Appendix F

Characteristics of Benthic Macrofauna of the Southern California Bight

Tim K. Mikel[1]
J. Ananda Ranasinghe[2]
David E. Montagne[3]

[1]Aquatic Bioassay and Consulting Laboratories, Inc., 29 North Olive Street, Ventura, CA 93001.
[2]Southern California Coastal Water Research Project Authority, 7171 Fenwick Lane, Westminster, CA 92683.
[3]County Sanitation District of Los Angeles County, P.O. Box 4998, Whittier, CA 90607.

Introduction

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 several thousand 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. Most of these programs collect site-specific information about the impacts of individual waste discharges. They assess the presence of impacts by comparing conditions along a gradient of sites from “near field” sites close to the discharge to “far field” sites some distance away, based on the assumption that there is no measurable discharge effect at the far field site.

Many of these programs include benthic studies because 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. The monitoring programs infer the presence or absence of discharge effects by assessing the nature of benthic response, reflected in changes in community composition along the gradient from near field to far field benthic samples.

An alternative way to infer the presence or absence of effects is to view conditions along the gradient in the context of regional background. This can be achieved by comparing results along the gradient to average conditions prevailing in areas that are some distance away from, and show no evidence of impacts from, anthropogenic sources. This approach does not assume that the far field sites are free of discharge effect and the gradient encompasses both impacted and unimpacted conditions, which may not be accurate. The alternative approach also takes into account the possibility of influences of other known or unknown sources, which could modify or obscure the effects of the discharge of concern. Comparisons with average conditions for the habitat could result in the conclusion that conditions all along the gradient fail to meet expectations for the habitat. Comparing conditions to average conditions for the habitat may also result in a more accurate description of the nature and extent of the impact caused by the discharge of concern.

In the last decade, three regional monitoring programs have collected the type of information necessary calculate average conditions for SCB habitats. Rather than being clustered around one or more discharge outfalls, spatially random samples were collected throughout the SCB in 1994 Bergen *et al.* (1998), 1998 Ranasinghe *et al.* (2003) and 2003

Ranasinghe *et al.* (2007). Subsequent analyses of these data (Bergen *et al.* 2001, Ranasinghe *et al.* 2003) identified depth as the primary determinant of benthic composition. These studies also delineated the primary coastal habitats as the inner (5 to 30 m deep), middle (30 to 120 m deep) and outer (120 to 200 m deep) mainland shelf, the upper slope (200 to 500m deep) and the lower slope and basins (500 to 1000 m deep); estuaries and bays were established as primary habitats on the land margins of the continuum.

Our objective here is, for minimally stressed sampling sites in each SCB benthic habitat, to present average values for community measures, higher taxonomic composition, and dominant species. This information can be used to provide context and facilitate evaluation of the results of other benthic monitoring studies that are more limited in space and time.

Methods

Sediments in SCB habitats were sampled and analyzed for three regional monitoring surveys between 1994 and 2003. Benthic macrofauna samples were collected from mid July to mid October in 1994 (Bergen *et al.* 1998), 1998 (Ranasinghe *et al.* 2003) and 2003 (Ranasinghe *et al.* 2007). They were collected 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.

Benthic samples were rinsed and transferred from formalin to 70% ethanol 3 to 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. Taxonomic inconsistencies among the three time periods were eliminated by cross-correlating the species lists, identifying differences in nomenclature, and consulting taxonomists for each program to resolve discrepancies.

Additional sediment samples were collected for analysis of sediment particle size distribution, sediment contaminants, and sediment toxicity. Sediment particle size analysis was accomplished by sieving samples through 1000-µm and 2000-µm sieves and analyzing material that passed through the sieves on Coulter LS230 or Horiba LA900 laser diffraction size analyzers. Metals other than mercury were analyzed by digesting sediment in strong acid and analyzing the digestate by inductively coupled plasma mass spectrometry, or inductively coupled plasma emission, flame atomic absorption or graphite furnace atomic absorption spectroscopy. Mercury was analyzed using cold vapor atomic absorption spectroscopy. Minimum detection limits for trace metals were specified as one-fifth the effects range low (ERL) concentration (Long *et al.* 1995). Organic chemicals were extracted, subjected to clean-up procedures, and analyzed by gas chromatography. Total organic carbon and total nitrogen were analyzed by a Carlo Erba 1108 CHN Elemental analyzer. Toxicity of the top 2 cm of sediment to the amphipod *Eohaustorius estuarius* was tested by a ten-day test.

Because our objective was to define natural groupings of stations with similar species composition, we used criteria similar to those of Bergen *et al.* (2001) to eliminate potentially contaminated sites from the analysis. A site was considered potentially contaminated if more than three chemicals exceeded Long *et al.* (1995) effects range low (ERL) values, one or more chemicals exceeded Long *et al.* (1995) effects range median (ERM) values, or it was located within the area of influence of a storm water or municipal waste water outfall. We also excluded sites that were disturbed by dredging shortly before sampling occurred. ERL and ERM values were calculated using concentrations of ten chemicals including seven metals (As, Cd, Cu, Pb, Hg, Ag, Zn) and three organics (total PCB's, low molecular weight PAHs and high molecular weight PAHs). Low molecular weight PAHs were standardized by summing the detected and below detection limit values for acenaphthene, anthracene, biphenyl, naphthalene, 2,6-dimethylnaphthalene, fluorene, 1-methylnaphthalene, 2-methylnaphthalene, 1-methylphenanthrene, and phenanthrene, while high molecular weight PAHs included benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, chrysene, dibenz(a,h)anthracene, fluoranthene, perylene, and pyrene. Cr, Ni, and DDT's were not included because, in our habitats, high (near ERM) background values are common with no detectable faunal response. Data from Mexican samples and low (<18 psu) salinity samples were eliminated prior to data analysis because they were beyond the scope of our study. After these exclusions, 564 stations remained for analysis (Table 1).

Table 1. Numbers of benthic samples collected in Southern California Bight habitats in the USA for regional monitoring surveys from 1994 to 2003. A site was considered potentially contaminated if more than three chemicals exceeded Long *et al.* (1995) effects range low (ERL) values, one or more chemicals exceeded Long *et al.* (1995) effects range median (ERM) values, it was located within the area of influence of a storm water or municipal waste water outfall, or known to have been disturbed by dredging shortly before sampling occurred.

Habitat	**Numbers of samples**	
	Collected	After eliminating potentially contaminated samples
1. Estuaries	55	32
2. Bays	201	90
3. Inner mainland shelf	193	104
4. Middle mainland shelf	309	156
5. Outer mainland shelf (200-500m)	68	46
6. Island shelf (5-200m)	85	81
7. Upper slope (200-500m)	33	31
8. Lower slope and basins (500-1000m)	33	24
Total	977	564

Habitat delineations (see Table 1) were based on recent (Ranasinghe *et al.* In prep) and previous (Bergen *et al.* 2001, Ranasinghe *et al.* 2003) assemblage analysis of these data or temporal subsets of it. The assemblage analyses identified naturally occurring assemblages in the Southern California Bight and the habitat factors that structure them. Assemblages were identified using hierarchical cluster analysis after eliminating potentially contaminated sites.

Habitat variables were tested across dendrogram splits in the cluster analysis results to assess whether the assemblages occupied different habitats.

Community measure means, higher taxonomic composition, and dominant species were compared among habitats. For habitats where data were available for multiple surveys, community measure means were also compared for the 1994, 1998 and 2003 surveys. Habitat means were calculated for five community measures: total abundance, number of taxa, Shannon-Wiener diversity, evenness, and dominance. Abundance and numbers of taxa were expressed as numbers per 0.1-m^2 sample. The Shannon-Wiener and evenness indices were calculated using natural logarithms (McIntosh 1967, Pielou 1969). Dominance was calculated as the minimum number of species whose combined abundance was equal to 75% of the individuals in the sample (Swartz *et al.* 1986, Ferraro *et al.* 1994).

Higher taxonomic composition was expressed as mean abundance and numbers of taxa per sample for each of seven groups of organisms. The groups were polychaeta, oligochaeta, arthropoda, mollusca, ophiuroida, other echinoderms, and other phyla.

Dominant species were evaluated on their abundances and occurrence at sites in each habitat. Fidelity of a species to a habitat was calculated as the percentage of sites in that habitat at which it occurred. Exclusivity of a species for a habitat was calculated as the percentage of total abundance that occurred in that habitat.

Results

A. Community Measures

i Bight-Wide Averages

Average macrofaunal abundance in the SCB for all three surveys was 452 organisms per 0.1 m^2 sample, and the average sample contained 59 taxa. The average Shannon-Wiener Diversity was 3.12, eveness was 0.78, and species dominance was 18.3.

ii Comparisons Among Habitats

Mean abundances of benthic macrofauna decreased with increasing distance from land (Figure 1A, Table 2). Abundances were highest in estuaries and bays, intermediate on the mainland and island shelf, and lowest on the slope and in basins. At 1308.5 and 802.7 individual animals per 0.1m^2 sample, mean abundances in estuaries and bays were nearly three times and twice the mean abundance on the island shelf, which was third highest at 473.3 per sample. Mainland shelf abundances ranged from 208.8 per sample on the outer shelf to 283.4 on the inner shelf and 389.5 on the middle shelf. The lowest abundances were observed on the upper slope (66.7) and lower slope and basins (26.0).

Patterns for numbers of taxa were similar to abundance patterns off the coast, but differed in bays and estuaries (Figure 1B, Table 2). The rank order for mean numbers of taxa was the same as for mean abundance for the shelf, slope, and basin habitats. The highest numbers of taxa were encountered on the island shelf and middle mainland shelf (79.2 and 78.4

per 0.1-m^2 sample, respectively), moderate numbers of taxa occurred on the inner and outer mainland shelves (62.3 and 55.2), and low numbers on the upper slopes (24.3) and lower slopes and basins (13.3). Numbers of taxa in estuaries (22.2 per sample) and bays (45.2) were about a third and half the numbers of taxa in shelf habitats although abundances were two to three times as large (Figure 1A, Table 2).

Table 2. Community measure means for habitats of the Southern California Bight. Ninety-five percent confidence intervals are presented in parentheses. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys. Dominance was calculated as the minimum number of species whose combined abundance was equal to 75% of the individuals in the sample (Swartz *et al.* 1986).

			Mainland Shelf					
	Estuaries	**Bays**	**Inner**	**Middle**	**Outer**	**Island Shelf**	**Upper slope**	**Lower slope & basins**
Abundance ($0.1\ m^{-2}$)	1,308.5 (±563.8)	802.7 (±161.5)	283.4 (±37.7)	389.5 (±30.3)	208.8 (±38.5)	473.3 (±72.7)	66.7 (±18.9)	26.0 (±5.9)
Numbers of taxa ($0.1\ m^{-2}$)	22.2 (±5.3)	45.2 (±3.7)	62.3 (±5.1)	78.4 (±4.4)	55.2 (±6.2)	79.2 (±7.9)	24.3 (±5.6)	13.3 (±2.2)
Shannon-Wiener diversity ($\log_e$)	1.68 (±0.18)	2.59 (±0.13)	3.48 (±0.09)	3.42 (±0.09)	3.43 (±0.12)	3.43 (±0.14)	2.74 (±0.21)	2.38 (±0.19)
Evenness ($\log_e$)	0.56 (±0.05)	0.68 (±0.03)	0.84 (±0.01)	0.78 (±0.01)	0.85 (±0.02)	0.78 (±0.02)	0.88 (±0.03)	0.92 (±0.02)
Dominance	3.6 (±0.9)	9.0 (±1.2)	22.5 (±1.7)	23.0 (±1.7)	21.3 (±2.2)	23.6 (±2.7)	12.4 (±2.6)	8.7 (±1.3)

Patterns for mean Shannon-Wiener diversity and dominance (Figures 1C and 1E) were similar to each other and to patterns for numbers of taxa (Figure 1B). Highest values were observed in shelf habitats and decreased landward in bays and estuaries, and seaward down slopes to basins. Evenness increased with distance from land and depth (Figure 1D).

iii Comparisons Among Surveys

Abundance patterns were stable over time for the two habitats that were sampled on three surveys and the three habitats that were sampled on two surveys (Figure 2A). Although mean abundance in bays increased from 749.5 per sample in 1998 to 904.0 per sample in 2003, the 95% confidence intervals overlap and the difference was not statistically significant. Patterns for numbers of taxa also were stable across surveys (Figure 2B). Stable temporal patterns were also observed for Shannon-Wiener diversity (Figure 2C), evenness (Figure 2D) and dominance (Figure 2E) in bays and on the inner, middle and outer shelf. The exception was the island shelf, where significant increases in diversity, evenness and dominance occurred from 1998 to 2003. This change was accompanied by an increase in the mean number of taxa per sample from 72.0 to 92.9 and a decrease in mean abundance from 484.6 to 451.9. These abundance and number of taxa differences were not statistically significant. Patterns for diversity, evenness, and dominance were similar to patterns for numbers of taxa (Figure 2).

B. Higher Taxonomic Composition

Mean abundances (Table 3) and relative contribution (Figure 3) of the major taxonomic groups varied among the habitats. Estuaries differed from all other habitats in the relatively lower dominance of polychaetes (43%), the high abundance of arthropods (35%), and the importance of oligochaetes (15%); oligochaetes were nearly absent from all other habitats. Bays were notable for the near absence of ophiuroids and other echinoderms (<1%), a characteristic shared with estuaries. On the open coast, shelf depth habitats were broadly similar in composition. The island shelf and inner mainland shelf share low abundances of ophiuroids relative to the middle and outer mainland shelf. The slope and basins shared very similar faunal composition with basins somewhat lower in abundance than the slope. Mollusks reached greatest relative importance (>20%) in these habitats, while polychaete dominance was somewhat lower (49%) than other open coastal habitats. Overall, polychaetes dominated abundance in all habitats with highest mean abundance in estuaries and bays and greatest relative importance on the island shelf (64%). Secondary dominance differed among habitats. Arthropods were most important in estuaries, and the island, inner and outer mainland shelves. They shared dominance with mollusks in bays, on the slope and in basins. On the middle mainland shelf, ophiuroids and arthropods were of equal importance.

Table 3. Mean abundances for major taxonomic groups in habitats of the Southern California Bight. Ninety-five percent confidence intervals are presented in parentheses. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

			Mainland Shelf					
	Estuaries	**Bays**	**Inner**	**Middle**	**Outer**	**Island Shelf**	**Upper slope**	**Lower slope & basins**
Polychaetes	560.3 (±343.7)	494.6 (±108.4)	160.2 (±23.5)	204.7 (±20.0)	116.0 (±20.9)	301.1 (±49.8)	32.4 (±10.6)	12.7 (±4.7)
Oligochaetes	194.9 (±157.9)	7.1 (±7.2)	0.4 (±0.5)	0.3 (±0.2)	0.3 (±0.5)	7.0 (±6.2)	0.03 (±0.07)	--
Arthropods	458.8 (±279.3)	131.9 (±43.1)	54.2 (±8.2)	63.9 (±8.5)	44.3 (±14.0)	73.4 (±21.0)	11.3 (±4.9)	5.1 (±2.2)
Molluscs	76.9 (±36.3)	144.2 (±53.4)	32.7 (±5.0)	28.1 (±3.8)	18.1 (±4.4)	40.3 (±8.8)	14.7 (±6.6)	5.3 (±1.4)
Ophiuroid Echinoderms	0.2 (±0.2)	3.9 (±1.6)	7.0 (±4.4)	63.9 (±8.2)	23.6 (±8.9)	15.9 (±4.4)	3.8 (±2.2)	1.0 (±0.6)
Other Echinoderms	0.3 (±0.3)	2.3 (±2.4)	1.5 (±0.6)	1.9 (±0.3)	2.2 (±0.8)	4.0 (±0.9)	2.2 (±0.8)	0.3 (±0.3)
Other Phyla	17.2 (±10.7)	18.8 (±4.8)	27.4 (±6.2)	26.6 (±4.7)	4.3 (±1.4)	31.5 (±13.0)	2.3 (±0.9)	1.5 (±0.8)

The number of taxa within each major taxonomic group (Table 4, Figure 4) exhibited three different patterns related to habitat and depth. Estuaries and bays shared near identical composition with overall richness higher in the bay habitat. Polychaetes contributed fewer than half the taxa, mollusks and arthropods were well and similarly represented. Substantial numbers of taxa belonging to other phyla (such as cnidarians) occurred in these inshore habitats, while echinoderms were nearly absent. A second pattern was common to open coast shelf-depth habitats. Polychaetes contributed approximately 50% of the species in these habitats; arthropods were the next most diverse group, followed by mollusks. A third pattern characterized by relatively low numbers of polychaete taxa and high mollusk and arthropod richness was typical of the slope and basin habitats. This deep-water pattern was very similar to that of estuaries and bays, differing only in the presence of echinoderms as contributors of diversity.

Table 4. Mean numbers of taxa for major taxonomic groups in habitats of the Southern California Bight. Ninety-five percent confidence intervals are presented in parentheses. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys. Oligochaetes were not further identified and were represented as a single class-level taxon in the data.

			Mainland Shelf					
	Estuaries	**Bays**	**Inner**	**Middle**	**Outer**	**Island shelf**	**Upper slope**	**Lower slope & basins**
Polychaetes	10.0 (±2.2)	20.9 (±1.5)	30.5 (±2.4)	39.8 (±1.9)	29 (±2.6)	40.8 (±3.4)	11.2 (±2.1)	5.4 (±0.9)
Oligochaetes	0.6 (±0.2)	0.4 (±0.1)	0.04 (±0.03)	0.1 (±0.04)	0.1 (±0.1)	0.3 (±0.1)	0.03 (±0.05)	--
Arthropods	4.3 (±1.0)	9.1 (±0.8)	14.1 (±1.1)	18.3 (±1.2)	13.7 (±2.3)	17.9 (±2.0)	5.0 (±1.6)	3.3 (±0.9)
Molluscs	5.2 (±1.3)	19.2 (±1.0)	9.4 (±0.8)	9.6 (±0.6)	6.9 (±0.8)	9.2 (±1.0)	4.8 (±1.1)	3.2 (±0.9)
Ophiuroid Echinoderms	0.1 (±0.1)	0.8 (±0.1)	1.0 (±0.2)	2.4 (±0.2)	2.1 (±0.4)	2.2 (±0.2)	0.9 (±0.3)	0.2 (±0.2)
Other Echinoderms	0.2 (±0.1)	0.2 (±0.1)	0.6 (±0.1)	1.0 (±0.1)	0.9 (±0.2)	1.5 (±0.2)	1.1 (±0.3)	0.2 (±0.1)
Other Phyla	1.8 (±0.6)	4.61 (±0.5)	6.6 (±0.6)	7.2 (±0.5)	2.5 (±0.5)	7.3 (±0.8)	1.2 (±0.4)	0.9 (±0.4)

C. Dominant Taxa

Dominant taxa in habitats at the ends of the estuarine gradient had high exclusivity indicating a tendency to occur primarily in the habitats where they are dominant, while dominant taxa in shelf habitats tended to have lower exclusivity and wider distributions. Ten of fourteen estuarine taxa ranked in the top ten for abundance or fidelity had exclusivity over 75 (Table 5), indicating that 75% or more of their abundance occurred in estuaries. Eleven of 16 similarly ranked bay taxa had exclusivity over 75 (Table 6). In contrast, one of 14, one of 12, none of 13, two of 15, and three of 17 similarly ranked taxa had exclusivity over 75 on the inner mainland shelf (Table 7), middle mainland shelf (Table 8), outer mainland shelf (Table 9), island shelf (Table 10) and the upper slope (Table 11). At the other end of the depth gradient, 11 of 16 lower slope and basin taxa ranked in the top ten for abundance and fidelity had exclusivity over 75 (Table 12).

The estuarine dominants included species often associated with organic pollution. *Capitella capitata* Complex ranked third for abundance and occurred at 68.8% of the estuarine sites, while *Streblospio benedicti* ranked sixth and occurred at 59.4% of these sites.

Table 5. Dominant taxa in estuaries. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at estuarine sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring in estuaries. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

Rank	Taxon Name	Mean Abundance (0.1 m^{-2})	95% CLM	Fidelity	Exclusivity
1	Oligochaeta	194.88	131.20	56.3	82.7
2	*Grandidierella japonica*	188.72	83.04	87.5	94.1
3	*Capitella capitata* Complex	130.19	94.95	68.8	94.8
4	*Monocorophium insidiosum*	124.44	172.49	40.6	99.4
5	*Monocorophium acherusicum*	118.34	81.46	40.6	77.8
6	*Streblospio benedicti*	117.34	90.81	59.4	99.2
7	*Dipolydora* spp.	85.75	111.10	50.0	96.6
8	*Mediomastus* spp.	70.19	88.26	46.9	20.9
9	*Pseudopolydora paucibranchiata*	51.31	52.18	71.9	17.9
10	*Armandia brevis*	22.84	34.61	37.5	81.0
11	*Acteocina inculta*	20.25	16.86	46.9	78.0
12	*Tagelus subteres*	18.53	16.05	53.1	38.3
16	*Protothaca* spp.	6.53	4.96	40.6	81.6
33	*Laevicardium substriatum*	1.81	1.05	40.6	31.0

Table 6. Dominant taxa in bays. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at bay sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring in bays.

Rank	Taxon Name	Mean Abundance (0.1 m^{-2})	95% CLM	Fidelity	Exclusivity
1	*Pseudopolydora paucibranchiata*	83.39	37.43	65.6	82.0
2	*Mediomastus* spp.	61.77	17.73	87.8	51.6
3	*Lumbrineris/Scoletoma* spp.	56.21	10.98	93.3	65.3
4	*Euchone limnicola*	47.08	21.00	61.1	99.0
5	*Musculista senhousia*	42.99	24.18	53.3	97.7
6	*Fabricinuda limnicola*	30.12	17.35	30.0	99.0
7	*Exogone lourei*	29.76	13.72	56.7	82.8
8	*Amphideutopus oculatus*	28.92	8.60	72.2	67.4
9	*Cossura* spp.	25.08	21.95	48.9	75.3
10	*Levinsenia* spp.	21.61	35.40	3.3	80.4
11	*Theora lubrica*	21.23	5.53	82.2	99.1
12	*Prionospio (Prionospio) heterobranchia*	20.39	5.67	66.7	92.5
13	*Leitoscoloplos pugettensis*	17.63	4.60	83.3	88.6
15	*Pista percyi*	13.58	4.14	66.7	81.8
19	*Euphilomedes carcharodonta*	11.96	5.98	64.4	45.5
44	*Glycera americana*	2.27	0.61	64.4	67.8

Table 7. Dominant taxa on the inner mainland shelf. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at inner shelf sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring on the inner shelf. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

Rank	**Taxon Name**	**Mean Abundance ($0.1\ m^{-2}$)**	**95% CLM**	**Fidelity**	**Exclusivity**
1	Maldanidae	13.15	3.98	69.2	34.7
2	*Spiophanes duplex*	12.36	2.59	93.3	10.5
3	*Paraprionospio pinnata*	9.10	1.81	80.8	44.2
4	*Mediomastus* spp.	8.65	3.26	75.0	8.4
5	*Lumbrineris/Scoletoma* spp.	7.72	4.73	75.0	10.4
6	*Amphideutopus oculatus*	7.37	2.20	57.7	19.8
7	*Spiophanes bombyx*	6.36	2.91	66.3	48.0
8	*Glottidia albida*	6.13	1.81	61.5	53.4
9	*Amphiodia* spp.	6.06	3.61	58.7	5.4
10	*Monticellina* spp.	5.45	1.96	64.4	32.7
13	*Tellina modesta*	3.98	1.00	73.1	81.0
17	*Tubulanus polymorphus*	3.49	0.71	69.2	38.8
19	Phoronida	3.24	0.79	65.4	14.8
35	*Nephtys caecoides*	1.63	0.32	65.4	52.3

Table 8. Dominant taxa on the middle mainland shelf. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at middle shelf sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring on the middle shelf. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

Rank	**Taxon Name**	**Mean Abundance ($0.1\ m^{-2}$)**	**95% CLM**	**Fidelity**	**Exclusivity**
1	*Amphiodia* spp.	60.38	6.85	95.5	80.4
2	*Spiophanes duplex*	39.54	5.17	97.4	50.3
3	Maldanidae	8.42	1.79	84.0	33.3
4	Phoronida	6.83	1.66	72.4	46.8
5	*Mediomastus* spp.	6.54	2.10	75.0	9.5
6	*Pectinaria californiensis*	5.97	1.15	73.1	73.3
7	*Prionospio (Prionospio) jubata*	5.65	0.87	75.0	47.4
8	*Lumbrineris/Scoletoma* spp.	5.20	0.92	78.8	10.5
9	*Chloeia pinnata*	5.04	1.44	48.1	38.3
10	*Phisidia sanctaemariae*	4.39	1.89	44.2	73.9
16	*Paraprionospio pinnata*	3.74	0.56	78.8	27.3
17	*Ampelisca brevisimulata*	3.65	0.57	75.6	59.6

Table 9. Dominant taxa on the outer mainland shelf. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at outer shelf sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring on the outer shelf. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

Rank	Taxon Name	Mean Abundance (0.1 m^{-2})	95% CLM	Fidelity	Exclusivity
1	*Amphiodia* spp.	19.96	6.58	87.0	7.8
2	*Spiophanes kimballi*	12.46	4.05	78.3	35.0
3	*Mediomastus* spp.	9.33	3.77	65.2	4.0
4	*Spiophanes duplex*	8.87	3.29	67.4	3.3
5	*Euphilomedes producta*	6.46	4.22	41.3	33.2
6	*Lumbrineris/Scoletoma* spp.	5.74	1.48	84.8	3.4
7	*Chloeia pinnata*	5.46	2.12	65.2	12.2
8	Maldanidae	4.67	1.26	71.7	5.4
9	*Pectinaria californiensis*	4.59	1.33	73.9	16.6
10	*Aphelochaeta* spp.	3.61	0.98	71.7	8.8
11	*Paraprionospio pinnata*	3.57	0.78	87.0	7.7
12	*Parvilucina tenuisculpta*	3.48	1.44	69.6	14.1
13	*Ampelisca careyi*	3.35	1.28	71.7	38.2

Table 10. Dominant taxa on the island shelf. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at island shelf sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring on the island shelf. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

Rank	Taxon Name	Mean Abundance (0.1 m^{-2})	95% CLM	Fidelity	Exclusivity
1	*Spiophanes duplex*	44.98	10.31	81.5	29.7
2	*Aphelochaeta* spp.	13.84	4.01	69.1	59.3
3	*Spiochaetopterus costarum*	13.77	17.78	58.0	73.9
4	*Chloeia pinnata*	11.60	3.59	51.9	45.7
5	*Paradoneis* spp.	8.98	5.56	28.4	96.4
6	*Lumbrineris/Scoletoma* spp.	8.84	3.31	76.5	9.2
7	*Prionospio (Prionospio) jubata*	8.68	2.75	67.9	37.8
8	*Mediomastus* spp.	7.16	2.62	69.1	5.4
9	*Apionsoma misakianum*	7.14	6.36	21.0	94.8
10	Oligochaeta	6.99	5.22	25.9	7.5
11	*Amphiodia* spp.	6.46	2.62	64.2	4.5
15	*Parvilucina tenuisculpta*	5.58	2.79	65.4	39.7
24	Maldanidae	4.04	0.97	70.4	8.3
33	*Euclymeninae* sp A	2.80	0.76	64.2	15.1
41	*Monticellina* spp.	2.15	0.51	63.0	10.0

Table 11. Dominant taxa on the upper slope. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at upper slope sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring on the upper slope. Calculations were based on potentially uncontaminated sites sampled for the three regional monitoring surveys.

Rank	Taxon Name	Mean Abundance (0.1 m^{-2})	95% CLM	Fidelity	Exclusivity
1	*Maldane sarsi*	5.81	3.28	54.8	43.6
2	*Amphiodia* spp.	2.52	1.51	41.9	0.7
3	*Chloeia pinnata*	2.32	2.36	25.8	3.5
4	*Aphelochaeta* spp.	1.84	1.26	32.3	3.0
5	*Amphissa bicolor*	1.68	1.67	25.8	94.5
6	*Fauveliopsis* spp.	1.65	1.20	32.3	50.5
7	*Tellina carpenteri*	1.58	1.64	22.6	9.6
8	*Paraphoxus* sp 1	1.48	1.50	22.6	95.8
9	*Prionospio (Prionospio) ehlersi*	1.19	0.54	45.2	92.5
10	*Onuphis iridescens*	1.13	0.50	51.6	40.2
13	Chaetodermatidae	1.00	0.45	48.4	22.5
17	*Brisaster latifrons*	0.87	0.50	35.5	37.0
19	*Ampelisca unsocalae*	0.81	0.45	38.7	65.8
19	*Paraprionospio pinnata*	0.81	0.34	41.9	1.2
25	Lineidae	0.58	0.28	35.5	2.6
27	*Limifossor fratula*	0.55	0.22	45.2	41.5
32	*Glycera nana*	0.52	0.25	35.5	3.9

Table 12. Dominant taxa on the lower slope and in basins. Taxa with the ten highest mean abundances and ten highest fidelities are presented in abundance rank order. Rank: Abundance rank; 95% CLM: 95% confidence interval for the mean abundance; Fidelity: Occurrence at lower slope and basin sites expressed as a percentage. Exclusivity: The percentage of total abundance occurring on the lower slope and in basins.

Rank	Taxon Name	Mean Abundance (0.1 m^{-2})	95% CLM	Fidelity	Exclusivity
1	*Paralysippe annectens*	2.58	1.71	29.2	96.9
2	*Eclysippe trilobata*	1.46	1.12	41.7	23.6
3	*Neilonella ritteri*	1.04	0.58	33.3	92.6
4	*Axinodon redondoensis*	0.96	0.43	54.2	95.8
5	Chaetodermatidae	0.88	0.31	58.3	15.2
5	*Leiochrides* spp.	0.88	0.39	50.0	100.0
5	*Leucon bishopi*	0.88	0.76	20.8	100.0
8	Maldanidae	0.83	0.57	37.5	0.5
9	*Maldane californiensis*	0.75	0.51	33.3	100.0
10	Fauveliopsis spp.	0.63	0.47	25.0	14.9
10	*Monticellina* spp.	0.63	0.41	33.3	0.9
14	*Triantella* sp A	0.54	0.27	37.5	100.0
16	Lineidae	0.42	0.23	33.3	1.5

Table 13. Taxa dominant in more than one habitat of the Southern California Bight. Abundance ranks (A), fidelity (F) and exclusivity (E) are presented for taxa within the ten highest mean abundances and ten highest fidelities for more than one habitat. Calculations were based on potentially uncontaminated sites sampled for three regional monitoring surveys.

				Mainland Shelf					
		Estuaries	**Bays**	**Inner**	**Middle**	**Outer**	**Island shelf**	**Upper slope**	**Lower slope & basins**
Oligochaeta	A	1					10		
	F	56.3					25.9		
	E	82.7					7.5		
Mediomastus spp.	A	8	2	4	5	3	8		
	F	46.9	87.8	75.0	75.0	65.2	69.1		
	E	20.9	51.6	8.4	9.5	4.0	5.4		
Pseudopolydora paucibranchiata	A	9	1						
	F	71.9	65.6						
	E	17.9	82.0						
Lumbrineris/ Scoletoma spp.	A		3	5	8	6	6		
	F		93.3	75.0	78.8	84.8	76.5		
	E		65.3	10.4	10.5	3.4	9.2		
Maldanidae	A			1	3	8	24		8
	F			69.2	84.0	71.7	70.4		37.5
	E			34.7	33.3	5.4	8.3		0.5
Spiophanes duplex	A			2	2	4	1		
	F			93.3	97.4	67.4	81.5		
	E			10.5	50.3	3.3	29.7		
Paraprionospio pinnata	A			3	16	11		19	
	F			80.8	78.8	87.0		41.9	
	E			44.2	27.3	7.7		1.2	
Amphiodia spp.	A			9	1	1	11	2	
	F			58.7	95.5	87.0	64.2	41.9	
	E			5.4	80.4	7.8	4.5	0.7	
Monticellina spp.	A			10			41		10
	F			64.4			63.0		33.3
	E			32.7			10.0		0.9
Phoronida	A			19	4				
	F			65.4	72.4				
	E			14.8	46.8				
Pectinaria californiensis	A				6	9			
	F				73.1	73.9			
	E				73.3	16.6			
Chloeia pinnata	A				9	7	4	3	
	F				48.1	65.2	51.9	25.8	
	E				38.3	12.2	45.7	3.5	
Aphelochaeta spp.	A					10	2	4	
	F					71.7	69.1	32.3	
	E					8.8	59.3	3.0	
Parvilucina tenuisculpta	A					12	15		
	F					69.6	65.4		
	E					14.1	39.7		
Chaetodermatidae	A							13	5
	F							48.4	58.3
	E							22.5	15.2
Lineidae	A							25	16
	F							35.5	33.3
	E							2.6	1.5

Pseudopolydora paucibranchiata, *Musculista senhousia*, and *Theora lubrica*, the three most abundant non-indigenous taxa in bays (Ranasinghe et al. 2005) were ranked first, fifth and eleventh for abundance and occurred at 65.6%, 53.3%, and 82.2% of bay sites, respectively. *P.*

paucibranchiata, the most abundant bay species was also a dominant in estuaries, ranking ninth for estuarine abundance and occurring at 71.9% of estuarine sites. However, 82.0% of its abundance was in bays.

Few shelf species had high exclusivity. Exceptions included *Tellina modesta*, *Amphiodia* spp., *Paradoneis* spp. and *Apionsoma misakianum*. *T. modesta* ranked 13th for abundance on the inner shelf with fidelity of 73.1 and exclusivity of 81.0. *Amphiodia* spp. had the highest abundance on the middle shelf with fidelity of 95.5 and 80.4 exclusivity. *Paradoneis* spp. and *A. misakianum* were ranked 5th and 9th for abundance on the island shelf with exclusivity of 96.4 and 94.8, respectively. However, fidelity for these two species was less than 30.

Three species-level taxa on the upper slope also had high exclusivity but low fidelity. *Amphissa bicolor*, *Paraphoxus* sp 1, and *Prionospio (Prionospio) ehlersi* ranked 5th, 8th, and 9th for abundance with exclusivity >90 but fidelity <50. Seven of 13 lower slope and basin taxa had exclusivity >90. Chaetodermatidae, the only lower slope and basin taxon with fidelity >50, had the third highest fidelity, 48.4, on the upper slope.

The polychaete species *Spiophanes duplex* and *Paraprionospio pinnata* were dominant across several shelf habitats (Tables 7 to 10 and 13). *S. duplex* ranked in the top four for abundance in all four shelf habitats with fidelity >75 in three of them. *P. pinnata* had fidelity >75 for the three mainland shelf habitats. The polychaete *Mediomastus* spp. ranked in the top ten for abundance in six of the eight habitats with fidelity >50 in five of them (Table 13). However, 51.6 of the individuals were collected in bays and another 20.9% in estuaries. Other organisms dominant in several shelf habitats included *Lumbrineris/Scoletoma* spp., Maldanidae, *Amphiodia* spp., *Monticellina* spp. and Phoronida. These composite taxa are difficult to identify to species and our ranking includes individuals of several species.

Discussion

The primary purpose of these results is to provide information about "background" values for benthic parameters in Southern California Bight habitats to facilitate comparisons for studies that collect limited numbers of samples or study limited areas. The data tables with means and 95% confidence intervals that we present here can be used to determine whether samples conform to expectations for background values. We include data for several commonly used community measures, composition by major taxonomic groups, and dominant species because evaluation of benthic communities at all three levels is necessary to reach a conclusion. As a simple example, the presence of abundances and diversity within background confidence limits is insufficient to conclude the presence of background conditions; the identity of dominant species and major taxonomic groups contributing to the community measures should also meet expectations.

The results are interesting beyond this limited purpose for several reasons. First, three of eight habitats were sampled in a regional monitoring program for the first time and the patterns we observe are new and potentially exciting. Previous sampling in bays and on the mainland and island shelves were repeated, extended shoreward into estuaries, and extended seaward down the outer shelf and into basins to a depth of 1,000 m. Although samples have previously been collected in these habitats, they usually target specific localities for specific purposes such as monitoring around drilling rigs. Regional monitoring surveys collect spatially random samples that are better suited to making broad generalizations. Patterns such as the lower numbers of taxa in estuaries and bays at one end and the upper and lower slopes and basins at the other, with the more diverse shelf habitats between are more believable. If sampling were focused spatially for some other purpose, it would be more difficult to eliminate the likelihood of patterns that are artifacts of site selection.

Additional interest is generated as ecological hypotheses are proposed to explain observed patterns. One example is the association between mean numbers of taxa and the number of dominant taxa with high exclusivity. More dominant species in the low diversity habitats at the ends of the depth gradient had high exclusivity than in the higher diversity habitats in between. About 70% of the dominant species in estuaries, bays, and the lower slope and basins had high exclusivity (>75). In the shelf and upper slope habitats, the equivalent number was always <20. Presumably, the habitats at the extremes are more stressful than the shelf habitats. Species that are adapted to the stresses that reduce the numbers of taxa may have a competitive advantage and occur more often than in other habitats. Animals that are physiologically adapted presumably are better equipped to deal with hypoxia on the lower slope and basins and the osmotic stress from episodic freshwater inputs in estuaries and bays.

There is a north to south gradient of conditions from the Santa Barbara Basin, which is hypoxic to anaerobic, to the San Diego Trough, which lacks a sill and is continuously flushed and hence much more diverse than the three nearshore basins to the north (Thompson *et al.* 1993). The Santa Barbara, Santa Monica and San Pedro Basins have sills within the oxygen minimum zone (OMZ) which result in basin waters with low (< 0.03 ppm) dissolved oxygen concentrations (Emery 1960). The San Diego Trough is open and the bottom is deeper than the OMZ and, therefore, these waters have higher oxygen concentrations then the northern basins.

Another hypothesis relates to the general conformity with the Pearson and Rosenberg (1978) model of relationships between benthic abundance and diversity reported here and sediment total organic carbon (TOC) values reported by Schiff *et al.* (2006). Numbers of taxa were highest and abundances intermediate in shelf habitats, where TOC ranged from 0.27% to 1.0%. In bay and estuary habitats, where TOC was intermediate (1.1% to 1.6%) abundances were much higher, but numbers of taxa were low. Abundance and numbers of taxa were lowest and both were low where TOC was highest (1.9% to 3.3%) on the slopes and in basins.

Comparisons of the patterns we observed with patterns in coastal benthic multi-habitat and large depth transect studies are also of considerable interest. These aspects of our study have been postponed, due to time constraints.

In our efforts to restrict our analysis to "background" samples, we selected samples based on sediment toxicity, chemical contaminants and proximity of sampling sites to wastewater and storm water discharges as in many previous studies (e.g., Weisberg *et al.* 1997, Van Dolah *et al.* 1999, Bergen *et al.* 2001, Paul *et al.* 2001). The effects of unknown and unquantifiable disturbances such as physical disturbances from dredging or anchors cannot be quantified and are a source of error. However, the frequency and prevalence of these disturbances are likely insufficient to affect our results.

The numbers of potentially uncontaminated samples available for background calculations ranged from 24 on the lower slope and basins, to 156 on the middle mainland shelf (Table 1). Despite this difference, the level of statistical certainty is not disproportionately high; the critical value for Student's t-distribution decreases by only 0.084 (from 2.064 to 1.098) as the number of samples increases from 24 to 120. We expect these calculations to be repeated while including additional data from future regional monitoring surveys.

We cannot discount the possibility of temporal variation affecting our background value calculations because the available data were from three regional monitoring surveys over nine years. The habitats that were sampled changed somewhat from survey to survey. Only two habitats, the inner and middle mainland shelf, were sampled for all three surveys (Figure 2). We examined benthic data from habitats that were sampled in multiple surveys (Figure 2) and concluded that temporal effects were not a serious concern.

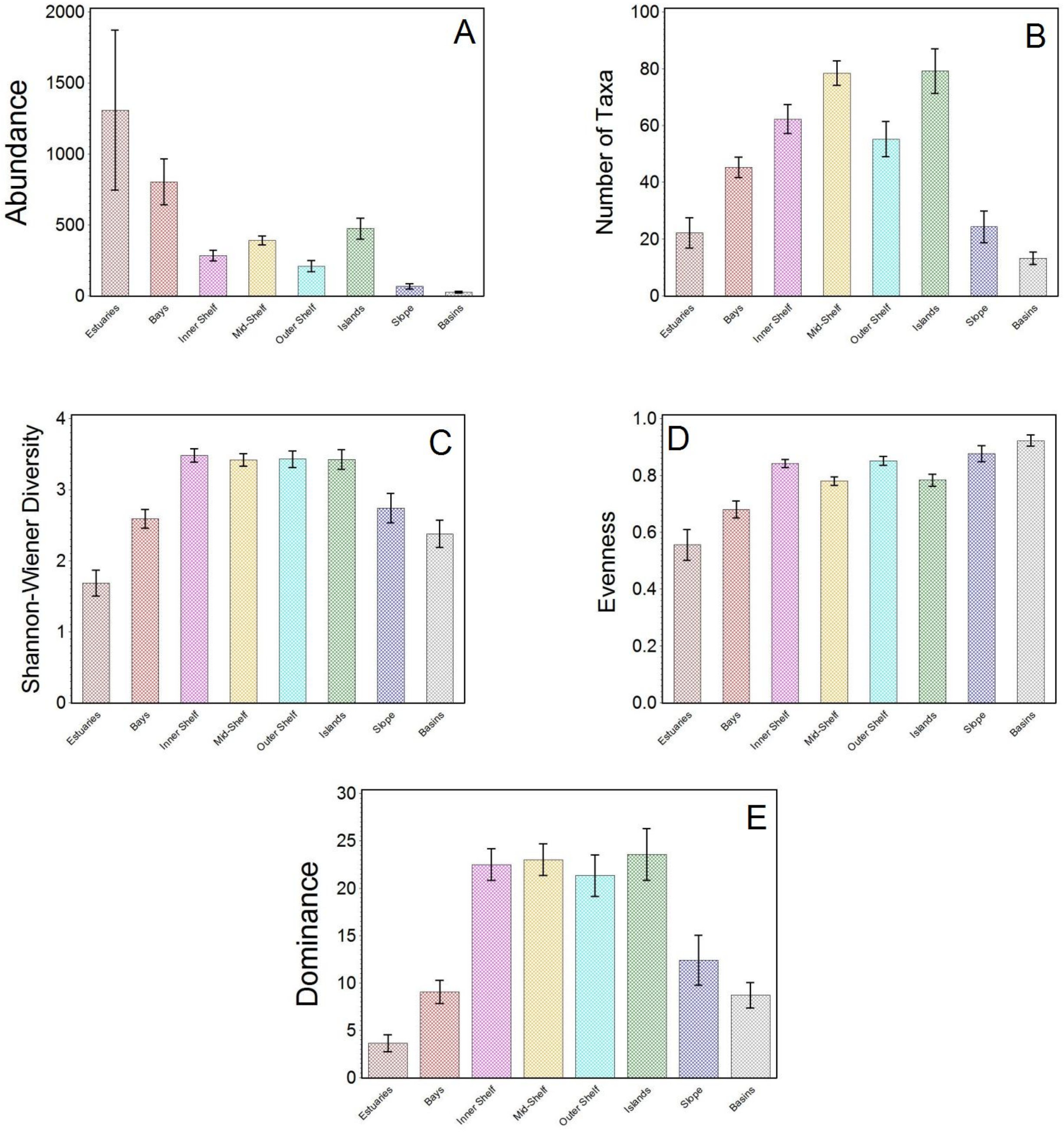

Figure 1. Benthic macrofaunal community measures for Southern California Bight habitats. A: Mean abundance (0.1 m^{-2}); B. Numbers of taxa (0.1 m^{-2}); C. Shannon-Wiener diversity ($\log_e$); D. Evenness ($\log_e$); E. Dominance (Swartz 1986). Error bars indicate 95% confidence intervals. Calculations were based on potentially uncontaminated sites sampled for the three regional monitoring surveys.

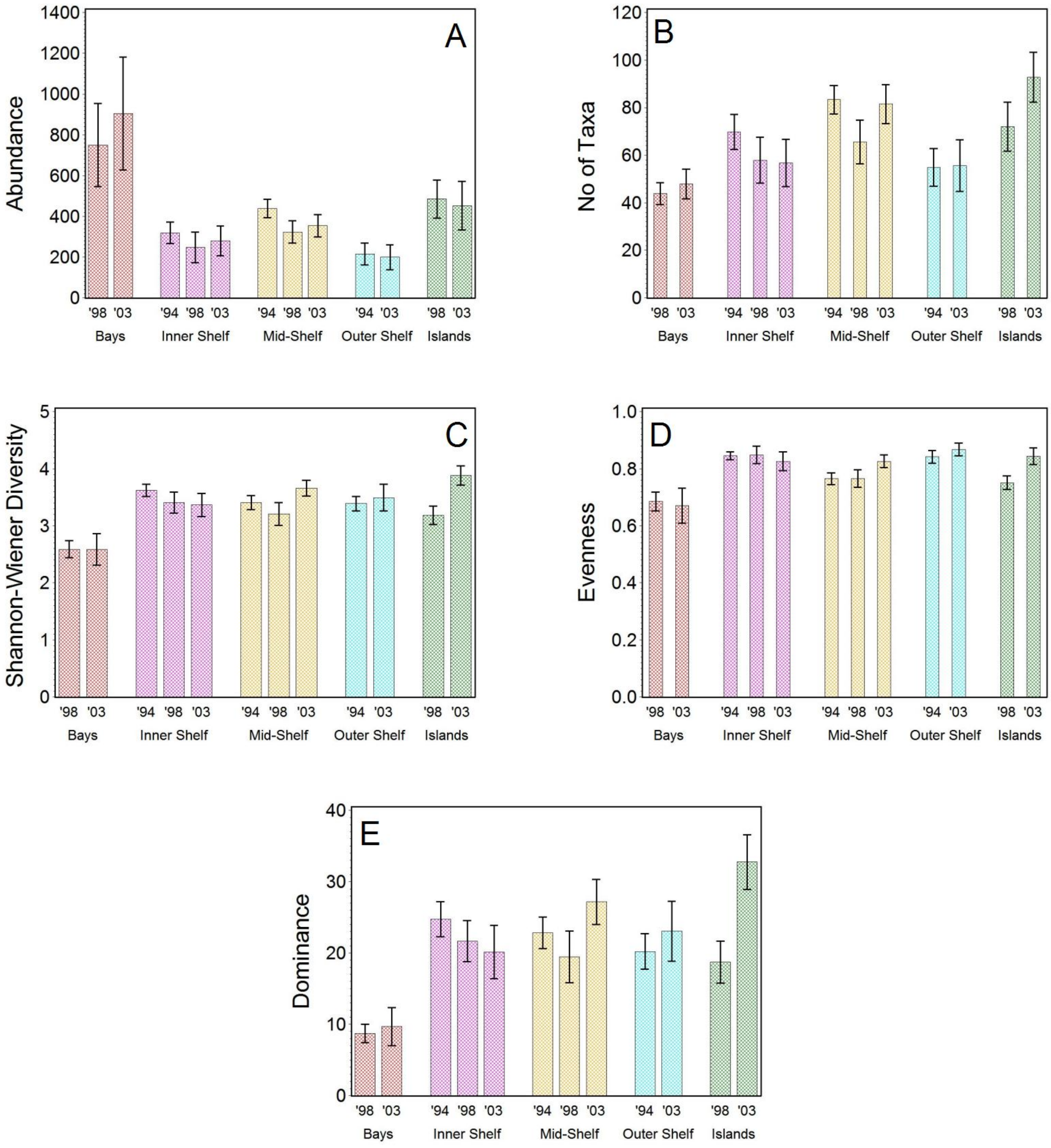

Figure 2. Benthic macrofaunal community measures for Southern California Bight habitats sampled in multiple surveys. A: Mean abundance (0.1 m^{-2}); B. Numbers of taxa (0.1 m^{-2}); C. Shannon-Wiener diversity (log$_e$); D. Evenness (log$_e$); E. Dominance (Swartz 1986). Error bars indicate 95% confidence intervals. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

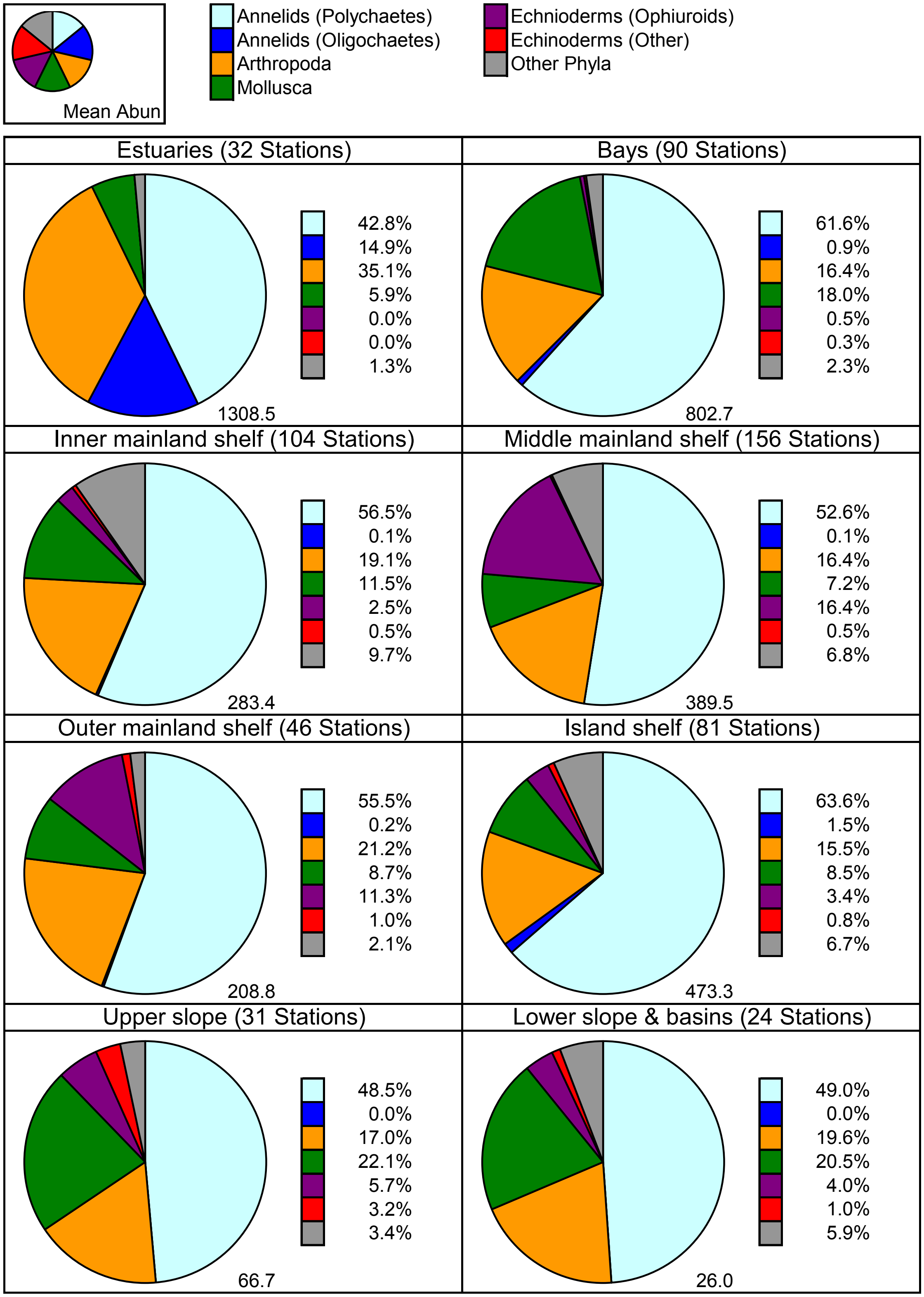

Figure 3. Distribution of macrofaunal abundance among major taxonomic groups in habitats of the Southern California Bight. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

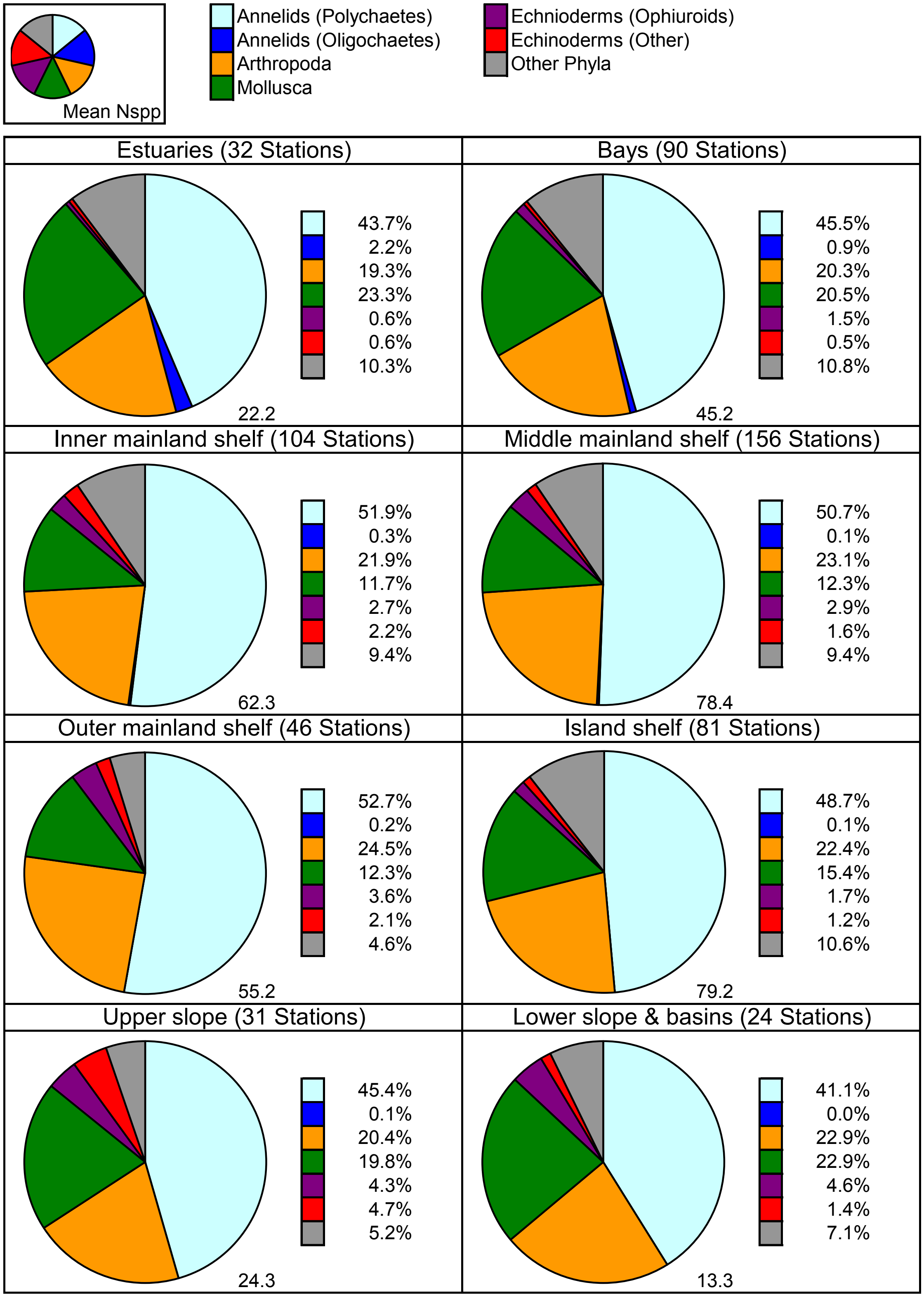

Figure 4. Distribution of numbers of taxa among major taxonomic groups in habitats of the Southern California Bight. Calculations were based on potentially uncontaminated sites sampled for the 1994, 1998 and 2003 regional monitoring surveys.

Literature Cited

Bergen, M., S.B. Weisberg, D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull and R.G. Velarde. 1998. Southern California Bight 1994 Pilot Project Volume IV: Benthic Infauna. Southern California Coastal Water Research Project. Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde and J.A. Ranasinghe. 2001. Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. *Marine Biology* 138:637-647.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde and J.A. Ranasinghe. 2001. Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. *Marine Biology* 138:637-647.

Emery, K.O. 1960. The Sea off Southern California: A Modern Habitat of Petroleum. Wiley. New York, NY.

Ferraro, S.P., R.C. Swartz, F.A. Cole and W.A. Deben. 1994. Optimum Macrobenthic Sampling Protocol for Detecting Pollution Impacts in the Southern California Bight. *Environmental Monitoring and Assessment* 29:127-153.

Long, E.R., D.D. MacDonald, S.L. Smith and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19:81-97.

McIntosh, R.P. 1967. An index of diversity and the relation of certain concepts to diversity. *Ecology* 48:392-404.

Paul, J.F., K.J. Scott, D.E. Campbell, J.H. Gentile, C.S. Strobel, R.M. Valente, S.B. Weisberg, A.F. Holland and J.A. Ranasinghe. 2001. Developing and applying a benthic index of estuarine condition for the Virginian Biogeographic Province. *Ecological Indicators* 1:83-99.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: An Annual Review* 16:229-311.

Pielou, E.C. 1969. An introduction to mathematical ecology. Wiley-Interscience. New York, NY.

Ranasinghe, J.A., A.M. Barnett, K.C. 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.

Ranasinghe, J.A., T.K. Mikel, R.G. Velarde, S.B. Weisberg, D.E. Montagne, D.B. Cadien and A. Dalkey. 2005. The prevalence of non-indigenous species in southern California embayments and their effects on benthic macroinvertebrate communities. *Biological Invasions* 7:679-686.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D.B. Cadien, R.G. Velarde and A. Dalkey. 2003. Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K.C., K. Maruya and K. Christenson. 2006. Southern California Bight 2003 Regional Monitoring Program Volume II: Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Swartz, R.C., F.A. Cole, D.W. Schults and W.A. DeBen. 1986. Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. *Marine Ecology Progress Series* 31:1-13.

Thompson, B., J. Dixon, S. Schroeter and D.J. Reish. 1993. Chapter 8: Benthic Invertebrates. pp:369-458 *in:* M.D. Dailey, D.J. Reish and J.W. Anderson *(eds)*. Ecology of the Southern California Bight. University of California Press. Berkeley, CA.

Van Dolah, R.F., J.L. Hyland, A.F. Holland, J.S. Rosen and T.R. Snoots. 1999. A benthic index of biological integrity for assessing habitat quality in estuaries of the southeastern USA. *Marine Environmental Research* 48:269-283.

Weisberg, S.B., J.A. Ranasinghe, L.C. Schaffner, R.J. Diaz, D.M. Dauer and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20:149-158.