differences in methodology among them are impediments to regional assessments of benthic condition throughout the SCB. They also impede comparisons of local patterns and trends to regional patterns and trends (National Research Council 1990). Regional assessments provide an opportunity to evaluate cumulative effects, particularly effects of episodic and non-point sources that cannot be assessed using local data alone. Regional assessments also provide information that enables managers to make decisions with a broader perspective by comparing the relative importance of different types of pollutant sources and chemicals for the SCB as a whole.

Recognizing the value of regional assessment, 12 agencies joined in a cooperative sampling effort to assess the ecological health of southern California's mainland shelf in the summer of 1994 (Bergen *et al.* 1998, 2000). This regional study, known as the Southern California Bight Pilot Project (SCBPP), yielded several benefits. It enabled scientists and managers to map the extent and assess relative degrees of perturbation at different locations. It also led to standardization of sampling methods when regional monitoring methods were adopted for facility-specific monitoring. Standardization extended beyond data collection to include data management as regional monitoring data were shared among participants. The SCBPP also provided an opportunity for regulators and dischargers to work together to develop assessment tools (Smith *et al.* 2001) for the interpretation of benthic data on regional and local scales.

Based on the success of the 1994 survey, a second cooperative regional survey known as Bight'98 was conducted by 62 organizations in 1998. Bight'98 expanded the spatial scope of the SCBPP in three ways: (1) sampling extended inshore to assess the condition of bays, harbors, and ports; (2) coastal sampling extended southward to include the Mexican mainland shelf as far south as Ensenada; and (3) coastal sampling extended westward to include the SCB island shelf.

Additional assessment tool development was also necessary for Bight'98 because of differences in the species assemblages inhabiting bays. The mainland shelf Benthic Response Index (BRI) developed for the 1994 survey could be used in Bight'98 to assess the Mexican mainland shelf and the SCB island shelf because the species assemblages were similar to the mainland shelf assemblages. However, the bay assemblages were distinct from the shelf fauna (Ranasinghe *et al.* 2003) and an extension of the BRI was developed to assess the condition of bay benthos (Smith *et al.* 2003). Due to data limitations, including a lack of samples from highly stressed bay bottoms, only limited validation of this tool was possible.

A third cooperative survey known as Bight'03 was conducted by 58 organizations in 2003. Bight'03 expanded on Bight'98 in two ways. The sampling effort was extended shoreward to include estuaries (including lagoons), and off the mainland and island shelves down slopes and basins to a depth of 1,000 meters. In addition, samples were collected at several targeted highly polluted sites in an effort to overcome limitations identified during Bight'98 bay index development. Data from these and many other bay and estuary samples were used to refine benthic assessment tools for bays and estuaries in conjunction with the State Water Resources Control Board's efforts to develop Sediment Quality Objectives (Appendix F).

This report describes the benthic macrofaunal studies of the Bight'03 Survey. The objectives of the report are to estimate the extent and magnitude of altered benthic macrofaunal communities in the SCB, and to evaluate whether the extent and magnitude of altered communities vary among geographic regions (Bight'03 Coastal Ecology Committee 2003). Additionally, the availability of data from multiple surveys spaced equally in time over 10 years provided an opportunity for evaluating temporal changes in some habitats.

The report is organized into eight sections and nine appendices. The sections address the objectives of the report. The appendices provide additional detail or describe ancillary studies, including the development of assessment techniques and tools.

Section 2 describes the study design and the field, laboratory, and data analysis methods. Section 3 presents the quality assurance procedures that ensured comparability of data produced by participating organizations and the results of quality control audits measuring their success. Section 4 presents our results and they are discussed in Section 5. Sections 6 and 7 present our conclusions and our recommendations. Section 8 lists the literature cited in the other sections.

Appendix A presents a list of organizations participating in Bight'03. Appendices B thru F contain detailed data and results supplementing Section 4. Appendix B contains detailed maps presenting our assessment of benthic condition at our sampling sites. Appendices C and D present values for several community measures at Bight'03 coastal, and bay and estuary sampling sites, respectively. Appendix E is a list of benthic species collected in Bight'03. Appendix F summarizes information and statistics about benthic communities for undisturbed sites in SCB habitats. These data can be used to provide context to future studies on smaller spatial and temporal scales.

Appendix G documents the performance of the assessment measure developed to assess the benthos of bays and estuaries. Appendix H describes the process based on best professional judgment that was used to evaluate the assessment measures developed in Appendix G.

Appendix I evaluates the cost-effectiveness of subsampling bay and estuarine samples as a first step in modifying sampling techniques in these habitats. Appendix J evaluates the effectiveness of several sediment grain size distribution measures at predicting benthic species distributions.

II. METHODS

This section describes the study design and the field, laboratory, and data analysis methods used to generate benthic data and estimate the extent and magnitude of altered benthic communities in the Southern California Bight (SCB) and selected geographic areas.

Study Design

Benthic samples were collected at 388 sites in the SCB between Point Conception, California and the United States-Mexican border. Eight additional samples were collected but did not meet quality assurance standards for sample processing (Section 3) and were excluded from all counts and calculations.

Sampling sites were selected using two designs: 351 sites in twelve geographic areas of interest were allocated using a random tessellation stratified (RTS) design (Table II-1; Figures II-1 and II-2); 37 nonrandom sites were selected for benthic assessment tool development and other ancillary purposes.

Table II-1. Bight'03 random tessellation stratified samples. Shown are geographic areas of interest (strata), their area, and the numbers of samples that were collected. Samples that failed processing quality assurance are excluded.

Habitat	Stratum	Area (km^2)	Samples
Bays	Estuaries: Los Angeles County	1.5	33
	Estuaries: Other	8.0	26
	Bays: Marinas	17.2	32
	Bays: Other	93.1	26
Coast	Inner Shelf (5-30 m)	1,144.0	27
	Middle Shelf (31-120 m)	1,837.3	32
	Outer Shelf (121-200 m)	592.7	22
	Island Shelf (5-200 m)	2,189.6	32
	Upper Slope (201-500 m)	3,057.6	28
	Lower Slope (501-1000 m)	7,539.9	33
Likely Discharge Influence	POTW: Large	165.5	32
	POTW: Small	28.1	28
Total		**16,674.5**	**351**

Only sites that were selected randomly with the RTS design were used to estimate the condition of the SCB. RTS designs are similar to stratified random designs, but samples are distributed more evenly across strata by subdividing them into hexagons and collecting a sample at a random location in each hexagon (Bergen 1996, Stevens 1997). Imposition of the hexagonal pattern minimizes clustering of the random samples.

Field Methods

Sediment samples for benthic macrofauna analysis were collected from mid July to mid October 2003 with a 0.1 m^2 Van Veen grab and sieved through a 1 mm mesh screen. Only samples penetrating at least 5 cm into the sediment with no evidence of sediment disturbance (e.g., washout or slumping) were processed. Material retained on the screen was placed for at least 30 minutes in a relaxant solution of 1 kg $MgSO_4$ or 30 ml propylene phenoxytol per 20 L of seawater, and then preserved in 10% sodium borate buffered formalin. Additional sediment samples were collected for analysis of sediment contaminants and sediment toxicity; these results are provided elsewhere (Bay *et al.* 2005, Schiff *et al.* 2006).

Laboratory Methods

Samples collected for macrofaunal analysis were distributed to five laboratories for sorting, identification, and enumeration. Samples were rinsed and transferred from formalin to 70% ethanol 3-14 days after collection. Organisms in the samples were sorted into six taxonomic categories (annelids, arthropods, molluscs, ophiuroids, other echinoderms, and other phyla), and sent to experienced taxonomists for species identification and enumeration.

Data Analysis

The primary objective of this report was to assess the extent of SCB area with altered benthic assemblages. "Altered benthic assemblages" differ from expectations for reference assemblages by exhibiting some indication of disturbance, which in turn connotes stress. It is generally recognized that current models of benthic response do not discriminate between anthropogenic and natural sources of disturbance (Borja *et al.* 2003).

The extent of area with benthic assemblages showing clear evidence of disturbance was estimated in two steps. The condition of the benthic assemblage at each site was first assessed using a measure of biointegrity. Then individual site assessments were combined to assess the extent and magnitude of alteration in geographic areas of interest (strata).

Benthic condition at each site was assessed on a four-category scale (Table II-2):

- Reference communities are expected to occur at undisturbed sites.
- At Response Level 1, communities exhibit some indication of stress, but only within the measurement variability of reference condition.
- At Response Level 2, communities exhibit clear evidence of physical, chemical, other anthropogenic, or natural stress.
- At Response Level 3 communities exhibit a high magnitude of stress.

Response Levels 2 and 3 are considered to be clear evidence of disturbed benthic communities ("poor condition") while Reference and Level 1 are not.

Different measures of biointegrity were used to assess coastal sites and sites in bays and estuaries because of ecological and benthic species abundance differences. Coastal sites were assessed with the Benthic Response Index (BRI; Smith *et al.* 2001). The same index was used to assess coastal sites for the 1994 and 1998 regional surveys. The response categories used here correspond to Smith et al. (2001) Response Levels, except that the original Response Levels 3 and 4 were combined into Response Level 3 for this assessment.

Table II-2. Characterization of response categories in coastal and bay habitats. Coastal sites were evaluated using the BRI (Smith *et al.* 2001). Bay and estuary sites were evaluated using the SQO26 index (Appendix G).

Benthic Response Level	Benthic Condition	Coastal Sites	Bay and Estuary Sites
Reference	Good	Reference	Reference
Level 1		Marginal deviation	Low Disturbance
Level 2	Poor	Biodiversity loss	Moderate Disturbance
Level 3		Community function loss or defaunation	High Disturbance

In bays and estuaries, the SQO26 biointegrity index, which is functionally equivalent to the coastal BRI, was used to assess benthic condition at each site. The SQO26 index is a combination of four benthic indices that performed better than any of the individual indices during bay assessment tool development (Appendix G). SQO26 combines the BRI, Relative Benthic Index (RBI), Index of Biotic Integrity (IBI), and a predictive modeling method based on the River Invertebrate Prediction and Classification System (RIVPACS). Each index was developed and validated to yield a result on the same four-category response level scale. The results were combined by expressing the categories numerically, with Reference = 1, Response Level 1 = 2, Response Level 2 = 3, and Response Level 3 = 4 and calculating the median of the four index results. If the median yields a decimal result it is rounded up to the next integer (in a conservative or protective direction). More details about these index approaches and their calibration to southern California bay data are provided in Appendix G.

Table II-3 presents the areas that were assessed for Bight'03 and the numbers of assessment samples collected in 2003. It also includes the numbers of samples collected from equivalent geographic areas and habitats for two previous surveys in 1994 and 1998 that were used for multiple survey comparisons. Although geographic area definitions were not absolutely identical for all three surveys, they were similar and comparable. Due to limitations of the biointegrity measures, it was not possible to assess every sample that was collected. For example, slope and basin samples from strata deeper than 200 m were not assessed because of concerns about potential inaccuracies of the index near the limits of its depth range. Although the BRI was calibrated in 1994 with samples up to 324 m deep, subsequent applications indicated bias toward the extremes of its depth range and we found substantial changes in species composition and abundance at depths of about 200 m (Appendix F) that potentially contribute to the bias. Because of these changes, and because most of the data used to calibrate the BRI were collected at depths <200m, we chose to limit its application to this depth. Estuary and bay samples where bottom water salinity was less than 18 psu were not assessed because the SQO26 was not developed for oligohaline (0.5 to 5 psu) or mesohaline (5 to 18 psu) salinities.

Our estimates of benthic condition were based on response levels at our sampling sites. By virtue of the RTS sampling design, each sample represents a known area, which is called the sample area weight. To obtain the total area at a response level, all the area weights for samples at that response level were summed. The proportion of area at a response level is the response level area divided by the total area. Sample area weights may not be equal throughout a stratum because additional samples may be allocated to facilitate evaluation of small, but important, areas.

Table II-3. Samples used for assessment and temporal comparisons. Shown are designated geographic areas of interest (strata), their area, and the numbers of samples for which benthic assessment data were available. The strata presented are for the 2003 survey. Strata were similar, but not identical between surveys because the sampling design was altered to emphasize different areas.

Habitat	**Stratum**	**Area Assessed (km^2)**	**Samples**		
			1994	1998	2003
Bays	Estuaries: Los Angeles County	1.5			20
	Estuaries: Other	6.0			21
	Bays: Marinas	17.2		39	32
	Bays: Other	93.1		74	26
Coast	Inner Shelf (5-30m)	1,144.0	66	56	27
	Middle Shelf (31-120m)	1,837.3	85	34	32
	Outer Shelf (121-200m)	592.7	36		22
	Island Shelf (5-200m)	2,189.6		53	32
Likely Discharge Influence	POTW: Large	165.5	64	30	32
	POTW: Small	28.1		29	28
Total		6,075.0	251	315	272

For statistical analysis, the four-category results were transformed to binary values by coding Reference and Response Level 1 samples as 0 ("Good Condition"; Table II-2) and Response Level 2 and Response Level 3 samples as 1 ("Poor Condition"). The proportion of area exceeding the good-poor threshold was then calculated as the mean of the scores using Thompson's (1992) ratio estimator:

$$m = \sum_{i=1}^{n} (p_i * w_i) \Big/ \sum_{i=1}^{n} w_i$$

where m is the mean score, p_i is the score at station i, w_i is the area weight for station i, and n is the number of stations sampled. The ratio estimator was used instead of a stratified mean because an unknown fraction of each stratum cannot be sampled (e.g., hard bottom). The estimated area, a random variable, was used as a divisor in place of the unknown true area that can be sampled. The standard error of the mean response was calculated as:

$$s = \sqrt{\sum_{i=1}^{n} ((p_i - m) * w_i)^2 \Big/ (\sum_{i=1}^{n} w_i)^2}$$

The 95% confidence intervals were calculated as 1.96 times the standard error. Use of the ratio estimator for the standard error approximates joint inclusion probabilities among samples and assumes negligible spatial covariance, an assumption that, based on the data, appears to be warranted. The assumption is conservative since violation would lead to an overestimate of the confidence interval (Stevens and Kincaid 1997).

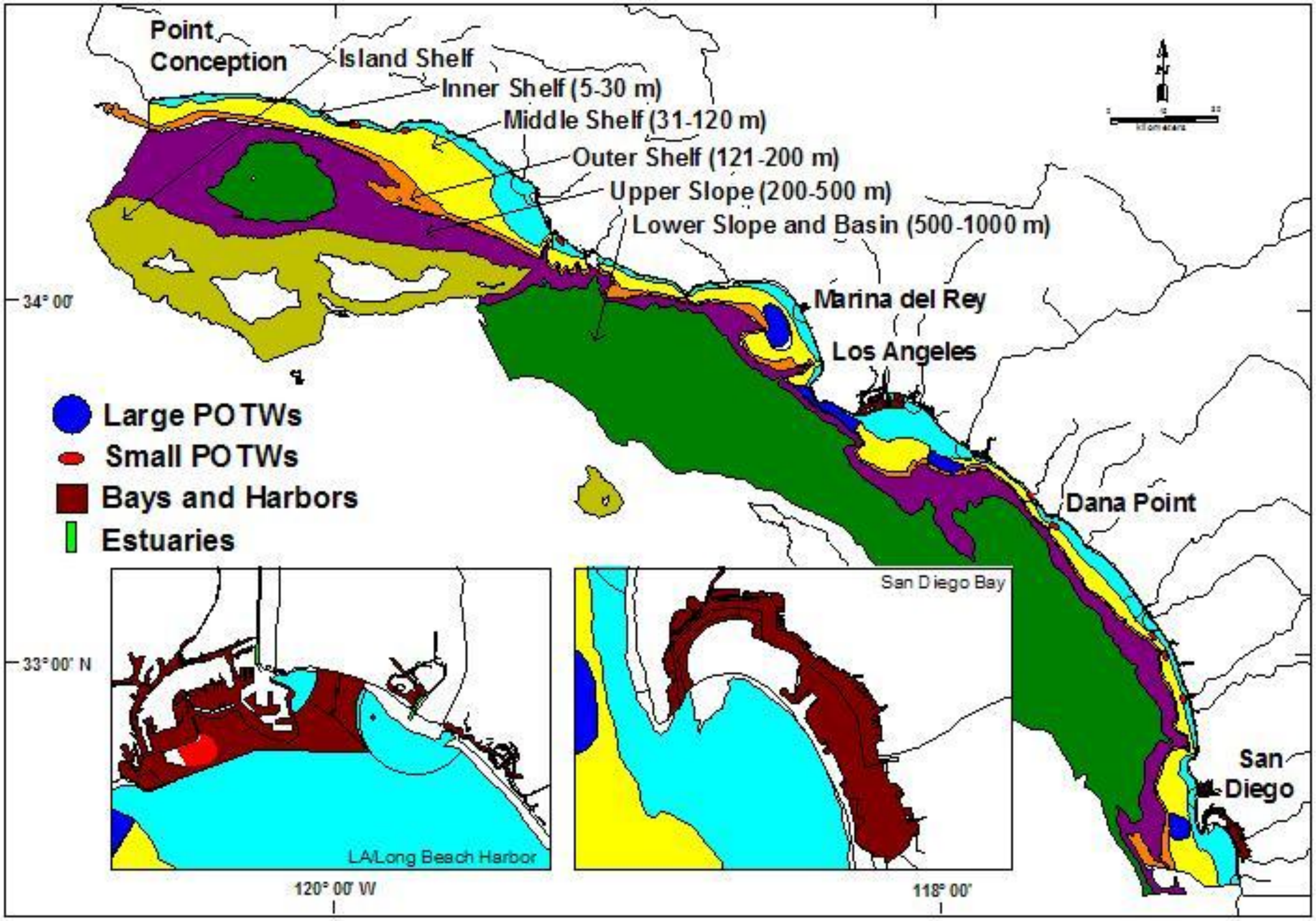

Figure II-1. Geographic areas of interest (strata) for Bight'03. Benthic condition was not assessed in bottoms deeper than 200m (the upper and lower slopes and basins) due to lack of a validated benthic assessment tool.

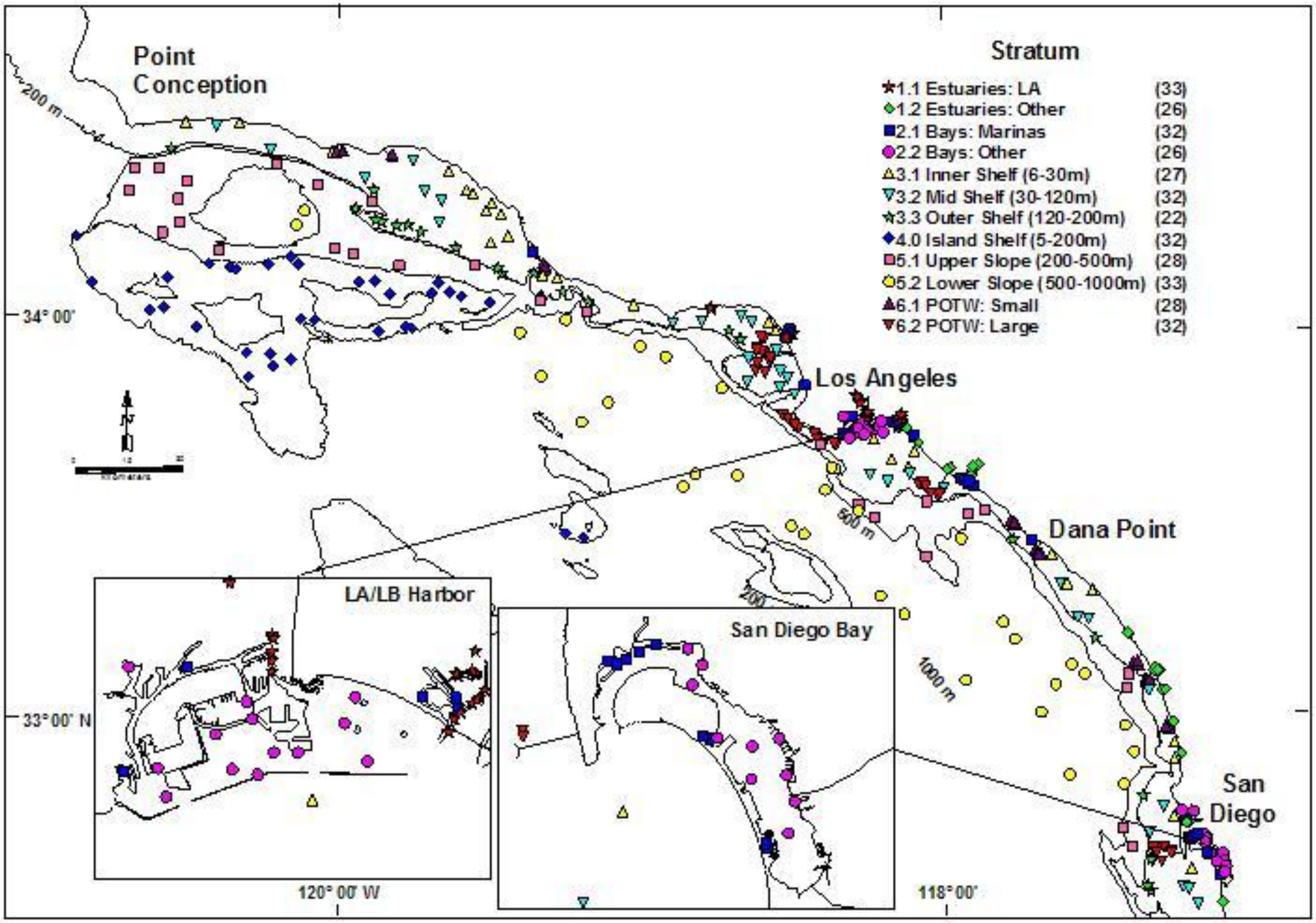

Figure II-2. Locations of random tessalation stratified (RTS) design sampling sites for Bight'03.

III. QUALITY ASSURANCE AND QUALITY CONTROL

Benthic macrofaunal community composition was included in the Bight'03 Coastal Ecology Work Plan (Bight'03 Coastal Ecology Committee 2003) as an indicator of biotic responses in sediments. Measuring community composition entails accurately collecting, identifying, and counting the organisms in samples. This section describes the field and laboratory procedures that ensured the quality of these data and presents the results of quality control audits, inter-team comparisons, and other statistics that document this process. The overall approach was to establish data quality objectives and assessment standards; produce manuals specifying field, laboratory, and data submission procedures; evaluate procedural compliance using field and laboratory audits; and evaluate achievement of data quality objectives using inter-team comparisons and other measures.

Data Objectives

The overall goal of the macrofaunal survey was to provide accurate identifications and counts of all of the benthic invertebrates in the samples within 11 months of sample collection. The identifications were to be as precise as practicable (i.e., to the lowest taxonomic category) with a goal of species-level identification for all specimens whose condition allowed it. The level of precision was driven by the analytical uses of the data, which included description of assemblages, and the development and application of assessment indices that depend on the distribution of species along pollution gradients.

To achieve this goal, measurement quality objectives (MQOs) were specified for several measurements and processes (Table III-1) in the Work Plan (Bight'03 Coastal Ecology Committee 2003). An MQO specifies the acceptable level of uncertainty for each measurement or process and is based on assessment standards developed in the Bight'03 Coastal Ecology Work Plan.

Table III-1. Measurement quality objectives for benthic macrofaunal sample collection and processing. NA: not applicable.

Activity	Accuracy	Precision	Completeness
Sample Collection	NA	NA	90%; 30 per stratum
Station Occupation	Within 100 m*	NA	NA
Sorting	5%	NA	90%
Total Abundance	10%	NA	90%
Number of Taxa	10%	NA	90%
Identification	10%	NA	90%

* within 200 m for Island sites

Field and Laboratory Manuals

As part of the planning effort, manuals were developed that specified procedures to be used for field sampling (Bight'03 Field Sampling & Logistics Committee 2003) and laboratory activities affecting benthic invertebrate samples (Bight'03 Benthic Committee 2003). These manuals were designed to produce consistency in the collection, handling, and processing of samples in order to meet Bight'03 survey goals, MQOs, and sample processing timelines.

An Information Management Plan (Bight'03 Information Management Committee 1998) imposed data reporting standards and data screening procedures to ensure that inconsistencies were not introduced as a result of differences in the manner in which species data were reported. The plan included formats and specifications for data submissions that were referenced in the laboratory manual. This plan also included provisions for electronic submission of species data that imposed automated error checking and reporting routines

Sample Collection

Prior to sampling, participating vessels were inspected and field crews audited to ensure that they were properly equipped and trained. Experienced biologists familiar with the sampling techniques conducted the audits. All vessels and field crews successfully passed the audits.

A total of 396 benthic macrofaunal grab samples were collected of which 359 were from the twelve random tessellation stratified assessment strata. The remaining 37 samples were collected from non-randomly selected sites for the purposes of benthic assessment tool development. The overall rate of successful sample collection (i.e., a station was occupied and grab samples successfully collected) was 80% (Table III-2), failing the MQO by 10%. As was the case in Bight'98, the island shelf was the most difficult habitat in which to collect grab samples, with only 53% of the attempts to occupy a site resulting in success. The most frequent cause of sampling failure was the presence of rocky bottom that is more prevalent on the insular shelf than in the other habitats sampled. The next lowest rate of success (64%) was within the estuary habitat where the leading causes of failure were salinity falling below the lower limit of 19 ppt stipulated in the sampling plan and difficulty accessing sampling sites due to inaccuracies in the GIS layer used to select sites.

Table III-2. Sample collection success by habitat.

Habitat	Occupation Attempts	Successful	Success Rate (%)
Estuaries	94	60	63.8
Bays	89	79	88.8
Island Shelf	60	32	53.3
Mainland Shelf	181	159	87.8
Upper Slope	31	28	90.3
Lower Slope & Basin	39	38	97.1
Total	**494**	**396**	**80.2**

Within each random tessellation stratified assessment stratum, the MQO was to collect 30 samples. We failed to meet the MQO in six of the twelve strata (Table III-3), lowering the precision of the estimates of areal extent below the intended 90% confidence interval of ±10%. For two strata (Bays, Other and Mainland Shelf, Deep), the completeness was further reduced as a result of sample sorting QC failures discussed below.

Table III-3. Stratum completeness by habitat.

Habitat	Stratum	# Samples collected
Estuaries	LA County	33
	Other	26
Bays	Marinas	32
	Other	28
Island Shelf	5-200 m	32
	Shallow (5-30 m)	27
Mainland Shelf	Mid (30-120)	32
	Deep (120-200 m)	27
Upper Slope	200-500 m	28
Lower Slope & Basin	500-1000 m	33
POTW	Small	28
	Large	33
Total		**359**

Station Occupation

The MQO for station occupation accuracy was achieved for 91% of the stations (Table III-4). Success rates were highest in bays and on the upper slope (100%) and lowest (15%) in the Basin. The poor performance in station occupancy in the Basin habitat was primarily the relatively greater depth range involved (500 to 1000 m), which results in very long wire-time during which maintaining station is difficult. The presumed uniformity of habitat conditions within the basin makes this failure less of a concern than within shallower habitats.

Table III-4. Station occupation accuracy by habitat.

Habitat	Sites	Distance from Nominal Location (m)					
		<=100 m	100-200 m	> 200 m	Maximum	Minimum	Mean
Estuaries	60	60	0	0	100	<1	36.3
Bays	79	76	2	1	224	<1	31.8
Island Shelf *	32	26	6	0	0	<1	63.8
Mainland Shelf	159	156	3	0	111	<1	32.4
Upper Slope	28	28	0	0	98	10	62.7
Lower Slope & Basin *	38	10	10	18	1175	1	234.9
Total	**396**	**356**	**21**	**19**	**1175**	**<1**	**57.0**

* Two Island Shelf sites and one Basin site with reported distances of >1.5 KM were assumed to be transcription errors. The mean accuracy within the stratum was assigned

Other Field Operational Guidelines

The Bight'03 Field Operations Manual required field crews to comply with several other operational guidelines to assure that the benthic samples were of consistent and high quality. All samples were to be collected during the index period of July 14 through September 5. Sixteen of 396 samples, fifteen within the LA County Estuary stratum, were collected beyond the closing date of the index period. The difficulty of sampling within the estuaries required that additional random sites be drawn at the end of the index period in order to collect a sufficient number of samples. The last sample collected was on October 16, 2003. All samples were to be collected between sunrise and sunset. With the exception of the Lower Slope and Basin stratum, where ship availability required 24-hour operations, only two samples were collected late but within 35 minutes of sunset. All samples met the grab acceptability requirements of minimum penetration (>5cm) and surface sediment disturbance. For random tessellation stratified samples, several strata were defined by depth criteria. All samples within these strata met the depth criterion with exception of one counterbalancing failure that had no net effect on stratum completeness (table III-5).

Table III-5. Compliance with stratum depth criterion.

Habitat	Stratum	Criterion (m)	# Samples collected	# Met Criterion	% Performance
Island Shelf	Island Shelf	5-200	32	32	100
	Shallow	5-30	27	27	100
Mainland Shelf	Mid	30-120	32	31*	97
	Deep	120-200	27	26*	96
Slope & Basin	Upper Slope	200-500	28	28	100
	Lower slope & Basin	500-1000	33	33	100

* Counter-balancing failure

Ten research vessels and sampling teams participated in collecting benthic samples during Bight'03. Each crew was responsible for submitting all field records related to the collection of benthic grabs within three months of the close of the index period. These records include two data types: station occupation and grab event data. Five of the ten teams submitted their field data on time. The last field data submission was two months after the deadline.

Sorting

Five laboratories sorted all samples that were collected and conducted re-sorts as specified in the laboratory manual (Table III-6). Ten percent of the residue was re-sorted to verify that the MQO of 5% (i.e., removal of at least 95% of the specimens) was achieved. One of two methods was used. In the aliquot method, 10% of the material of every sample was re-sorted. In the whole sample method, 10% of the samples sorted by each individual were re-sorted in their entirety.

Table III-6. Sample sorting and re-sorting by participating laboratories.

Laboratory	Samples Assigned	Aliquot Method		Whole Sample Method			Completeness %
		# Required	# Re-sorted	# of Sorters	# Required	# Re-sorted	
A	38	-	-	7	7	38	100
B	60	60	52				86*
C	62	-	-	6	9	9	100
D	172	172	172	-	-	-	100
E	64	64	64	9	12	15	100
Total	**396**						**100**

* Eight samples were disposed of after sorting without going through the required quality controls

One laboratory disposed of eight samples after sorting without performing the required quality control. Because it was impossible to determine whether these eight samples met the MQO, the data from those samples was excluded from the final data set and subsequent analyses, reducing the total number of sites collected for purposes of assessment to 351. This loss lowered completeness on three strata (Table III-7), two of which (Bays, Other and Mainland Shelf, Deep), were below the MQO of 30 samples per stratum. The other affected stratum (POTW, Large) met the completeness MQO despite the loss of one sample.

Table III-7. Affect of sorting QC failures on stratum completeness.

Habitat	Stratum	# Samples collected	# Failed Sorting QC	# Samples Accepted
Bays	Other	28	2	26
Mainland Shelf	Deep (120-200 m)	27	5	22
POTW	Large	33	1	32

The sorting efficiency of each of the five laboratories met or exceeded the MQO of 95% (Table III-8). The overall mean sorting efficiency was 97.7.

Table III-8. Sorting efficiency. MQO of 5% expressed as 95% removal.

Laboratory	Sorting Efficiency (%)			MQO (%)
	Low	High	Mean	
A	97.1	100	98.9	95.0
B	95.0	100	95.8 *	95.0
C	95.0	100	97.8	95.0
D	95.0	100	97.1	95.0
E	95.9	100	98.9	95.0
Total	**95.6**	**100**	**97.7**	**95.0**

* Efficiency based upon results from 52 of 60 samples sorted. Eight samples were disposed after sorting of without going through required quality control.

Identification and Enumeration

The goal of the macrofaunal survey was to identify all benthic invertebrates contained in samples to species level and count them. Several obstacles made the description of this task much simpler than its execution. First, macrofaunal communities are very complex, comprising hundreds to thousands of individuals from many different taxa. A recent listing of benthic invertebrates from the SCB continental shelf and slope contains over 2000 species from 15 phyla and 47 classes (Southern California Association of Marine Invertebrate Taxonomists 2001). Second, many of these species are poorly known, and our appreciation of their diversity is limited. Nine percent of the species in the SCAMIT listing have not been formally described. In the Bight'03 survey, 13% of the reported species were undescribed. This state of knowledge contributes to variation in the results related to the taxonomists identifying the specimens. Because of differences in opinion and experience, different taxonomists produce slightly varying accounts of the taxa present in samples of identical composition (Ranasinghe *et al.* 2003). The condition of specimens may be a third obstacle. Specimens are frequently damaged during sampling, increasing the difficulty of recognition. In some cases, the lack of knowledge of ontogenetic effects on morphology prevents species-level identification of juveniles. All of these factors lead to inconsistencies in the reported abundances of individual taxa.

Several steps were taken to mitigate the effects of these obstacles on data quality. They were considered necessary because 21 taxonomists in nine different teams identified organisms in the samples; each team included taxonomists capable of identifying all taxa likely to occur.

First, single "specialty" taxonomists identified three taxonomic groups (anthozoans, platyhelminths and aplacophorans) that were inconsistently identified in a previous survey. By relying on a single taxonomist, we sought to eliminate inconsistencies introduced by multiple taxonomists. Second, communication among the taxonomic teams was facilitated by an email list-server dedicated to this purpose. Messages posted to the list-server were posted to all participating taxonomists. They used the system to alert each other of unusual or newly encountered species, circulate descriptions of provisional taxa and request information and assistance. Approximately 270 messages were posted to this list server during the course of sample processing

The Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) also helped by focusing activities on Bight'03 needs. SCAMIT is an organization that promotes the study of marine invertebrate taxonomy in Southern California and standardizes regional taxonomic nomenclature. All Bight'03 taxonomists are members of SCAMIT. In the months prior to Bight'03, SCAMIT focused its efforts on anticipated taxonomic problems based on problems encountered in the previous survey. During sample processing, SCAMIT increased the frequency of meetings and dedicated them to Bight'03 issues. During the 13 months it took to process samples, SCAMIT organized eight meetings for participating taxonomists.

While the goal of the study was to identify all organisms to species, only 76% of the specimens were identified to this level (Table III-9). The dominance of two supra-specific taxa in the estuary habitat was an important contributor to that rate. *Capitella capitata* complex, a group of undifferentiated sibling species, and unidentified oligochaetes were among the community dominants in the estuaries. These two taxa were 20 and 10 times more abundant in the estuary samples than in all other samples combined. Overall, the primary cause of failure to achieve species-level identification was the condition of specimens, which accounted for over 87% of the higher taxon identifications (Table III-10). The remaining 12.9% were the result of insufficient taxonomic knowledge to discriminate species.

Table III-9. Success at species-level identification. Of 1,664 taxa reported, 1,269 (76.3%) were at species level.

Habitat	Number of Organisms	Species-level Identification	
		N	%
Estuaries	106,467	69,643	65.4
Bays	69,234	58,898	85.1
Island Shelf	16,135	12,942	80.2
Mainland Shelf	50,775	41,707	82.1
Upper Slope	1,719	1,442	83.9
Lower Slope & Basin	1,488	1,221	82.1
Total	**245,818**	**185,853**	**75.6**

Table III-10. Reasons for failure to achieve species-level identifications.

Reason		Proportion (%)
	Condition of Specimens	87.1
Lack of Taxonomic Knowledge	Bight'03 rules stipulated identification at a higher taxonomic level (e.g., oligochaeta)	5.0
	Regionally recognized species complexes	6.4
	Other problems discovered during synoptic data review	1.5

Data Submission and Time Line

Upon completion of sample processing, each team submitted results in formats stipulated in the Bight'03 Information Management Plan. The results were combined into a single database. Data submission took two months longer than the original deadline of 11 months after sample collection established in the Coastal Ecology Work Plan but was considerably more rapid than in Bight'98 (24 months). For the first time, a web-based data submission tool was used for benthic data submission. This tool enforced compliance with data table structures and rules as well as screening all taxa names for conformance with nomenclature standards. This approach was highly successful, eliminating any violations of data table structures and rules and reducing errors in the submitted taxa names by 66% over previous regional surveys. Correction of the remaining nomenclatural errors was accomplished in hours rather than days, as had been the experience in the Bight'98 survey.

Synoptic Data Review

After data from all of the teams were combined into a single data set, Bight'03 taxonomists conducted a synoptic data review. The goal of the review was to produce final data that were as consistent and free of taxonomic errors as possible. To achieve this, the data were presented in a form that facilitated the discovery of inconsistencies in taxonomy. Potential inconsistencies were identified, discussed, and resolved. Decisions resolving the inconsistencies were applied to the submitted data to produce the final data set.

The synoptic data review resulted in a number of changes that improved consistency of nomenclature and reduced variation in identification level. Most changes combined taxa to a higher taxonomic category. In some cases, species reporting patterns suggested an uneven distribution of knowledge among the taxonomists (Table III-11). Others turned on specimen condition and were “smoothed” by lumping to a single taxon name. Other changes corrected violations of identification rules such as the inclusion of pelagic species or specimen fragments. Taxon names in approximately 5% of the data base records were changed after the synoptic data review. Data base records are unique for each species-site combination; they store names and abundances for each species collected at each site.

Table III-11. Changes in levels of identification after the synoptic data review. Changes indicate persisting regional taxonomic problems.

Group	Name Adopted After Synoptic Data Review	Level	Number of Taxa Combined
PHYLUM NEMERTEA			
Class Anopla	Palaeonemertea	Order	3
Order Heteronemertea	Lineidae	Family	8
Class Enopla			
Order Hoplonematerea	*Amphiporus* spp.	Genus	4
PHYLUM MOLLUSCA			
Class Gastropoda,			
Order Neotaenioglossa	*Lirobittium* spp.	Genus	3
Order Heterostropha	*Turbonilla* spp.	Genus	4+
Class Bivalvia			
Order Veneroida	*Protothaca* spp.	Genus	2
PHYLUM ANNELIDA			
Class Polychaeta			
Order Spionida	*Cirratulus* spp.	Genus	2
Order Phyllodocida	*Aphrodita* spp.	Genus	3
	Dorvillea (S.) spp.	Genus	2
Order Eunicida	*Driloneries* spp.	Genus	3
	Mooreonuphis spp.	Genus	3
PHYLUM ARTHROPODA			
Class Malacostraca			
Order Amphipoda	Corophiidae	Family	3
PHYLUM PHORONA			
Order Phoronida	Phoronida	Order	2+

Sample Reanalysis to Assess Data Quality

To evaluate success at meeting identification and enumeration objectives and to assess data quality, a subset of samples was re-analyzed. For this evaluation, 10% of the samples analyzed by each team, selected at random, were distributed to other teams for reanalysis. Taxonomists performing reanalysis had no access to original analysis results. When reanalysis was complete, the original and reanalysis data were compared and a list of discrepancies was compiled. Discrepancies were classified as errors when they were caused by inaccurate identifications, incorrect counts, or specimens overlooked in the original analysis. They were classified as differences, rather than errors, when they resulted from the use of a junior synonym or other unconventional nomenclature, apparent specimen loss, or differences of opinion about the taxonomic level to which an organism could be identified (e.g., *Ampelisca* sp. vs. *Ampelisca lobata*). Error rates for each sample were calculated as ratios of the difference between the original and resolved values to resolved values. The resolved values represented the “truth” by consensus among the original and reanalysis taxonomists. These error rates were used to assess data quality relative to the MQOs.

Re-analysis results are available for only 27 samples and for four of the five laboratories (eight of the nine teams) providing identifications. Thirty-eight samples were selected, distributed, and re-analyzed, but inadequate documentation of results prevented the use of the information from eleven samples. The 27 samples amounted to 7% of the 391 samples analyzed by the taxonomic teams participating in re-analysis. These 27 samples included 1,429 data records or 7.5% of the 19,149 records produced by the eight teams and 6.1% of the records in the final data set.

The average performance of each assessed lab met the MQO for all three metrics (Table III-12). However, two of the labs failed to achieve at least one of their objectives in two of their samples.

Table III-12. Means (and ranges) of error rates for total abundance, numbers of taxa, and identification accuracy.

Lab	Number of Samples		Error Rate (%)		
	Plan	Actual	Total Abundance	Number of Taxa	Identification Accuracy
A	4	4	0.6 (0-1.9)	2.7 (0 – 4.5)	6.0 (3 – 7.7)
B	6	6	5.7 (2.0 – 16.1)	5.5 (3.3 – 10.3)	4.7 (2.0 – 9.2)
C	3	3	1.7 (0.8-3.0)	2.8 (0.9 – 5.6)	5.5 (5.4 – 5.6)
D	18	14	0.9 (0 – 4.1)	1.4 (0 – 5.1)	3.5 (0 – 17.9)
E	7	0	-	-	-
All	**38**	**27**	**2.0 (0 – 16.1)**	**2.7 (0 – 10.3)**	**4.3 (0 – 17.9)**

Discussion

The challenge of producing an accurate and internally consistent description of the species composition of benthic macrofaunal communities over a wide range of habitats and depths was considerable. The necessity of relying on a large number of taxonomists added to the complexity of the task. However, measures to coordinate and standardize taxonomic practices can effectively meet these challenges.

In this survey, we provided species-level identifications for 76% of the specimens collected. As discussed above, the high abundance of two groups of species, *Capitella capitata* complex and oligochaeta, account for the significantly lower performance (65%) in samples from the estuary habitat. With these exceptions, species-level identification within the estuary habitat was 83%, comparable to other habitats and similar to that achieved in the two previous regional surveys (81-82%). The consistency of this performance is in part related to the fact that 15 of the 21 taxonomists involved have worked on all three regional surveys.

In Bight'03, one-quarter fewer taxa (42) posed unexpected problems than in the Bight'98 survey (57) and three-quarters fewer than SCBPP survey (169). There were two reasons for this continued improvement. SCAMIT has continued to use problems discovered in the Bight surveys to focus its activities in the period between the surveys. Keys and other identification aids were produced for many problem taxa, facilitating consistent treatment in the Bight'03 survey. Second, as in Bight'98, we used specialty taxonomists for three groups that presented obstacles to consistent treatment despite these efforts at standardization. The specialty taxonomist treatment of the anthozoans, platyhelminths and aplacophorans separated 57 taxa that were anticipated to present special challenges regionally.

While the MQOs were met on average, a small number of failures occurred in all three identification metrics. Most failures resulted from overlooked specimens, suggesting insufficient care during sample analysis. The ability of most teams to achieve MQOs, as well as their performance in the Bight'03 and SCBPP surveys, indicates that the MQOs are reasonable and achievable.

Another area in which performance can be improved is in the conduct of our data quality assessment re-analysis. As in Bight'98, this process was hampered by inadequacy of the record keeping, this time for 11 of 38 samples. The sample reanalysis, discrepancy tabulation and resolution are unavoidably complex activities and typically beyond the scope of the normal sample processing practices of the participating laboratories. In addition, the dispersion of taxonomists geographically across southern California complicates communication and is a barrier to centralized and uniform data recording and record keeping that would greatly facilitate this process. The fact that this is the second survey in which record keeping related to sample re-analysis has prevented the desired level of data quality assessment suggests that a revision to the procedures is needed. The nature of the failures further suggests that such a revision should focus on centralizing the quality assessment effort around a dedicated team to simplifying the redistribution of samples and promoting more uniform record keeping.

While we were unable to conduct the level of data quality assessment that we had intended, a more serious failure was the loss of data from eight samples for failure to carry out the required quality control measures for sample sorting. Because sorting is fundamental to the ultimate utility of the resulting data, it is essential that that step be subject to strict controls. The loss of these eight samples lowered the level of precision in the estimates of condition in two strata and prevents integration of biology with chemistry and toxicity data from these individual sites. As a matter of good laboratory practice and to avoid similar failures in the future, it is essential that the failing laboratory examine their practices and take corrective action.

Logistical Recommendations

Our results demonstrate that Bight'03 data are of very high quality. In addition there were several substantial improvements in data processing and submission that shortened the time between field sampling and final data submission. However, there are still challenges evident in our failure to meet our stratum completeness goals, major time lines, quality controls related to sorting, and completeness of quality assessment activities. Performance to achieve these goals can be improved by implementing the following recommendations in future regional surveys. The fact that many of these recommendations are similar to those made in the Bight'98 final report demonstrates that these are persistent problems that require attention early in the planning process for future regional surveys.

1. **Keep better records about sampling design and implementation.** While improvements were achieved in Bight'03 over the previous two regional surveys, information about the criteria used to define strata and details of nominal station selection and allocation were not readily available to resolve discrepancies identified during data analysis. Efforts should be made to institutionalize this information for easy retrieval during data analysis even if data analysis occurs several years after sample collection.

2. **Further shorten the timeline for submission and quality control of field data.** Station occupation data was submitted in a more timely fashion in Bight'03 than in previous

regional surveys, but there is still a need to improve in this regard. The use of a computer application for the capture of station occupation and sampling event information should be mandatory. In those cases where such a system was not used, field data submission was slower and errors, particularly in recording of latitude and longitude, were more frequent. Mandatory use will require that the software program be developed, tested and deployed well in advance of the index period, a schedule that has proven difficult in the past.

3. **Shorten the analysis timeline.** Efforts should be made to shorten the time interval between sample collection and data submission and to synchronize activity across teams with respect to sample processing. Competing priorities for some of the participating teams resulted in delays during Bight'98 and again in Bight'03. Because several steps in the production of a final data set require completion of sample processing and data submissions by all teams, delays by one team affect the others. The resulting periods of unplanned inactivity exacerbate scheduling and management problems for all teams. This same recommendation accompanied the Bight'98 Benthic report. Significant progress was made (initial data submissions in 13 vs. 24 months) but the quality assessment activities continue to be protracted, contributing to breakdowns in the process.

4. **Continue using regional survey results to focus SCAMIT activities**. The reduction in taxa lumped due to unshared taxonomic knowledge is directly attributable to SCAMIT activities in the years between the Bight'03 and Bight'98. These efforts drew upon the results of our QC efforts in the previous regional surveys. This model should be pursued in the future. Supporting and promoting active participation in SCAMIT by taxonomists within the region will continue to be essential to the success of future surveys.

5. **Continue using specialty taxonomists.** Taxonomic specialization should continue as a means of ensuring consistent treatment of problematic groups. The present practice of producing diagnostic keys and presenting them at SCAMIT meetings to facilitate consistent treatment by other taxonomists in the future should also continue. Because of their dominance and potential importance to the assessing the biointegrity of estuarine sites, consideration should be given to employing this approach in the identification of oligochaetes.

6. **Revise the sample re-analysis data assessment procedure.** The continued failure to achieve the intended level of data quality assessment by means of sample re-analysis suggests that the process as currently implemented is too complicated and difficult. A reconsideration of the procedures focused on centralizing the role of re-analytical lab, discrepancy tabulation and resolution around a single team should be considered.

7. **Establish data formats and controls for sediment grain size distribution data.** While improvements over Bight'98 were realized, this recommendation is repeated, as there are still problems. The uncertainty about the existence of gravel data experienced in Bight’98 for specific samples was repeated. Because sediment grain size distribution information is important for interpreting sediment chemistry and benthic macrofauna

data, it would be useful to establish procedures to acquire data more directly and reduce uncertainty about the presence of gravel.

8. **Enforce relational integrity for sample location and date information between data tables.** As in Bight'98, there was some confusion during data analysis because sampling dates in the station occupation, grab event, and benthic macrofauna data tables did not match. The confusion would have been avoided if the information management system forced relational integrity for site identification and date information between the tables.

IV. ASSESSMENT RESULTS

The purpose of this section is to assess the extent and magnitude of ecological habitat alteration in the Southern California Bight (SCB). Benthic condition is widely used as an indicator of alterations to biological responses due to disturbances of sediments, including those caused by chemical contamination. We evaluated benthic condition for the region at two temporal scales, first assessing the areas we sampled in 2003 for Bight'03 and then, where data were available, including comparable areas from Bight'03 and two previous regional monitoring efforts in 1994 and 1998 in a second assessment. Evaluations were conducted at three spatial scales: (a) the entire SCB, (b) geographic areas of interest (i.e., strata; Table II-3) individually, and (c) collectively as coastal or bay and estuary habitats.

The extent of area with benthic assemblages showing clear evidence of disturbance was estimated in two steps. The condition of the benthic assemblage at each site was first assessed using a measure of biointegrity. Individual site assessments in geographic areas of interest (strata) were then combined to assess the extent and magnitude of alteration.

Benthic condition at a site was assessed on a four-category scale: Reference and Response Levels 1, 2 and 3 (Table II-2). A Reference community is expected to occur at undisturbed reference sites. At Response Level 1, a community exhibits some indication of stress, but only within the measurement variability of reference condition. At Response Level 2, a community exhibits clear evidence of physical, chemical, other anthropogenic, or natural stress. Communities at Response Level 3 exhibit a high magnitude of stress. Level 2 and Level 3 are considered to be clear evidence of disturbed benthic communities in “poor condition” while Reference and Level 1 are not; they are considered “good condition.” More details about our methods are provided in Section 2.

Bight'03

We estimated that 5975 km^2 (98.4%) of the 6075 km^2 area sampled were in good condition in 2003 (Figure IV-1). The balance, 100km^2 (1.6%) were in poor condition, with clear evidence of disturbance. Of the area in good condition, 5409 km^2 (89.0%) were in Reference Condition and 566 km^2 (9.3%) were at Response Level 1, which is not considered clear evidence of disturbance. Benthic condition at individual sampling sites is presented in Figure IV-2 and Appendices B, C and D.

Of the habitats sampled in 2003, the island and middle shelf strata were in the best state, with all sites in Reference condition and no evidence of disturbance (Table IV-1; Figure IV-3). The outer mainland shelf and areas surrounding large and small Publicly Owned Treatment Works (POTWs) also showed no clear evidence of disturbance, although 13.6%, 21.9%, and 10.7% of these strata, respectively, were estimated at Response Level 1. Most (92.6%) of the inner mainland shelf was also in good condition but 7.4% was classified in poor condition at Response Level 2 indicating a loss of biodiversity. None of the sites sampled on the coastal shelf or slope habitats were classified at Response Level 3.

Table IV-1. Benthic condition of strata sampled in 2003 as the percentage of the area at each benthic community Response Level. Response Levels 2 and 3 are considered to be clear evidence of disturbed benthic communities in "poor condition" while Reference and Level 1 are not. Detailed Response Level definitions are provided in Table II-2. POTW-L: Large (>100 mgd) Publicly Owned Treatment Works; POTW-S: Small (<100 mgd) Publicly Owned Treatment Works.

Stratum	Area (km^2)	Response (Percent of area)			
		Reference	Level 1	Level 2	Level 3
Middle shelf	1,837.3	100.0	0.0	0.0	0.0
Island shelf	2,189.6	100.0	0.0	0.0	0.0
Outer shelf	592.7	86.4	13.6	0.0	0.0
POTW-L	165.5	78.1	21.9	0.0	0.0
POTW-S	28.1	89.3	10.7	0.0	0.0
Inner shelf	1,144.0	59.3	33.3	7.4	0.0
Other (non-marina) bays	93.1	34.6	57.7	3.8	3.8
Marinas	17.2	31.3	43.8	21.9	3.1
Other (non-LA county) estuaries	6.0	7.0	50.5	34.1	8.4
Los Angeles County Estuaries	1.5	12.8	32.0	50.5	4.8

Of the strata sampled in 2003, bays and estuaries were in the worst condition both collectively (Figure IV-3) and individually (Table IV-1; Figure IV-4). The most severely altered benthic communities (Response Level 3) occurred only in these habitats. Collectively, 12.6% of the area sampled in the southern California bays and estuaries showed clear evidence of disturbance (Figure IV-3). Larger proportions of estuaries were disturbed than marinas or other bays (Figure IV-4), with about half of these areas in poor condition. The Los Angeles (LA) County estuaries and the estuaries in other counties combined (i.e., Orange County, San Diego County) had 55% and 43% of their area, respectively, classified as clearly disturbed. It is noteworthy that 3 of 3 samples taken in the Dominguez Channel and 3 of 4 samples in Agua Hedionda Lagoon were clearly disturbed as were 5 of 6 samples taken from the San Gabriel Estuary. The remaining samples that indicated poor benthic condition were distributed throughout the other estuaries without pattern.

In contrast to estuaries and lagoons, 25.0% of the marina areas were clearly disturbed, while the other bay habitats (bays other than marinas) were less affected with only 7.7% of the area clearly disturbed. In total, 14.8 km^2 out of a total of 117.8 km^2 of the bay and estuarine areas (12.6%) were in poor condition.

Temporal Comparisons

The availability of data from multiple surveys over nine years provided an opportunity for evaluating temporal changes in some habitats. In addition to the Bight'03 samples collected in 2003, the Southern California Bight Pilot Project (SCBPP) collected samples in 1994 and Bight'98 sampled in 1998. Temporal comparisons were restricted to areas that were sampled in multiple surveys. Only the inner and middle mainland shelf (to a depth of 120 m) were sampled for all three surveys (Table II-3). The outer mainland and island shelves and the bays (but not estuaries) were sampled twice. Similar RTS sampling designs were used for all three surveys.

The proportion of undisturbed area in good condition on the SCB inner and middle mainland shelf decreased from 98.4% in 1994 to 97.6% in 1998 and 97.2% in 2003 (Figure IV-5), although these changes were not statistically significant. The area in Reference condition decreased from 89.7% in 1994 to 84.0% in 1998 and 83.4% in 2003. Most of this change from Reference was to Response Level 1, which increased from 8.6% in 1994 to 13.6% and 13.8% in 1998 and 2003, respectively. Response Level 1 is not considered to be clear evidence of disturbed benthic communities.

Alteration at the most severe level, Response Level 3, was not observed anywhere on the coastal shelf during any of the regional surveys (Figure IV-6). The proportion of area in good condition tended to increase over time on the middle and outer mainland shelf and in areas influenced by large POTW discharges. The proportion of area in good condition on the island shelf and areas under the influence of small POTW discharges apparently remained unchanged. Only the inner shelf stratum tended to show a decline in the proportion of area in good condition.

In the bay areas sampled in both 1998 and 2003, areas in good condition increased slightly, without statistical significance, in both marinas and other bays (Figure IV-7). The percentage of area in poorest condition (Response Level 3) tended to decrease in marinas, but remained about the same in other bays.

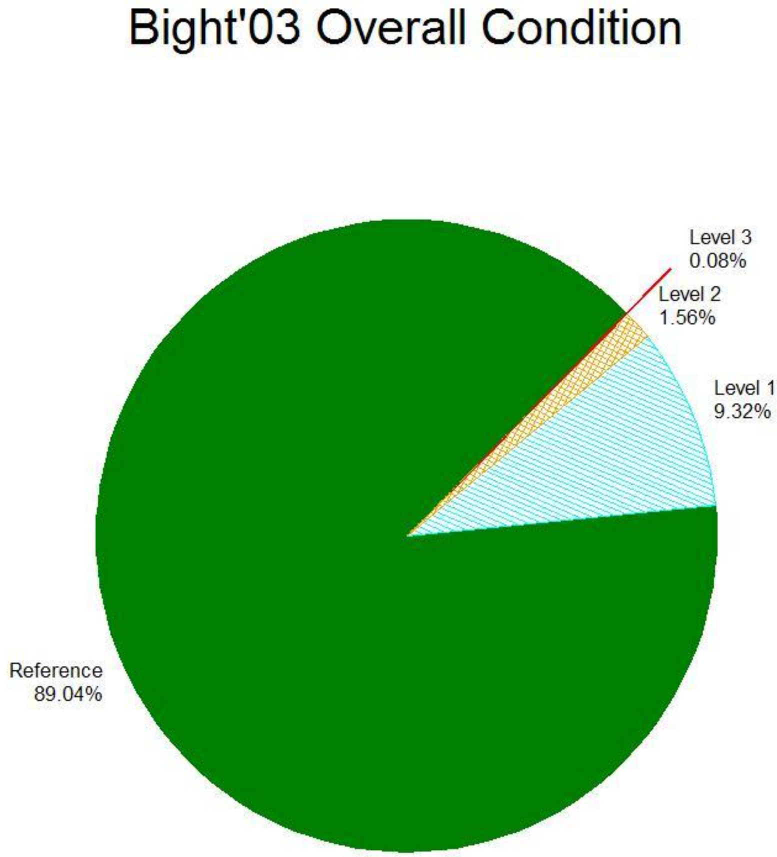

Figure IV-1. Estimate of benthic condition for the area of the Southern California Bight sampled for Bight'03 in 2003. Response Level 2 and Response Level 3 are considered clear evidence of disturbed benthic communities. See Table II-2 for a detailed description of benthic condition categories.

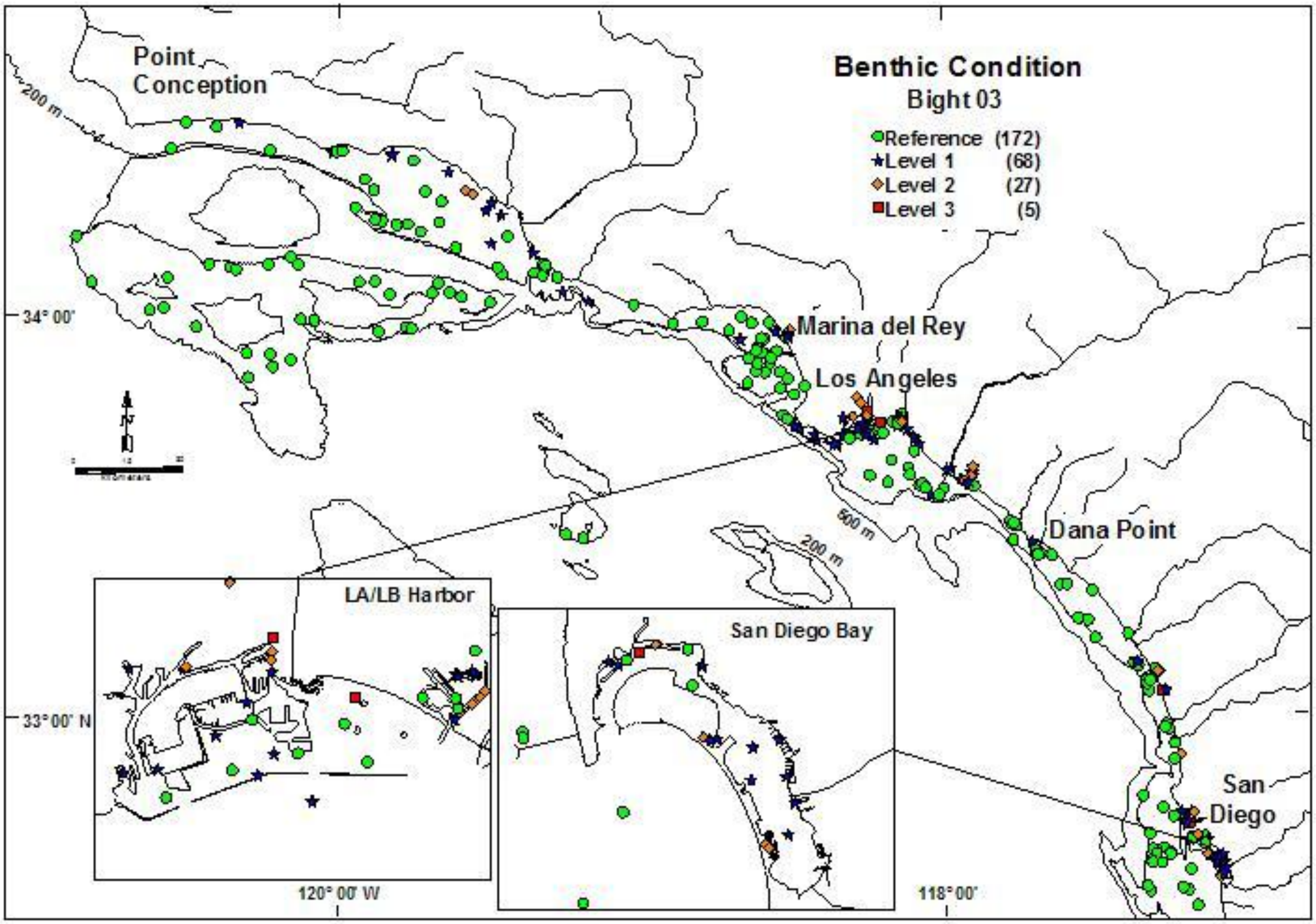

Figure IV-2. Benthic condition at sites sampled in 2003 for Bight'03. See Table II-2 for a description of benthic condition categories. See Appendix B for more detailed maps.

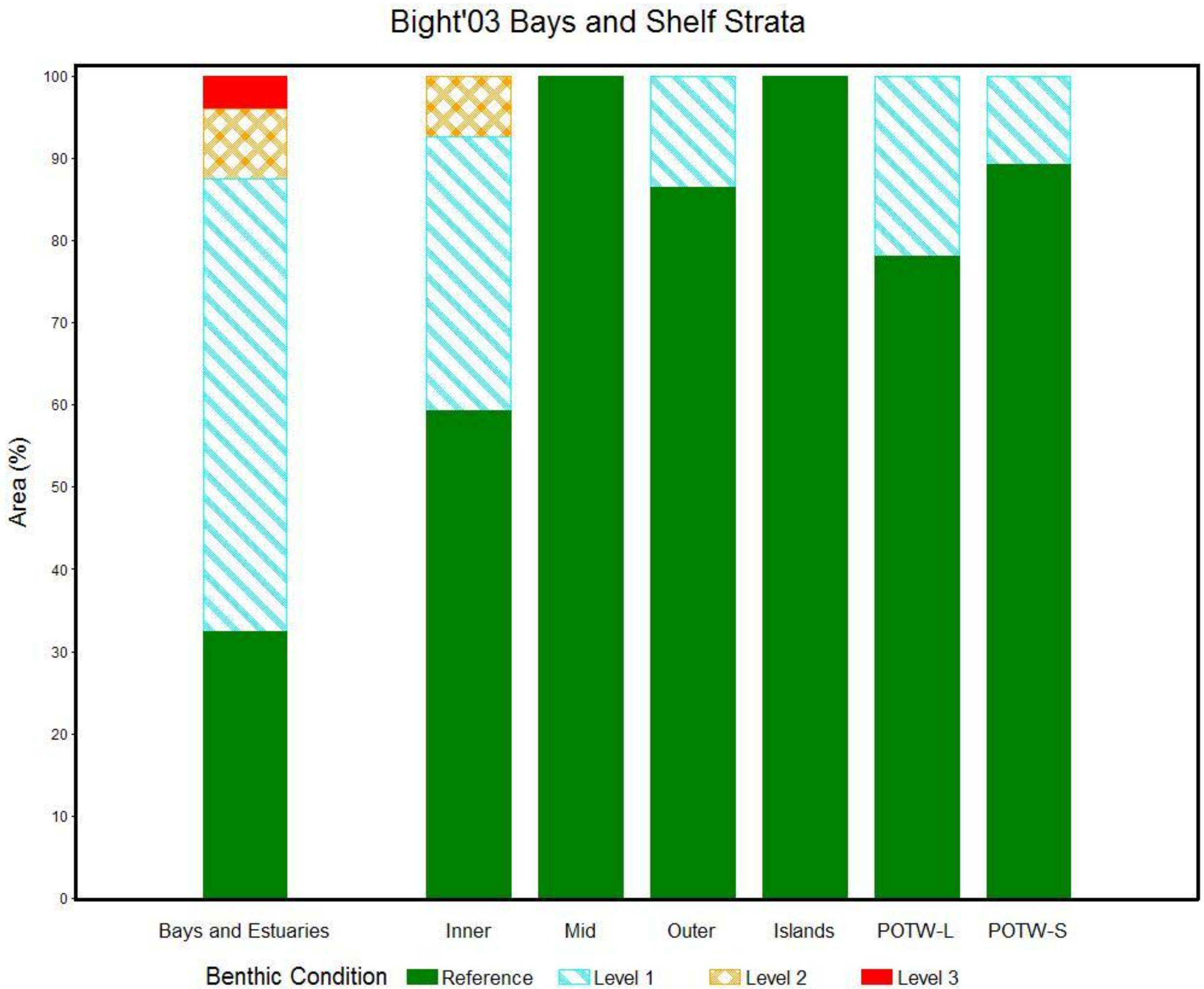

Figure IV-3. Estimates of benthic condition for areas of interest (strata) sampled for Bight'03 in 2003. Response Level 2 and Response Level 3 are considered clear evidence of disturbed benthic communities. See Table II-2 for a detailed description of benthic condition categories. Inner: Inner mainland shelf (5-30 m deep); Mid: Middle mainland shelf (31-120 m deep); Outer: Outer mainland shelf (121-200 m deep); Islands: Island shelf (5-200 m deep); POTW-L and POTW-S: Areas influenced by discharges from large (>100 mgd) and small (<100 mgd) Publicly Owned Treatment Works.

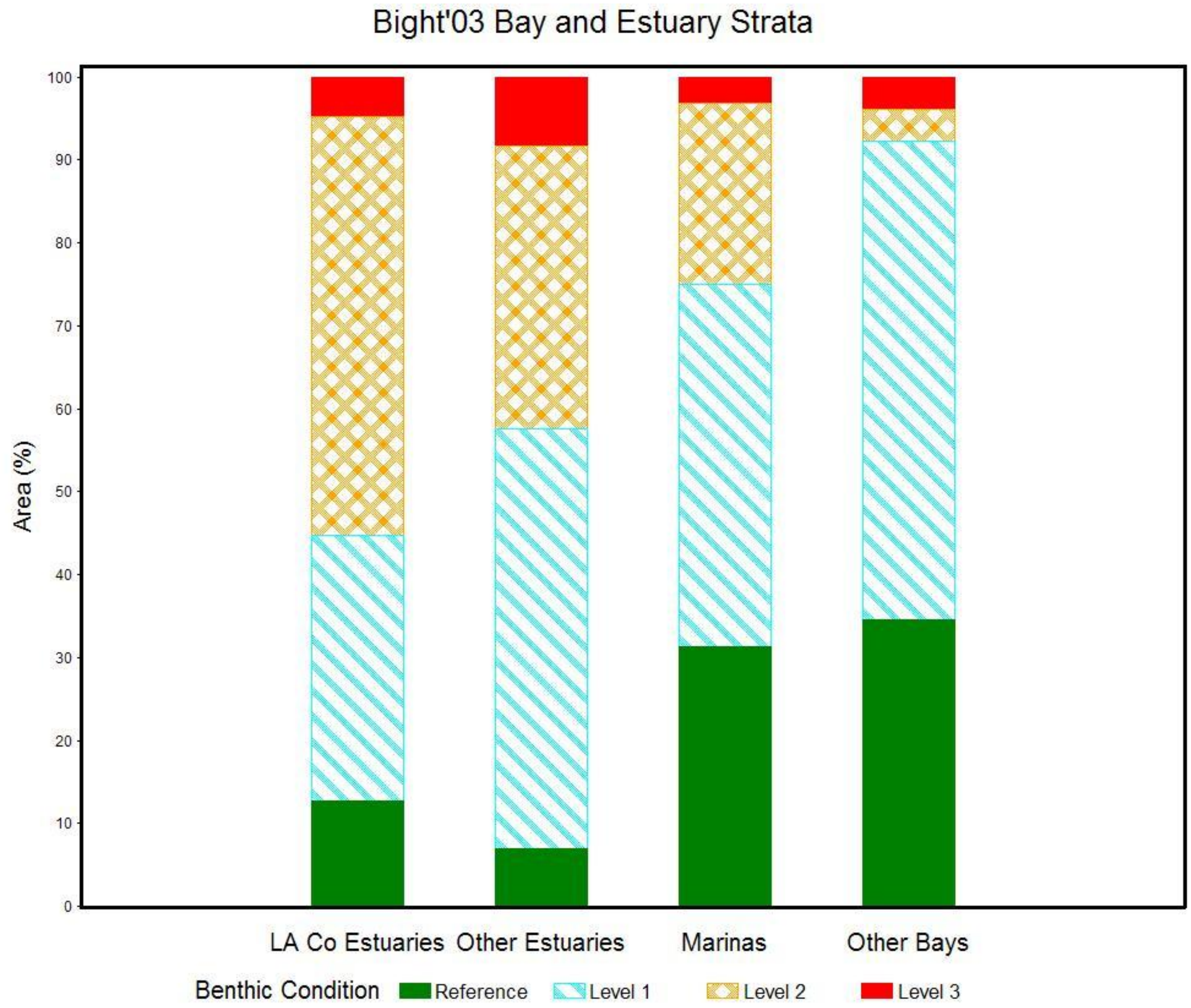

Figure IV-4. Estimates of benthic condition for bay and estuary strata sampled for Bight'03 in 2003. Response Level 2 and Response Level 3 are considered clear evidence of disturbed benthic communities. See Table II-2 for a detailed description of benthic condition categories.

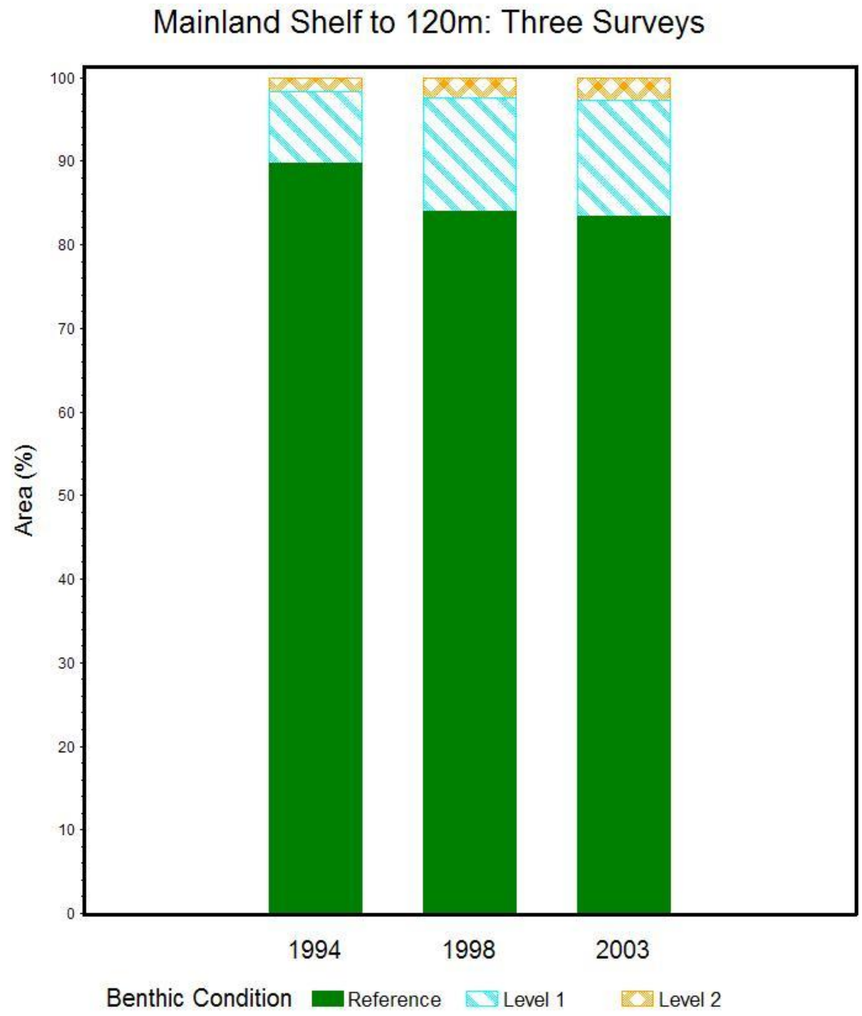

Figure IV-5. Estimates of benthic condition for the mainland shelf area sampled in all three regional surveys. Response Level 2 and Response Level 3 are considered clear evidence of disturbed benthic communities. See Table II-2 for a detailed description of benthic condition categories.

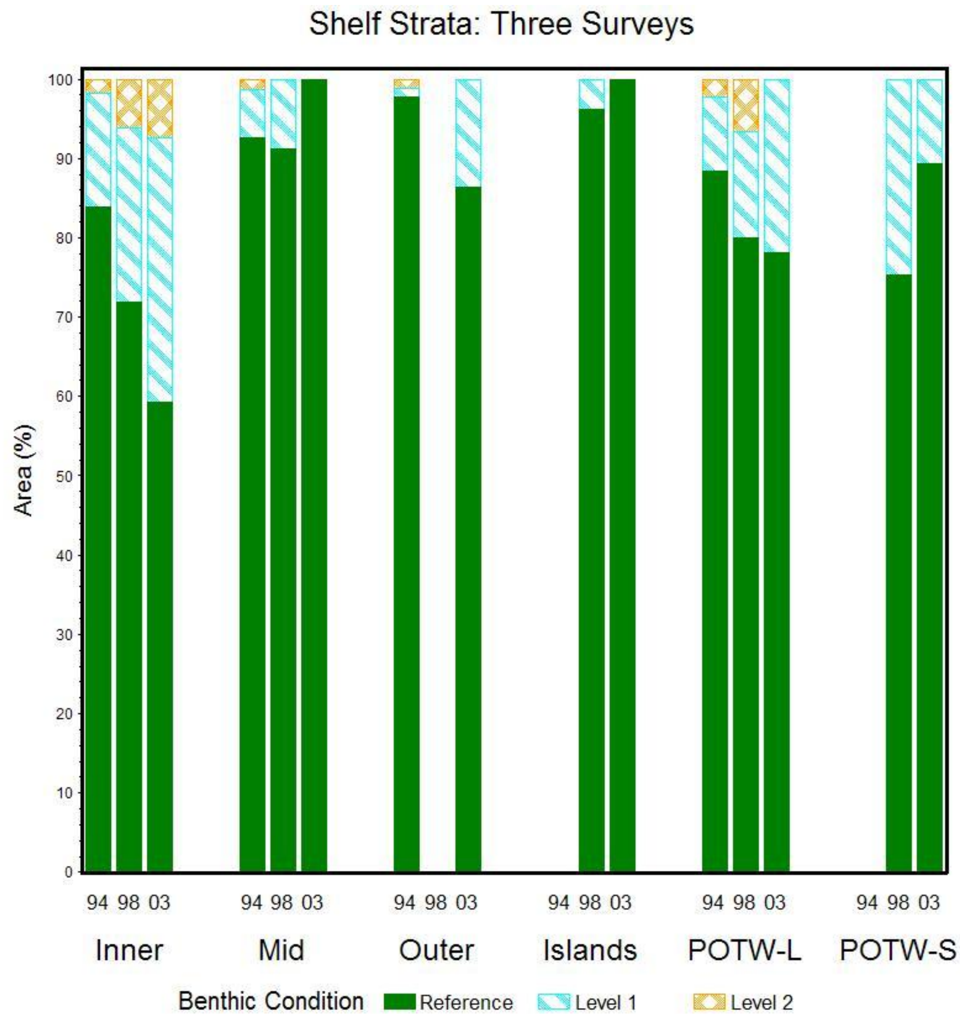

Figure IV-6. Estimates of benthic condition for coastal areas of interest (strata) sampled in more than one regional survey. Response Level 2 and Response Level 3 are considered clear evidence of disturbed benthic communities. See Table II-2 for a detailed description of benthic condition categories. Inner: Inner mainland shelf (5-30 m deep); Mid: Middle mainland shelf (31-120 m deep); Outer: Outer mainland shelf (121-200 m deep); Islands: Island shelf (5-200m deep); POTW-L and POTW-S: Areas influenced by discharges from large (>100 mgd) and small (<100 mgd) Publicly Owned Treatment Works.

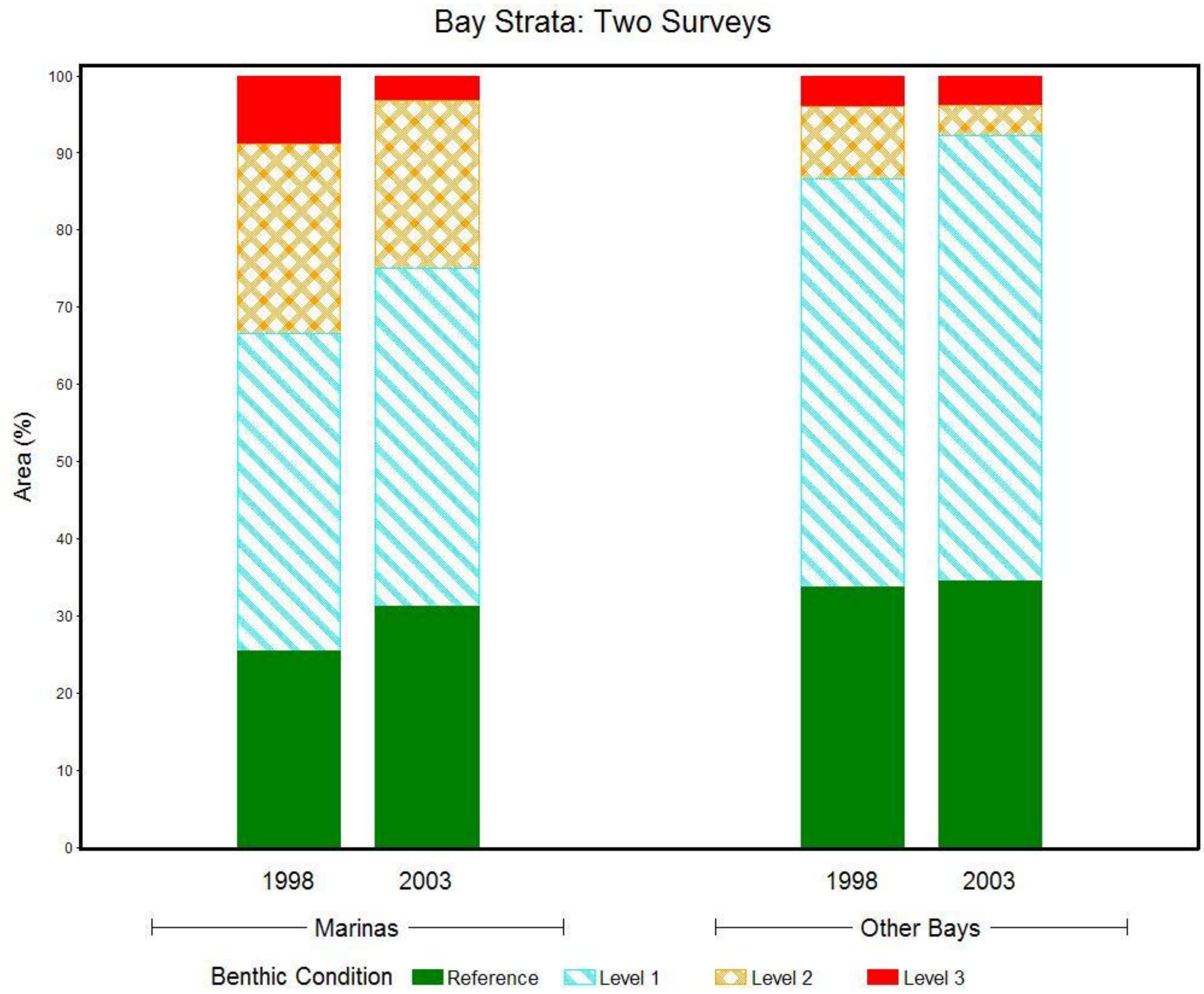

Figure IV-7. Estimates of benthic condition for bay strata sampled during the 1998 and 2003 regional surveys. Response Level 2 and Response Level 3 are considered clear evidence of disturbed benthic communities. See Table II-2 for a detailed description of benthic condition categories.

V. DISCUSSION

While SCB benthos appear healthy overall, not all habitats are in the same condition. More than 98% of the SCB supported benthic macrofaunal communities in good condition. Virtually none of the benthos in the Channel Islands, small POTW, large POTW, middle and outer mainland shelf strata were considered to be in poor condition. However, over half the benthos in estuaries, and nearly one-quarter of the benthos in marinas, were clearly disturbed. Other investigators have observed the impact to benthos in marinas of the SCB. Fairey *et al*. (1996) found that most of the degraded benthic sites in San Diego Bay were in or near shipyards and marinas. Anderson *et al*. (2001) determined that the Dominguez Channel/Consolidated Slip, which contains a marina and receives discharges from an urban watershed, had the most degraded benthos in Los Angeles/Long Beach Harbor. Similarly, stations in the back basins of Marina Del Rey had benthos in poor condition (Aquatic Bioassay and Consulting Laboratories 2004). In contrast to marinas, very little study of benthic condition has been attempted in estuaries of the SCB. This study not only determined that estuaries in the SCB were 7 to 14 times more likely to have impacted benthos relative to the rest of the SCB, but that the benthos in the most urban estuaries (e.g., LA estuaries) were 25% more likely to be in poor condition than other, less urban, estuaries of the SCB.

One reason marinas and estuaries may have relatively poor benthic condition is because these habitats are receptors of many sources of potential pollutants. Estuaries receive inputs from agricultural, construction, and urban upstream activities. Bightwide, pollutant loadings from agricultural and urban watersheds rival pollutant loadings from more traditional sources such as large and small POTWs (Ackerman and Schiff 2003, Schiff *et al.* 2003). Unlike POTWs, however, watershed discharges are untreated and estuaries serve as sinks where these watersheds meet the ocean. Marinas receive pollutant inputs from recreational boating activities, which can contribute significant quantities of copper from antifouling bottom paints and petroleum hydrocarbons from fuels (Schiff *et al.* 2004). Relatively high concentrations of metals and trace organic pollutants have been measured in sediments from SCB marinas and estuaries previously (Fairey *et al.* 1996, Anderson *et al.* 1998). Schiff *et al*. (2006) found that estuaries and marinas of the SCB had the greatest extent of chemical contamination and were predisposed to accumulating sediment contaminants relative to other habitats of the SCB in 2003. Bay *et al.* (2005) also determined that marinas and estuaries had the greatest frequency of sediment toxicity relative to other habitats in the SCB in 2003. Estuarine fauna are also subject to substantial natural seasonal stress due to the Mediterranean climate of southern California. Rainfall is heavy, but restricted to a few months of the year. Massive freshwater flows in fall and winter result in osmotic stress as organisms struggle to prevent electrolyte loss and dilution, and physical stress as strong currents scour bottom sediments. Thus, it was not surprising that estuaries and marinas were determined to be in poorer benthic condition than ports and industrialized waterways or the coastal shelf.

The precision and accuracy of benthic condition assessment is a function of the assessment tools that are used. Assessment tools help to condense the tremendous amount of biological information in a sample into a single number that is easier to understand and communicate to others. For example, an average sample from the mainland shelf of the SCB may contain thousands of individuals and hundreds of species per square meter. Two assessment tools were used in this study; the BRI for mainland continental shelf and upper continental slope habitats and the SQO26 for embayment habitats. Because embayments had rarely been assessed previously, the SQO26 was specifically developed for this study (Appendix G). The SQO26 is a combination of multivariate and multimetric biointegrity indices that correctly identified the benthic condition for 94.3% of the independent samples used for evaluation. This performance surpasses the status classification rates achieved by most previous benthic biointegrity index development efforts. Despite its success, however, the SQO26 has limited applicability in certain situations. For example, the SQO26 was not developed for brackish (<18 psu) water estuaries and lagoons. More than five of the lagoons in the SCB during the summer of 2003 were considered brackish and, thus, could not be evaluated.

The BRI used to assess benthic condition on the mainland shelf and upper slope also has its limitations. The BRI is a multivariate-based assessment tool that was calibrated for depths from 5-324 m. Validation analyses showed that the BRI was most accurate between 31-200 m, which includes habitats on the middle and outer continental shelf. There was no calibration of the BRI for sites greater than 324 m depth and only limited calibration from 200 m to 324 m, so no assessment could be conducted for the SCB continental slope and basins. This remains a point of interest because Schiff *et al.* (2006) indicated that the SCB continental slope and basins are habitats that appear to accumulate sediment contaminants. Despite attempts to improve its performance in depths less than 30m, the BRI remains less accurate in evaluating samples from the inner shelf, presumably because there was less of a pollution gradient available for calibration.

Despite their success in assessing benthic condition, both the BRI and SQO26 cannot discriminate the individual stressor(s) responsible for poor benthic condition. If impaired benthic condition does exist, neither the BRI nor the SQO26 can distinguish which constituent(s) is responsible for the impairment. In addition, neither the BRI nor the SQO26 can distinguish between anthropogenic (e.g., chemical stress) and natural (e.g., salinity or storms) impacts. Ultimately, the goal of any assessment would be to measure and designate the likely stressor(s) of benthic condition.

It appears that the SCB mainland shelf is not changing rapidly. Results from the current study in 2003 were similar to the estimates from regional studies in 1994 (Bergen *et al.* 1998, 2000) and 1998 (Ranasinghe *et al.* 2003a). The area of the coastal shelf in poor benthic condition has remained between 1.6 and 2.8% over the 9-year time span. This temporal assessment of benthic condition is limited, however, to the inner and middle coastal shelf strata that were sampled in all three surveys. Trend information from other habitats of interest (i.e., embayments) cannot be assessed at this time. There were three mainland shelf areas that had the most sites deviating from good benthic condition in 1994 and 1998; these included sites located on the Palos Verdes Shelf, Santa Monica Bay, and the Eastern Santa Barbara Channel. These were the same general locations with sites in poor benthic condition in the present study.

The Bight regional monitoring program series are not presently designed well to show temporal trends. One potential limitation to assessing temporal trends is consistency in taxonomy among surveys, but this problem has been overcome and the Bight program is now the model of consistency and quality nationally (Ranasinghe *et al.* 2003b). A second weakness to trend detection is spatial. The only strata consistently sampled in the surveys from 1994, 1998, and 2003 have been the inner and middle shelf. A third limitation is the magnitude of change that the current design can effectively detect; 95% confidence intervals about areal estimates for any single stratum is approximately $\pm$10%. These design weaknesses converge when small changes occur consistently over time. For example, the amount of area in the SCB with benthos in Reference condition has monotonically decreased between 1994 and 2003 with concomitant increases in the percentage of area at Level 1, but all of these changes were less than five percent. These are potential trends that managers would want to know about, but cannot presently be identified with certainty. Given the limits of trend assessment with the current random design, improved designs to detect trends might be a consideration for future surveys.

VI. CONCLUSIONS

- Benthic macrofauna in nearly all of the Southern California Bight (SCB) are generally healthy.

- Macrofauna in 98.4% of the Southern California Bight were in reference condition or deviated only marginally from reference in the summer of 2003. There was no evidence of disturbance in three habitats, the mid-mainland shelf, outer mainland shelf, and the island shelf. Our estimate of undisturbed area for the inner shelf was 92.6%. Areas of wastewater discharge were not substantially different from other areas with respect to the condition of the benthic macrofaunal community. Where benthic community impacts were observed, they occurred most frequently in bays and estuaries.

  The proportion of disturbed area and the severity of disturbance was greater in bays and estuaries than in any other SCB habitat. Altogether, 12.6% of the area was considered impacted in bays and estuaries in the summer of 2003. Moreover, the most altered benthic communities (Response Level 3) were only observed in bay and estuarine habitats. Benthic communities in poor condition occupied more than half (55.2%) the area of Los Angeles County estuaries, nearly half (42.5%) of other estuaries in southern California, and one quarter (25.0%) of the area in marinas.

- We could not assess the quality of benthic communities in deep strata such as the upper continental slope or lower slope and basin or in estuarine areas with substantial amounts of brackish water.

  Species composition and relative abundance change with depth around the continental shelf break at approximately 200 m beneath the ocean's surface. Compared to the continental shelf where most ocean monitoring occurs, the benthic community assemblages in deep water habitats of the mainland upper slope or lower slope and basin (200 m to 1,000 m) are very different. Yet our tools for assessing benthic community condition have only been calibrated and validated adequately to depths of 200 m. Therefore, we could not assess the condition of these unique habitats. We also could not assess estuary and bay samples where bottom water salinity was less than 18 psu because the SQO26 was not developed for oligohaline (0.5 to 5 psu) or mesohaline (5 to 18 psu) salinities.

- Overall, our assessment of regional benthic community condition has remained the same between 1994 and 2003.

No significant differences were observed in the areal extent of disturbed benthos in habitats that were sampled in more than one regional survey.

VII. RECOMMENDATIONS

The Bight'03 Regional Monitoring Survey successfully achieved its primary objective measuring the extent and magnitude of alterations in benthic macrofauna in coastal, bay and estuarine habitats of the Southern California Bight (SCB). Disturbed and undisturbed communities were differentiated and the magnitude of disturbance measured using two biointegrity indices, the Benthic Response Index (Smith *et al.* 2001) in coastal habitats and the SQO26, which was developed concurrently with this effort (Appendix G) in bay and estuarine habitats. Bight'03 also described SCB benthic communities in detail (Appendix F), measuring community statistics, such as diversity and abundance as well as species composition. Data from site-specific programs can be compared with these descriptions to interpret local patterns and trends within a regional context.

We recommend periodic repetition of similar regional monitoring surveys to assess the health of benthic macrofauna in the SCB. While Bight'03 provided useful information on current conditions, benthic communities will change as conditions change. Regional climatic events, such as El Ninos and La Ninas, can affect benthic communities. Inputs from anthropogenic sources may increase or decrease over time. Non-indigenous species that previously were absent may establish populations that dominate communities and modify habitat. Assessing macrofaunal biointegrity Bight-wide provides a perspective for interpreting data from smaller scale monitoring around discharges, comparative information about the extent and severity of impacts from various sources, and information about changes over time. The biointegrity of benthic macrofauna is a direct measure of a living resource that environmental laws and regulations intend to protect. Benthic macrofauna also integrate the effects of multiple types of stress and multiple insults over time. As such, benthic macrofauna are one of the most relevant measures of sediment quality.

This section presents recommendations for consideration during planning for subsequent regional monitoring programs in an effort to improve on the success of Bight'03. The recommendations are:

- **Improve the accuracy and precision of assessment tools**.

  As the Bight regional monitoring program has expanded into new habitats, it has required the development of new assessment tools. Thus far, new tools have been developed for the continental shelf and for saline embayments and estuaries. These biointegrity indices have been especially important in assessing the condition of rarely monitored habitats as well as integration into ongoing monitoring programs. However, there are additional habitats for which there is concern, but assessment tools do not exist or are poorly developed. These habitats include:

  Estuaries. Because approximately half of all estuaries assessed in Bight'03 exhibited impacted benthic communities, assessment measures for embayments should be improved. For instance, no assessment tool is available for brackish and freshwater areas of euryhaline estuaries. Data from additional studies collected as part of the State's Sediment Quality Objectives program could be used to create new measures of biointegrity and refine existing tools.

Slopes and basins. Biointegrity measures are not available for the continental slope and deep basins, although the Sediment Chemistry part of Bight'03 (Schiff *et al.* 2006) showed that they are sinks for pollutants moving off the mainland shelf. Developing assessment measures to detect the presence or absence of altered benthic macrofaunal communities in these areas will help define the areal extent of impacts from human activities in the SCB.

Inner and outer shelf. Despite a known bias in biointegrity indices used to assess inner and outer mainland shelf habitats, we lack the ability to recalibrate and validate our current assessment tools. An investment in improving these tools would be beneficial in determining the potential impact from stormwater and small POTW discharges.

- **Improve our understanding of the mechanism(s) of impact in estuaries.**

  Bight'03 demonstrated that estuaries are an area of concern because of the disproportionately large frequency of impacted benthic communities. However, the degree of impact due to anthropogenic sources relative to natural perturbations is unknown. For example, sediment contaminants certainly accumulate in estuaries (Schiff *et al.* 2006). However, these ecosystems are also subject to periodic inundation by freshwater and scour during storm events and perhaps even chronic stress due to marginally reduced salinities during dry weather. An improved understanding of the mechanisms and processes that impact estuarine benthos would be an appropriate next step in understanding the extent of biological impacts and nature of the cause of impact. This understanding does not necessarily have to be a part of a Bight regional monitoring program, but may be undertaken as a special study.

- **Improvements to sampling and analysis in estuaries are critical.**

  Because standard sampling and analysis methods are not available in estuaries, the Bight'03 regional monitoring program applied standard open ocean procedures. It was immediately obvious that these methods were ineffective in terms of sampling success and laboratory efficiency for estuaries. Identifying cost-effective methods for sampling macrobenthos that collect representative samples in estuarine areas is essential for the success of future estuarine monitoring and assessments. Studies such as Appendix I and those by the State's program to develop Sediment Quality Objectives are a good start towards modifying existing sampling methods.

- **The Regional Monitoring survey design should be re-evaluated to maintain and improve trend detection.**

  Previous regional monitoring surveys were specifically designed to address questions about extent and magnitude. Implicit within this study design is that trend evaluation can occur after multiple surveys are conducted. Bight'03 represented the first opportunity to examine potential trends in spatial extent over the last nine years.

However, this analysis met with some difficulty. Some temporal comparisons were complicated by differences in taxonomic identification, but these difficulties have been remedied. A second hurdle was dissimilarity in sample frame. Since 1994, the Regional Monitoring Program has moved into both shallower and deeper water, increasing its areal extent by a factor of three and often into unexplored habitats. Even more habitats are being recommended for future surveys. However, some consistency in areal extent is necessary to ensure that temporal trends can be evaluated. Therefore, the study design for future Regional Monitoring surveys needs to be re-evaluated and configured to ensure that information to address questions about trends are collected over similar spatial scales and habitats.

- **Maintain taxonomic continuity to assure accuracy and reliability**.

  A recent survey conducted by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) clearly shows that we are in a crisis of losing the majority of our trained macroinvertebrate taxonomists within the next ten years. Worse yet, there are very few taxonomists being trained to replace them. Bight'03 strained the capacity of existing taxonomic laboratories. Managers must start acting now, in collaboration with University partners, to engage taxonomic expertise and enlist students if we are to maintain taxonomic continuity and assure ongoing accuracy and reliability of benthic macroinvertebrate monitoring.

  Besides maintaining our existing expertise, there are new areas of taxonomic diversity that could be explored. In particular, a large proportion of the taxonomic diversity in estuaries was in the oligochaetes, which are rarely encountered offshore. Specialty taxonomy to evaluate whether there are meaningful delineations within this taxon should be explored prior to the next Bight regional monitoring program.

- **Investigate the relationship between non-indigenous and indigenous fauna in embayments.**

  Previous regional monitoring studies indicated that non-indigenous species were not a serious impact to native species in terms of total abundance or species richness. It is possible that detailed studies, however, will identify native species that are negatively impacted by increases in non-indigenous fauna. The potential deleterious effects of non-indigenous species should not be dismissed without thorough study.

- **Implement procedural recommendations**.

  Procedural recommendations for maintaining data quality, improving record keeping, and reducing the time required to produce final data are listed at the end of Section 3. Implementing these recommendations in future regional monitoring efforts will facilitate the attainment of project objectives in a timely fashion.

VIII. LITERATURE CITED

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APPENDIX A

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/529_B03_Benthic_Appendix_A.pdf

APPENDIX B

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/529_B03_Benthic_Appendix_B.pdf

APPENDIX C

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/529_B03_Benthic_Appendix_C.pdf

APPENDIX D

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/529_B03_Benthic_Appendix_D.pdf

APPENDIX E

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APPENDIX F

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APPENDIX H

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APPENDIX I

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/529_B03_Benthic_Appendix_I.pdf