Benthic macrofaunal community condition in the Southern California Bight, 1994-2003

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ABSTRACT

To assess benthic macrofaunal community condition in southern California, 838 sites were sampled using spatially random designs in 1994, 1998, or 2003. Benthic community condition was assessed on a four-category scale and the area in each category estimated. Overall, benthic macrofauna in southern California were in good condition during 2003, with 98% of the area in reference condition or deviating only marginally. There was no evidence of disturbance near the Channel Islands or small wastewater discharges, and virtually none on the mainland shelf. In contrast, bay and estuary macrofaunal communities were more frequently disturbed with nearly 13% of the area supporting disturbed benthos. The condition of the mainland shelf did not change substantially over the nine-year period, with 1.6 to 2.8% of the area in poor benthic condition. Southern California benthic condition evaluations may be improved by extending the depth and salinity ranges of assessment tools, and improving trend detection methods.

INTRODUCTION

The Southern California Bight (SCB) is an important and unique ecological resource in one of the most densely populated coastal regions of the USA. The SCB is an 80,000 km^2 body of water with over 300 km of shoreline (Schiff *et al*. 2000, Stein and Cadien 2009) and complex topography providing a variety of habitats. It is in a transitional area that is influenced by currents from cold, temperate ocean waters from the north and warm, tropical waters from the south (Hickey 1993). The diverse habitats and mixing of currents facilitate the coexistence of a broad range of marine life, including more than 2000 species of invertebrates and 500 species of fish (Stein and Cadien 2009).

The activities of the Southern California human population result in substantial environmental stress. In 2000, the population was 16.5 million, or one seventeenth the population of the United States (Chang 2007) and is expected to increase by 37% to 22.6 million by 2025 (Southern California Association of Governments 2001). Population growth has resulted in the conversion of open land into non-permeable surfaces and more than 75% of southern Californian bays and estuaries have already been dredged and filled for conversion into harbors and marinas (Horn and Allen 1985). The SCB is also home to fifteen municipal wastewater treatment facilities, 8 power generating stations, 10 industrial treatment facilities, and 18 oil platforms that discharge to the open coast. Los Angeles/Long Beach Harbor is the largest commercial port in the United States, and San Diego Harbor is home to one of the largest US Navy facilities in the country.

Benthic macrofauna have been used extensively over the past three decades to assess environmental impacts from discharges and outfalls at small spatial scales (e.g., Dauer *et al*. 1979, Dauer and Conner 1980, Stull *et al*. 1986, Tapp *et al*. 1993, Ferraro *et al*. 1994, Stull 1995, Stull *et al*. 1996, Diaz *et al*. 2004a, Hall *et al*. 2005). They have proved to be reliable and sensitive indicators of the condition of marine and estuarine environments (Diaz *et al*. 2004b, Borja *et al*. 2008, Borja *et al*. 2009). They include a diverse mixture of organisms with a wide range of physiological tolerances, and are well suited for use as indicators because they have limited

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mobility (Diaz *et al*. 2004b, Blanchet *et al*. 2008) and respond to many different types of environmental stress. Benthic organisms have high exposure to chemical contaminants, which tend to sink to the bottom and comingle with the sediments in which the benthic organisms live and burrow. Environmental impacts due to discharges, outfalls, and other sources of pollution are inferred from differences in the composition of benthic macrofaunal communities between affected and unaffected areas, and affected and unaffected periods of time.

Over the last decade, assessment science has progressed from local impact assessments to regional assessments of marine and estuarine sediment quality based on benthic macrofaunal community condition (Bergen *et al*. 1998, 2000; Paul *et al*. 2000; Hyland *et al*. 2003; Kiddon *et al*. 2003; Ranasinghe *et al*. 2003a, US Environmental Protection Agency 2004, Ranasinghe *et al*. 2007). Spatially random benthic samples are collected regionally and benthic community condition is assessed in relation to regional reference conditions using benthic indices. Regional monitoring programs identify the areas that potentially most need, and will benefit most from, restorative and management actions.

A series of regional monitoring programs sampled benthic macrofauna and other ecosystem components throughout the SCB in 1994, 1998, and 2003, providing an opportunity to assess the effects of human activities on southern California benthic macrofaunal communities. The objectives of this study were to: 1) assess the extent and magnitude of altered and disturbed Southern California Bight benthic communities in 2003, 2) evaluate whether patterns of alteration and disturbance vary among habitats and geographic regions, and 3) identify changes in patterns of alteration and disturbance over time.

METHODS

The area in the Southern California Bight with benthic assemblages showing clear evidence of disturbance was estimated in three steps. Spatially random benthic samples were collected during three regional surveys in summer 1994, 1998, and 2003 and the organisms in the samples were identified and counted. Next, benthic indices were calculated from the species abundances and used to evaluate benthic condition at each sampling site on a four category scale. Finally, the area in each condition category was estimated as the sum of the areas represented by the sampling sites in each condition category.

Benthic samples were cumulatively collected at 838 sites in summer 1994, 1998 or 2003 in areas from 3 to 200 m deep. The sites were selected using generalized random tessellation stratified (GRTS) designs (Bergen 1996, Stevens 1997, Stevens and Olsen 2004) stratified by habitats and potential sources of pollution (Table 1). A subset of the stratum definitions were applied to all three surveys.

Table 1. Distribution of sampling sites. Coastal stratum depth ranges are presented in parentheses. POTW = Publicly owned treatment works.

Habitat	Stratum	Stratum Area (km^2)	Number of Sites		
			1994	1998	2003
Bays and Estuaries	Los Angeles County Estuaries	1.5			20
	Other Estuaries	6.0			21
	Marinas	17.2		39	32
	Other Bays and Harbors	93.1		74	26
Coastal	Inner Shelf (5 - 30 m)	1144.0	66	56	27
	Middle Shelf (31 - 120 m)	1837.3	85	34	32
	Outer Shelf (121 - 200 m)	592.7	36		22
	Island Shelf (5 - 200 m)	2189.6		53	32
Likely Discharge Influence	Large (≥100 mgd) POTW	165.5	64	30	32
	Small (<100 mgd) POTW	28.1		29	28
Total		**6,075.0**	**251**	**315**	**272**

At each site, sediments were collected with a 0.1 m^2 Van Veen grab and sieved through a 1 mm mesh screen. Materials retained on the screen were placed in a relaxant solution of 1 kg $MgSO_4$ or 30 ml propylene phenoxytol per 20 L of seawater for at least 30 minutes, and then fixed in buffered 10% formalin. In the laboratory, organisms retained on the screens were sorted from debris, identified to the lowest practical taxon (most often species), and counted.

The species abundance data were used to calculate benthic indices which were used to assess the condition of the benthic community in each sample on a four category scale. The four categories were: 1) Reference - a community that would occur at a reference site for that habitat; 2) Marginal deviation from reference - a community that exhibits some indication of stress, but might be within measurement variability of reference condition; 3) Affected - a community that exhibits evidence of physical, chemical, natural or anthropogenic stress; and 4) Severely affected - a community exhibiting a high magnitude of stress. At mainland and island shelf sites, the Benthic Response Index (BRI; Smith *et al.* 2001) was calculated from the species abundance data and the condition category was determined from the BRI response level corresponding to the index value (Table 2). At bay and estuary sites, four benthic indices were calculated and the condition categories (Table 2) were assigned using threshold index values established during index development (Bay *et al*. 2009, Ranasinghe *et al*. 2009), when the indices were calibrated and validated with southern California data using the original index approaches. The bay and estuary indices used in the study were the Index of Biotic Integrity (IBI; Thompson and Lowe 2004), Relative Benthic Index (RBI; Hunt *et al*. 2001), River Invertebrate Prediction and Classification System (RIVPACS; Wright *et al*. 1993, Van Sickle *et al*. 2006) and the BRI (Smith *et al*. 2001). The condition category of each bay and estuary site was evaluated as the median of the numeric categories (Reference = 1, Severely Affected = 4) of the four indices; if the median for the index combination fell between categories, it was rounded to the higher effects category.

The area in each condition category in 2003 was estimated for the entire area, and for geographic areas of interest or strata (Table 1). Where previous data were available, 2003 stratum assessments were compared with results for the 1994 and 1998 regional monitoring surveys. The area in each benthic condition category was estimated as the sum of the area weights for samples in each condition category and 95% confidence limits were calculated using the local variance estimator for GRTS designs (Stevens and Olsen 2003). The proportion of area exceeding the good-poor condition threshold was calculated using the Horvitz-Thompson ratio estimator (Horvitz and Thompson 1952, Stevens 1997) and 95% confidence limits were calculated as 1.96 times the standard error (Stevens and Kincaid 1997).

RESULTS

2003 Regional Survey

Of the 6,075 km^2 sampled in 2003, 5,975 km^2 (98%) were in good condition (Table 3). The remaining 100 km^2 (2%) were in poor condition,

Table 2. Characterization of response categories. Sites were evaluated using the BRI (Smith *et al.* 2001) on the mainland and island shelves, and a combination of four benthic indices (Ranasinghe *et al.* 2009) in estuaries and bays.

Benthic Condition	Benthic Response Category	BRI Response Level	Shelf Definition	Estuary and Bay Definition
Good	1	Reference	Reference	Reference (unaffected)
	2	Level 1	Marginal Deviation	Low Disturbance (marginal deviation from reference)
Poor	3	Level 2	Biodiversity Loss	Moderate Disturbance (clear evidence of stress)
	4	Levels 3 and 4	Community Function Loss or Defaunation	High Disturbance (high magnitude of stress)

Table 3. Percentage of stratum area in each benthic response category in 2003. Categories 3 and 4 are benthic communities in “poor condition” with clear evidence of disturbance, while Categories 1 and 2 are benthic communities in “good condition” with no clear evidence of disturbance. Large POTWs are Publicly Owned Treatment Works discharging ≥100 mgd; Small POTWs discharge <100 mgd.

Habitat	Stratum	Stratum Area (km^2)	Benthic Response Category (Percent of Area)			
			Good Condition		Poor Condition	
			Category 1 (Reference)	Category 2 (Marginal)	Category 3 (Affected)	Category 4 (Severely Affected)
Coastal	Island Shelf	2189.6	100	0	0	0
	Outer Shelf	592.7	86	14	0	0
	Middle Shelf	1837.3	100	0	0	0
	Inner Shelf	1144.0	59	33	7	0
Likely Discharge Influence	Large POTW	165.5	78	22	0	0
	Small POTW	28.1	89	11	0	0
Bays and Estuaries	Marinas	17.2	31	44	22	3
	Other (non-marina) Bays	93.1	35	58	4	4
	Los Angeles County Estuaries	1.5	13	32	51	5
	Other (non-LA county) Estuaries	6.0	7	51	34	8
Southern California Bight	All	6075.0	89	9	2	0

with clear evidence of disturbance. Of the area in good condition, 5,409 km^2 (89% of the total area) were in Response Category 1 (Reference Condition) and 566 km^2 (9% of the total) were in Response Category 2, which is not considered clear evidence of disturbance.

The island and middle shelf strata were in the best state, with all sites in Reference Condition and no evidence of disturbance (Table 3). The outer mainland shelf and areas surrounding large and small Publicly Owned Treatment Works (POTWs) also showed no clear evidence of disturbance, although 14, 22, and 11% of these strata, respectively, were in Response Category 2. Most (93%) of the inner mainland shelf was also in good condition, but 7% was classified in poor condition in Response Category 3, indicating a loss of biodiversity. None of the sites sampled on the mainland or island shelves were classified in Response Category 4, which is the category indicative of the most disturbed conditions.

Of the strata sampled in 2003, bays and estuaries were in the worst condition both collectively and individually (Table 3). The most severely altered benthic communities (Response Category 4) occurred only in these habitats. Collectively, 13% of the area sampled in the southern California bays and estuaries showed clear evidence of disturbance. Larger proportions of estuaries were disturbed than marinas or other bays (Table 3), 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. Eleven of the 20 estuary samples in poor condition were from only three water bodies: three of three samples taken in the Dominguez Channel and three of four samples in Agua Hedionda Lagoon were clearly disturbed, as were five of six samples taken from the San Gabriel Estuary. The remaining samples indicating poor benthic condition were distributed throughout other estuaries without apparent pattern.

In contrast to estuaries and lagoons, only 25% of the marina areas were clearly disturbed, while the other bay habitats (bays other than marinas) were less affected with only 8% 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 (13%) were in poor condition.

Comparison of the 1994, 1998, and 2003 Surveys

The proportion of undisturbed area in good condition on the southern California inner and middle mainland shelf decreased from 98% in 1994 and 1998 to 97% in 2003 (Figure 1; Table 4), although this change was not statistically significant. The area in Reference Condition decreased from 90% in 1994 to 84% in 1998 and 83% in 2003. Most of this change from Reference was to Response Category 2, which increased from 9% in 1994 to 14% in 1998 and 2003. Response Category 2 is not considered to be clear evidence of disturbed benthic communities.

Alteration at the most severe level, Response Category 4, was not observed anywhere on the coastal shelf during any of the regional surveys (Figure 2; Tables 3 and 4). 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

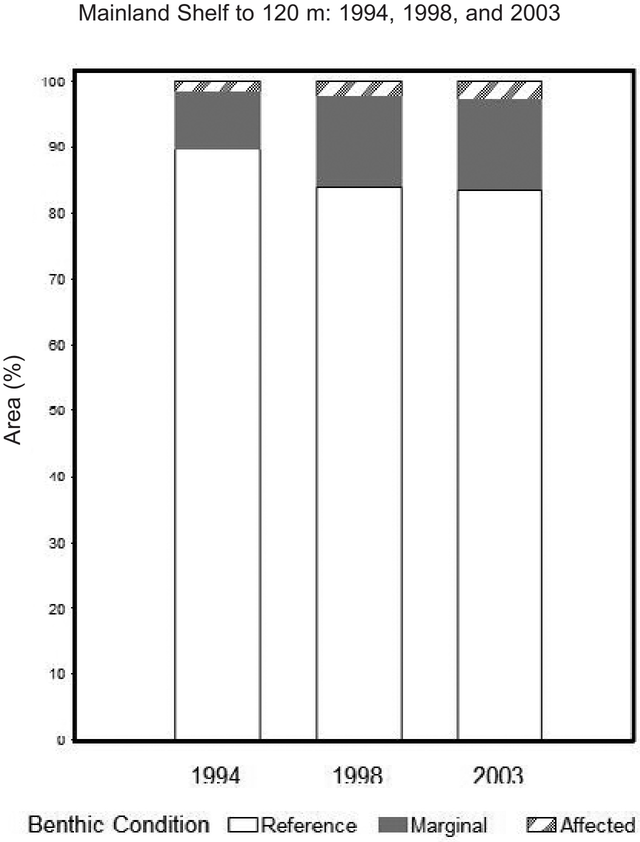

Figure 1. Area estimates of benthic condition for the mainland shelf area sampled in 1994, 1998, and 2003. Affected condition is considered clear evidence of disturbed benthic communities. Benthic Response Categories are characterized in Table 2.

Table 4. Percentage of area in benthic response categories for strata sampled in more than one regional survey. Large POTWs are Publicly Owned Treatment Works discharging ≥100 mgd; Small POTWs discharge <100 mgd.

Habitat	Stratum	Stratum Area (km^2)	Year	Benthic Response Category (Percent of Area)			
				Good Condition		Poor Condition	
				Category 1 (Reference)	Category 2 (Marginal)	Category 3 (Affected)	Category 4 (Severely Affected)
Coastal	Island Shelf	2,189.6	1998	96	4	0	0
			2003	100	0	0	0
	Outer Shelf	592.7	1994	98	1	1	0
			2003	86	14	0	0
	Middle Shelf	1,837.3	1994	93	6	1	0
			1998	91	9	0	0
			2003	100	0	0	0
	Inner Shelf	1,144.0	1994	84	14	2	0
			1998	72	22	6	0
			2003	59	33	7	0
	Inner and Middle Shelf	2,981.3	1994	90	9	2	0
			1998	84	14	2	0
			2003	83	14	3	0
Likely Discharge Influence	Large POTW	165.5	1994	88	9	2	0
			1998	80	13	7	0
			2003	78	22	0	0
	Small POTW	28.1	1998	75	25	0	0
			2003	89	11	0	0
Bays	Marinas	17.2	1998	26	41	25	9
			2003	31	44	22	3
	Other Bays	93.1	1998	34	53	9	4
			2003	35	58	4	4

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.

The area in good condition increased slightly, but without statistical significance, in the marina and other bay habitats sampled in both 1998 and 2003 (Figure 3; Table 4). The percentage of area in poorest condition (Response Category 4) tended to decrease in marinas, but remained about the same in the other bays.

DISCUSSION

While SCB benthos are healthy overall, not all habitats are in the same condition. More than 98% of the SCB supported benthic macrofaunal communities in good condition and virtually none of the benthos in the Channel Islands, small POTW, large POTW, middle and outer mainland shelf strata were in poor condition. However, benthos in over half the sampling sites in estuaries, and nearly one-quarter of the sites in marinas, were clearly disturbed. Other investigators have observed the impact to benthos in SCB marinas. Fairey *et al*. (1996) reported 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 and Consolidated Slip, which contains a marina and receives discharges from an urban watershed, had the most degraded benthos in the Los Angeles - Long Beach Harbor complex. Benthos in the back basins of Marina Del Rey were also reported to be in poor condition (Aquatic Bioassay and Consulting Laboratories 2004). In contrast to the marinas, SCB estuarine benthos have not previously been studied extensively. In the present study, estuaries in the

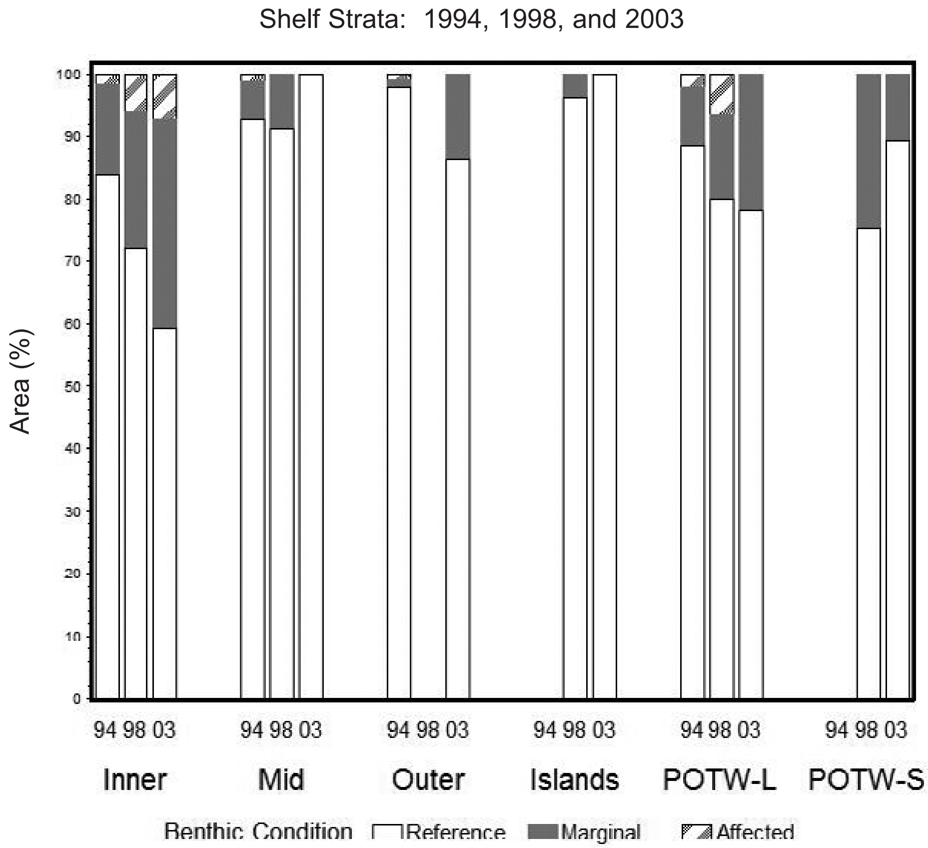

Figure 2. Area estimates of benthic condition for coastal areas of interest (strata) sampled in more than one regional survey. Affected and severely affected conditions are considered clear evidence of disturbed benthic communities. Benthic Response Categories are characterized in Table 2. Inner: Inner 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.

SCB were 7 to 14 times more likely to have impacted benthos than the rest of the SCB, and benthos in urban estuaries in Los Angeles County were 25% more likely to be in poor condition than other, less urban, estuaries of the SCB. Therefore, benthos in SCB marina and estuarine habitats are most likely to benefit from regulatory and restorative management actions.

One reason marinas and estuaries may have relatively poor benthic condition is because they receive pollutants from multiple sources. Estuaries receive inputs from upstream agricultural, construction, and urban activities. In the SCB, 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, Lyon and Stein 2009). 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 and other metals 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, in 2003, estuaries and marinas of the SCB had the greatest extent of chemical contamination and were predisposed to accumulating sediment contaminants relative to other habitats. Bay *et al*. (2005) also determined that, in 2003, marinas and estuaries had the greatest frequency of sediment toxicity relative to other habitats in the SCB. 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

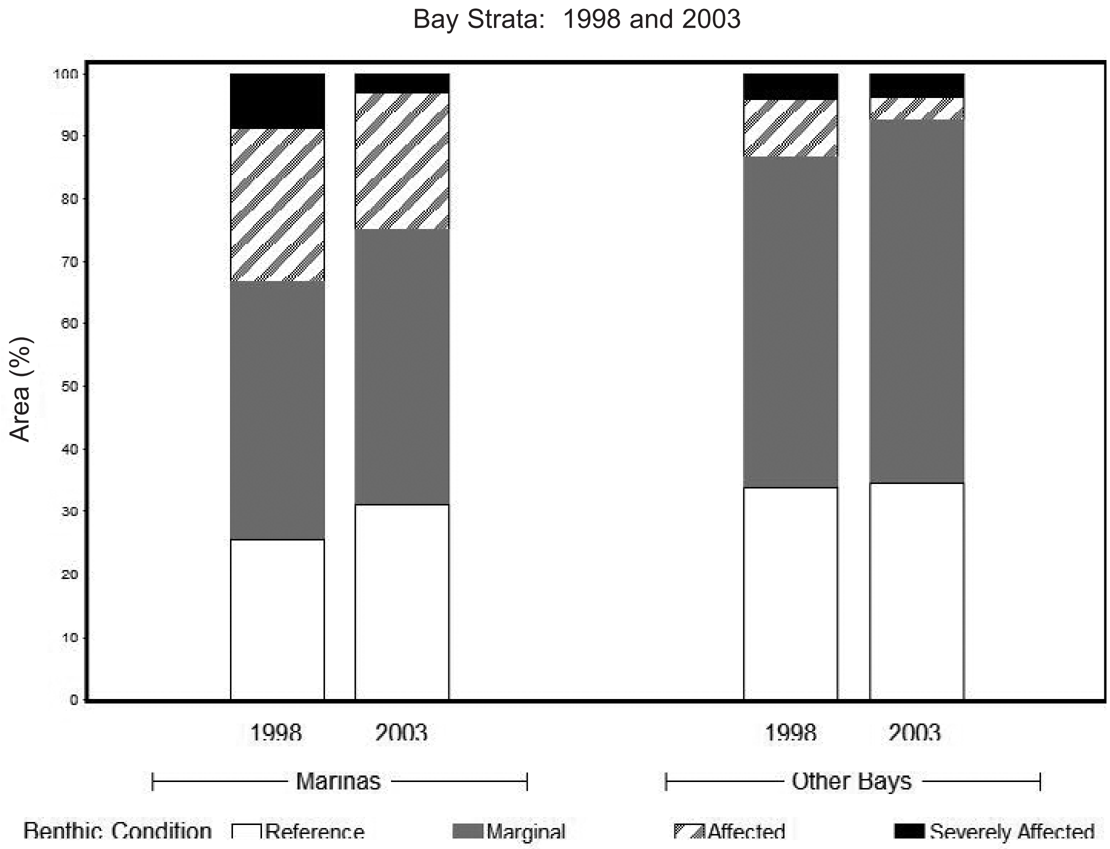

Figure 3. Area estimates of benthic condition for bay strata sampled in 1998 and 2003. "Affected" and "Severely Affected" are considered clear evidence of disturbed benthic communities. Benthic Response Categories are characterized in Table 2.

struggle to prevent body fluid 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 condense the large amounts of biological information present in a sample into a single number that is easy to interpret and communicate. The average sample from the mainland shelf of the SCB contains thousands of individuals and close to 100 species. Two assessment tools were used in this study; the BRI (Smith *et al*. 2001) for the mainland and island shelf, and a combination of benthic indices (Bay *et al*. 2009, Ranasinghe *et al*. 2009) in bays and estuaries. Because embayments had rarely been assessed previously, a combination of multivariate and multimetric biointegrity indices was developed specifically for this study. The validation of the embayment index performance surpassed the status classification rates achieved by most previous benthic biointegrity index development efforts (>94%). Despite this success, the benthic index combination has limited applicability in certain situations. For example, it was not developed for brackish water (<18 psu) estuaries and lagoons; five of the lagoons sampled in the SCB during the summer of 2003 contained brackish water and could not be evaluated.

The BRI (Smith *et al*. 2001) used to assess benthic condition on the mainland shelf and upper slope also has its limitations. The BRI is a multivariate assessment tool that was calibrated for shelf depths from 5 to 324 m. Validation analyses showed that the BRI was most accurate from 31 to 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 to 324 m. Therefore, the condition of 61 benthic samples from continental slope and basin habitats deeper than 200 m were not assessed in 2003. This is a point of considerable interest because Schiff *et al*. (2006) reported that contaminants are accumulating on the SCB continental slope and basins are accumulating sediment contaminants.

Despite their success in assessing benthic condition, both the BRI and the benthic index combination cannot discriminate the individual stressors responsible for poor benthic condition. If impaired benthic condition does exist, neither biointegrity measure can distinguish which constituents are responsible for the impairment. In addition, neither can distinguish between anthropogenic (e.g., chemical stress) and natural (e.g., salinity, wave, or storm) impacts. Ultimately, the goal of any assessment would be to measure and designate the stressors that are the likely cause of observed poor benthic condition.

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 nine-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, such as marinas, bays, and estuaries, cannot be assessed at present due to the short time series. 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 mainland shelf sites in poor benthic condition in the present study. The Palos Verdes Shelf and Santa Monica Bay receive flow from the two largest POTW discharges in the SCB; current discharges introduce only small amounts of pollutants, but legacies of past discharges remain in the sediments as elevated organic and toxicant concentrations. The Eastern Santa Barbara Channel receives runoff from the Santa Clara River agricultural watershed.

The SCB regional monitoring program series are not presently well designed 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 series is now a model of consistency and quality (Ranasinghe *et al*. 2003b). A second weakness to trend detection is spatial. Only the inner and middle shelf strata were consistently sampled in 1994, 1998, and 2003. 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 +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 deviating marginally from reference (Benthic Response Category 2), 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.

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