Spatial Variability in Southern California Demersal Fish and Invertebrate Catch Parameters in 1994

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The four major publicly owned treatment works (POTWs) of Southern California are required to routinely monitor receiving waters near their outfalls as part of their discharge permits. Although localized fixed-site monitoring has been conducted for more than two decades, few regional surveys have been conducted. The Southern California Coastal Water Research Project (SCCWRP) conducted a survey along the 60-m isobath from Point Conception to the United States-Mexico border in 1976 (Word *et al.* 1977, Word and Mearns 1979). SCCWRP also conducted reference site surveys on a more limited basis but at three depths (30, 60, and 150 m) in 1985 (Thompson *et al.* 1987) and 1990 (Thompson *et al.* 1993b). However, there had never been a comprehensive benthic survey of the mainland shelf of the Southern California Bight (SCB) that measured water-column characteristics, measured sediment and tissue contamination, and collected data on infaunal and demersal fish and invertebrate populations at the same time and locations.

In August 1993, the Southern California Bight Pilot Project (SCBPP) was formed to conduct a regional survey of ecological conditions in soft-bottom habitats on the mainland shelf of the SCB (SCBPP 1994b, Bergen *et al.*, 1995; see *The Southern California Bight Pilot Project: An Overview,* this annual report). The SCBPP included representatives of 12 federal, state, and local agencies: United States Environmental Protection Agency (USEPA); Environmental Monitoring and Assessment Program (EMAP) and Region IX); California State Water Resources Control Board; California Regional Water Quality Control Boards (Los Angeles, Santa Ana, and San Diego Regions); City of Los Angeles, Environmental Monitoring Division; County Sanitation Districts of Los Angeles County (CSDLAC); County Sanitation Districts of Orange County (CSDOC); City of San Diego, Metropolitan Wastewater Department (CSDMWWD); Santa Monica Bay Restoration Project (SMBRP); and SCCWRP.

This survey was conducted from July to August 1994 by the four major POTWs and SCCWRP using a randomized grid sampling design developed specifically for the SCBPP by the USEPA EMAP (SCBPP 1994b). Data were collected for water quality, benthic infauna, sediment characteristics and contaminants, demersal fish and invertebrates, contaminant bioaccumulation by demersal fish, and sediment toxicity. The survey was designed to determine the average conditions in the SCB, and if conditions differ by region (e.g., north, central, south, and Santa Monica Bay), depth (inner, middle, and outer shelf), or proximity to outfalls or stormdrains.

Spatial variability in trawl catch parameters in the SCB have been described in earlier studies (Carlisle 1969, Allen and Voglin 1976, Mearns *et al.* 1976, Allen 1977, Allen and Mearns 1977, Word *et al.* 1977, Allen 1982, Thompson *et al.* 1987, Thompson *et al.* 1993a,b). However, the more extensive studies were conducted in the 1970s and conditions have changed as a result of general ocean warming and El Niños of the 1980s and 1990s (CSDLAC 1990, SCCWRP 1992). Further, improvements in wastewater treatment have also resulted in changes in fish and invertebrate populations at outfall areas (Stull 1995). However, there has been no recent Bight-wide survey that could address regional, depth, and outfall/nonoutfall variability in trawl catch parameters in the SCB. The objective of this study is to describe variability in demersal fish and invertebrate catch parameters (abundance, biomass, numbers of species, and diversity) in the SCB by region, depth, and proximity to outfalls. This analysis is part of a larger study of the spatial variability in demersal fish and invertebrate assemblages from the SCBPP survey of 1994.

MATERIALS AND METHODS

Study Area

The study area was the mainland shelf of Southern California from Point Conception, California, to the United States-Mexico border at depths of 10 to 200 m (Figure 1). Although focusing on the soft-bottom habitat of the shelf, it also included the water-column above these depths. The following subpopulations (i.e., comparison categories) were defined within this area for the trawl survey: regions — north (Point Conception to Point Dume), central (Point Dume to Dana Point), and south (Dana Point to U. S.-Mexico border); depth — inner shelf (10-25 m); middle shelf (26-100 m); and outer shelf (101-200 m); and outfall and nonoutfall areas. Outfall areas were delineated prior to the survey as broad regions encompassing much or all of the area monitored around ocean outfalls of the major publicly-owned treatment works (i.e., Hyperion Treatment Plant, Joint Water Pollution Control Plant, County Sanitation Districts 1 and 2 of Orange County, and Point Loma Wastewater Treatment Facility) (SCBPP 1994b).

Sampling Design

The sampling design for this survey was a modification of a design developed for the EMAP-Estuaries Louisiana Province (Summers *et al.* 1993). SCCWRP *et al.* (1994b), Bergen *et al.* (1995), and *The Southern California Bight Pilot Project: Sampling Design*, (this annual report) provide details of the survey design. A triangular grid of points was randomly placed over a map of the survey area and sampling sites were selected at random from the grid. The grid provided a systematic separation of sampling sites and the random selection of sampling sites provided an unbiased sample (SCBPP 1994b). The original EMAP grid was enhanced 7 x 7 x 7 fold, providing a base grid

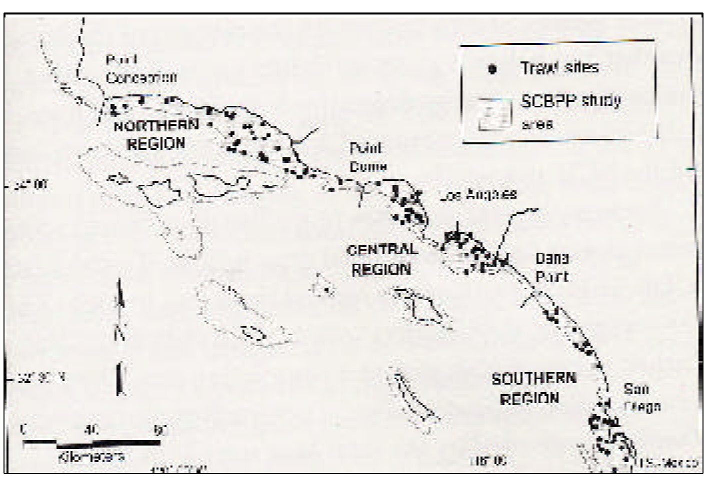

FIGURE 1. Stations sampled by trawl in on the mainland shelf of Southern California from depths of 10-200 m, Southern California Bight Pilot Project survey, July-August 1994.

with a hexagonal cell size of 1.89 km^2. Initially, the total area of the mainland shelf of the SCB (3,809 km^2) was divided by the cell size (1.89 km^2) to determine the number of cells needed to fill up the SCB area (i.e., 2013) (Table 1). Based upon cost and effort constraints, we chose to sample 140 trawl stations during the survey. At one station per cell, these would represent 0.070 (7.0 %) of the total number of possible cells. The cells then would have to be expanded by 1/0.070 or 14.3 times to cover the area. Thus each cell in the new grid would represent an area of 27.0 km^2. However, because of the need to obtain about 40 samples per subpopulation (to constrain the breadth of the 95% confidence limits of the cumulative distribution function (CDF; described below)), only the regional subpopulations would have been adequately tested. Thus, we produced more intensified grids to provide an adequate sampling effort in the inner and outer shelf (i.e., shallow and deep) zones and in the outfall areas (Table 1). Rather than basing the grid on the total SCB area, we determined the areas for the populations needing adjustment and then determined inclusion probabilities and area-weights. The area-weight of the station is expressed as one point (sample) for a given amount of area. Thus stations in outfall areas, inner and outer shelf nonoutfall areas, and middle shelf nonoutfall areas had area-weights of 12.6, 23.7, and 47.3 km^2, respectively. A sampling station site was placed randomly in each of the selected hexagonal cells.

Field Sampling

The trawl survey was conducted from July 12 to August 22, 1994 by five agencies in different regions: SCCWRP, with contractor MBC Applied Environmental Sciences (northern); CLAEMD (north-central); CSDLAC (mid-central); CSDOC with contractor MEC Analytical Systems, Inc. (south-central and north-southern); CSDMWWD (south-southern). Trawl samples were collected according to standard methods described in a field manual developed specifically for the survey (SCBPP, FCT 1994). Stations were located by standard or differential global positioning systems (GPS). If a site was not trawlable or too deep, stations could be moved up to 100 m from the nominal station site (but not to exceed 10% of the depth at that site). Samples were collected with 7.6 m head-rope semiballoon otter trawls with 1.25 cm cod-end mesh. Trawls were towed for 10 min at 0.8-1.2 m/sec (1.5-2.4 kn).

Fish and invertebrates were identified to species, individuals were counted, and species were weighed to the nearest 0.1 kg (using spring or platform scales). Lengths of individual fish were measured by centimeter size class on measuring boards; total length was measured for cartilagi-

TABLE 1. Area weights and inclusion probabilities of trawl stations in grid population areas in the Southern California Bight Pilot Project survey, July-August 1994[a].

Level 2 (Trawl) Populations	Area (km^2)	No. Cells[b]	Point Probability[c]	No. Samples[d]	Inclusion[e]	Population Cell (Station) Area-weight[f]
Outfall Areas	496	262	0.150	39	0.079	12.6
Inner[g] and Outer[g] Shelf Nonoutfall	1537	812	0.080	65	0.042	23.7
Middle[g] Shelf Nonoutfall	1777	939	0.040	38	0.021	47.3
Total	3809	2013		142		

[a]Based on information from D. L. Stevens and Mike McDowell, ManTech Environmental Research Services, Inc., Corvallis, OR 97335.
[b]Area of a cell is 1.892 km^2. Number of cells in a population = population area/cell area.
[c]Point probability = number of points or samples/number of cells.
[d]Number of samples = point probability/no. cells.
[e]Inclusion probability = point probability/cell area.
[f]Population cell area-weight = 1/inclusion probability.
[g]Inner shelf = 10-25 m; middle shelf = 26-100 m; outer shelf = 101-200 m.

nous fishes and board standard length for bony fishes. Each organism was also examined for external anomalies. Organisms requiring further identification, those with anomalies, and voucher specimens were fixed in 10% buffered Formalin-seawater solution on the boat and returned to the laboratory.

Quality Assurance/Quality Control

Because five agencies and two contractors participated in sample collection, special quality assurance/quality control procedures (QA/QC) were developed for the study (SCBPP 1994a). Field equipment and sampling protocol were described in a field operations manual (SCBPP, FCT 1994), which was developed by representatives of the five agencies. Field crews were required to adhere to the specified standards and protocols.

Prior to the first cruise, the equipment and sampling procedures utilized by each agency were checked during a precruise quality assurance check-out. Taxonomic aids for specific groups of invertebrates and fishes were distributed and discussed prior to the survey. During the cruise, quality control checks were made to assure that field equipment and procedures followed those prescribed in the manual. Species identifications, counts, lengths, weights, and anomalies were also randomly checked to ensure the quality of the data.

A voucher specimen for each species and species/ anomaly combination collected by each agency was also fixed and returned to the laboratory for confirmation. Photo vouchers were made for larger specimens. Voucher specimen identifications were checked by predetermined taxonomic specialists. Misidentifications were corrected in the field data.

Field data were checked and entered into a computer database by agency personnel. All computer data submitted to SCCWRP was checked against the original field data. After approval by the agencies and trawl QA/QC officer, the data were made available electronically to all participating SCBPP agencies.

Statistical Analyses

Demersal fish catch parameters included abundance, biomass, number of species, and Shannon-Wiener diversity (Shannon and Weaver 1949), all expressed per haul.

Cumulative distribution functions (CDFs). The survey was specifically designed to address questions regarding the spatial distribution of the data. These included the determination of cumulative distribution functions (CDFs) (see *The Southern California Bight Pilot Project: Sampling Design* in this annual report). CDFs provide graphical information on the percent of the survey area that lies below a given indicator value. From these graphs, medians can be determined, and these and overall distributions can be compared among subpopulations and and the SCB as a whole.

Each ecological indicator (e.g., fish abundance) value from a station has an associated area-weight. To calculate a CDF, indicator values are ranked from low to high. The area-weights at each station with a given indicator value are then accumulated, giving a cumulative sum of weight at each ranked indicator value. Then each cumulative sum of weight is divided by the total area weight to give a cumulative frequency distribution (with proportions adding up to 1.0) (D. L. Stevens, Jr., ManTech Environmental Research Services, Inc., Corvallis, OR 97335, pers. comm., 1995).

Area-weighted summary statistics. Area-weighted means, standard deviations, and 95% confidence limits were calculated using specially derived equations (Appendix 1). The area-weighted median was determined from the CDF; it represents the value at which 50% of the area lies above or below. This median thus differs from unweighted observation medians, defined as the value at which 50% of the observations lie above or below.

Statistical tests. G-tests were used to test for significant differences between subpopulations in the amount of subpopulation area lying below the Bight-wide area-weighted median for each parameter. The null hypothesis was that there was no difference between the subpopulations in the amount of area below the SCB median. Although in effect, this also generally tests the difference between subpopulation medians (Sokal and Rohlf 1995), this difference is not always reflected in the medians. For this test, the area in each subpopulation below the Bight median was determined and used in either a 2 x 2 G-test for independence in two-sample comparisons or an R x C (row by column) G-test for independence in three-sample comparisons (Sokal and Rohlf 1995). In both cases, William's correction was applied to reduce the Type I error, as recommended in Sokal and Rohlf (1995). If significant differences occurred in three-sample comparisons, the simultaneous test procedure (Sokal and Rohlf 1995) was used to determine which pairs differed significantly (thus giving an analogous result as application of a Student-Newman-Keuls test following an analysis of variance).

RESULTS

Sampling Success

Trawl samples were collected from 114 of 140 (81%) proposed trawl stations from Point Conception, California, to the U. S.-Mexico border and from depths of 9 to 215 m (Figure 1). Trawl success by sampling subpopulation ranged from 67 to 92% (Table 2). The highest success occurred in the northern region and the lowest in the southern region. By depth, sampling was most successful (88%) on the middle shelf and least successful (70%) on the outer shelf. Sampling success was lower (85%) in outfall areas than in nonoutfall (91%) areas. Most of the failures were due to unsuitable bottom topography (e.g., rocky, ridges) or obstructions (e.g., breakwater, kelp bed, outfall construction); three stations were not sampled because they were too deep; one was south of the U. S.-Mexico border; and one was not sampled due to gear failure. The greatest number of the trawl samples were collected from the middle shelf, north, and nonoutfall subpopulations.

TABLE 2. Distribution of sampling effort and success by subpopulation for Southern California Bight Pilot Project survey, July-August 1994.

Subpopulation	Number of Stations Planned	Number of Stations Successful	Percent Successful
Region			
Northern	49	45	92
Central	49	41	84
Southern	42	28	67
Depth Zone			
Inner Shelf (10-25 m)	36	30	83
Middle Shelf (26-100 m)	60	53	88
Outer Shelf (101-200 m)	44	31	70
Middle-Shelf Outfall Status			
Outfall	27	23	85
Nonoutfall	33	30	91
Total (All Stations)	140	114	81

Fish Catch Parameters

Abundance per haul. A total of 18,912 fish was taken during the survey (Table 3). The number of fish per haul (trawl) ranged from 3 to 781. Both the lowest and highest individual values occurred in the southern region, with lowest values occurring on the inner shelf and highest on the outer shelf. The median for the Bight as a whole was 103 individuals per haul, with subpopulation medians ranging from 38 (inner shelf) to 238 (outer shelf). Fish abundance was significantly higher (less area below the Bight median) in the southern region than in the central and northern regions; medians were 169, 95, and 95, respectively (Tables 3 and 4). Fish abundance differed significantly between each of the three depth zones and increased with increasing depth; medians were 38, 131, and 238 on the inner, middle, and outer shelf, respectively. Fish abundance was also significantly higher at outfall than at nonoutfall areas; medians were 167 and 123. The CDF curves for fish abundance were distinctly different for depth and outfall status but intertwined for regions (Figure 2).

Biomass per haul. A total of 621.8 kg of fish was taken during the survey (Table 3). The biomass of fish per haul ranged from 0.5 to 48.3 kg. The lowest individual values occurred in the northern region and on the outer shelf but the highest individual value was found in the central region on the middle shelf in the outfall area. The median for the Bight as a whole was 3.4 kg /haul, with subpopulation medians ranging from 2.8 (nonoutfall areas) to 6.4 kg (outer shelf). Fish biomass was significantly

TABLE 3. Demersal fish abundance, biomass, numbers of species, and diversity by subpopulation in the Southern California Bight Pilot Project survey, July-August 1994.

Category	No. Stations	Unweighted Values[a] Total	Range (per Haul)[b] Min	Max	Weighted Values (per Haul)[c] Median	Mean	SD	95% CL	Percent below Bight Median
Abundance (no. individuals)									
Region									
Northern	45	6131	15	371	95	137	100	29	53.8
Central	41	7064	17	726	95	159	148	46	59.9
Southern	28	5717	3	781	169	197	171	62	33.9
Depth Zone									
Inner Shelf	30	1515	3	170	38	50	37	14	93.9
Middle Shelf	53	9271	23	726	131	157	103	28	42.7
Outer Shelf	31	8126	15	781	238	259	177	63	26.4
Outfall Status (Middle Shelf)									
Outfall	23	4887	43	726	167	212	151	62	22.1
Nonoutfall	30	4384	23	324	123	146	86	31	47.6
Total (All Stations)	114	18912	3	781	103	157	134	24	50.0
Biomass (kg)									
Region									
Northern	45	170.5	0.5	13.2	3.0	3.6	2.5	0.7	63.0
Central	41	301.8	1.0	48.3	4.0	6.7	7.3	2.1	36.0
Southern	28	149.5	0.6	15.2	4.7	5.7	4.2	1.9	38.9
Depth Zone									
Inner Shelf	30	137.0	0.6	25.4	3.2	4.6	4.8	1.7	54.8
Middle Shelf	53	277.1	0.6	48.3	3.0	4.3	5.0	1.2	58.0
Outer Shelf	31	207.7	0.5	13.9	6.4	6.6	3.9	1.4	27.3
Outfall Status (Middle Shelf)									
Outfall	23	165.4	1.0	48.3	3.8	7.2	9.7	4.0	43.9
Nonoutfall	30	111.7	0.6	15.2	2.8	3.7	3.1	1.1	62.6
Total (All Stations)	114	621.8	0.5	48.3	3.4	4.9	4.8	0.8	50.0
Number of Species									
Region									
Northern	45	60	5	19	12.0	12.2	3.6	1.1	41.8
Central	41	61	5	23	10.0	10.9	4.2	1.3	63.4
Southern	28	58	3	18	11.0	11.4	4.2	1.7	52.7
Depth Zone									
Inner Shelf	30	35	3	14	7.5	7.8	2.8	1.0	94.4
Middle Shelf	53	60	7	23	12.6	12.7	3.5	1.0	38.6
Outer Shelf	31	51	5	18	12.7	12.8	3.7	1.3	34.7
Outfall Status (Middle Shelf)									
Outfall	23	45	7	23	12.8	13.8	3.6	1.5	28.6
Nonoutfall	30	48	7	19	12.5	12.5	3.4	1.2	40.6
Total (All Stations)	114	88	3	23	11.4	11.7	3.9	0.8	50.0
Shannon-Wiener Diversity (bits/individual)									
Region									
Northern	45	-	0.87	2.37	1.92	1.72	0.38	0.12	34.7
Central	41	-	0.40	2.56	1.57	1.45	0.44	0.14	50.9
Southern	28	-	0.50	2.18	1.82	1.47	0.47	0.20	32.4
Depth Zone									
Inner Shelf	30	-	0.50	2.18	1.39	1.45	0.45	0.16	64.9
Middle Shelf	53	-	0.58	2.56	1.64	1.63	0.43	0.13	45.8
Outer Shelf	31	-	0.40	2.18	1.65	1.63	0.41	0.15	48.0
Outfall Status (Middle Shelf)									
Outfall	23	-	0.58	2.56	1.89	1.58	0.43	0.17	20.9
Nonoutfall	30	-	0.67	2.37	1.65	1.64	0.43	0.15	46.6
Total (All Stations)	114	-	0.40	2.56	1.58	1.59	0.44	0.09	50.0

[a]Unweighted values are catch values; weighted values are adjusted by station area weights.
[b]The average area sampled during a trawl tow was 2944 m^2.
CL=confidence limits (± value); Min = minimum; Max = maximum; No. = number; SD = standard deviation.

lower (more area below Bight median) in the northern region than in the central and southern regions (medians were 3.0, 4.0 and 4.7 kg, respectively) (Tables 3 and 4). Biomass was significantly higher (6.4 kg) on the outer shelf than on the middle and inner shelves; medians were 6.4, 3.0, and 3.2 kg, respectively. Fish biomass was also significantly higher at outfall than at nonoutfall areas (medians 3.8 and 2.8, kg). CDF curves for fish biomass were distinctly different for outfalls (Figure 2). Curves for central and southern regions generally intertwined. Some inner and middle shelf stations had much higher biomass than any outer shelf station.

Number of species per haul. A total of 88 species of fish was taken during the survey (Table 3). The number of fish species per haul ranged from 3 to 23. The lowest individual value occurred in the southern region on the inner shelf whereas the highest value occurred in the central region on the middle shelf in the outfall area. The median for the Bight as a whole was 11.4 species /haul, with subpopulation medians ranging from 7.5 (inner shelf) to 12.8 (outfall area). The number of fish species was significantly higher (less area below Bight median) in the northern than in the central region but values did not differ significantly in north vs. south and central vs. south comparisons; medians were 12.0, 10.0, and 11.0 in northern, central, and southern regions, respectively (Tables 3 and 4). The number of species was significantly lower on the inner shelf than on the middle and outer shelves; medians were 7.5, 12.6, and 12.7, respectively. The number of fish species did not differ significantly between outfall and nonoutfall areas (Table 4). The CDF curves for number of fish species for the inner shelf were distinctly different from the other depth zones, which intertwined (Figure 2). Curves for regions and outfall status also intertwined.

TABLE 4. Results of significance tests of demersal fish and invertebrate catch parameters by specific subpopulations, Southern California Bight Pilot Project survey, July to August 1994.

Parameter	Regions	Depths	Midshelf Outfall vs NonOutfall
Fish			
Abundance	Yes	Yes	Yes
	N=C<S	I<M<O	OF>NOF
Biomass	Yes	Yes	Yes
	N<C=S	I=M<O	OF>NOF
Species	Yes	Yes	No
	N>C, N=S, C=S,	I<M=O	
Diversity	Yes	Yes	Yes
	N=S>C	I<M=O	OF>NOF
Invertebrates			
Abundance	Yes	Yes	No
	N>C=S,	I<M=O	
Biomass	Yes	Yes	Yes
	N=S>C	I<M<O	OF>NOF
Species	No	I<M=O	No
Diversity	Yes	Yes	Yes
	N=S<C	I>M=O	OF>NOF

Null hypothesis was that there was no difference between subpopulations in amount of area below the median for the Southern California Bight (from SCBPP survey).
Significance tests used were 2 x 2 G-test for 2 subpopulations and R x C G-test for 3 populations.
Tests were significant at $p < 0.05$.
N = north; C = central; S = south; I = inner shelf; M = middle shelf; O = outer shelf; OF = outfall, middle shelf; NOF = nonoutfall, middle shelf.

Diversity per haul. Fish diversity ranged from 0.40 to 2.56 bits/individual. Both lowest and highest individual values occurred in the central region, with the lowest on the outer shelf and the highest on the middle shelf in the outfall area (Table 3). The median for the Bight as a whole was 1.58 bits/individual/haul, with subpopulation medians ranging from 1.39 (inner shelf) to 1.92 (northern region). Fish diversity was significantly lower (more area below Bight median) in the central region than in the southern or northern regions; medians were 1.57, 1.82 and 1.92, respectively (Tables 3 and 4). Diversity was significantly lower on the inner shelf than on the middle and outer shelf (medians were 1.39, 1.64 and 1.65, respectively). Fish diversity was significantly higher at the outfall than in the nonoutfall area (medians 1.89 and 1.65). CDF curves for fish diversity were distinctly different for outfall and nonoutfall areas (Figure 2). The curve for inner shelf was also distinctly lower whereas those of the other zones intertwined. The regional subpopulation curves intertwined.

Summary of fish catch parameter results. In summary, fish catch parameters varied by region, depth, and outfall status (Table 4). Regionally, the north had significantly lower fish biomass than the other regions and higher numbers of species than the central region. The central region had significantly lower fish diversity and the southern region had significantly higher abundance than the other regions. Bathymetrically, numbers of species and diversity were significantly lower on the inner shelf; fish biomass was significantly higher on the outer shelf; and fish abundance increased with increasing depth, differing significantly between each of the depth zones. Abundance, biomass, and diversity were significantly higher at outfall than at nonoutfall areas.

Invertebrate Catch Parameters

Abundance per haul. A total of 66,333 invertebrates was taken during the survey (Table 5). The number of invertebrates per haul ranged from 0 to 11,616. The lowest individual value occurred in the

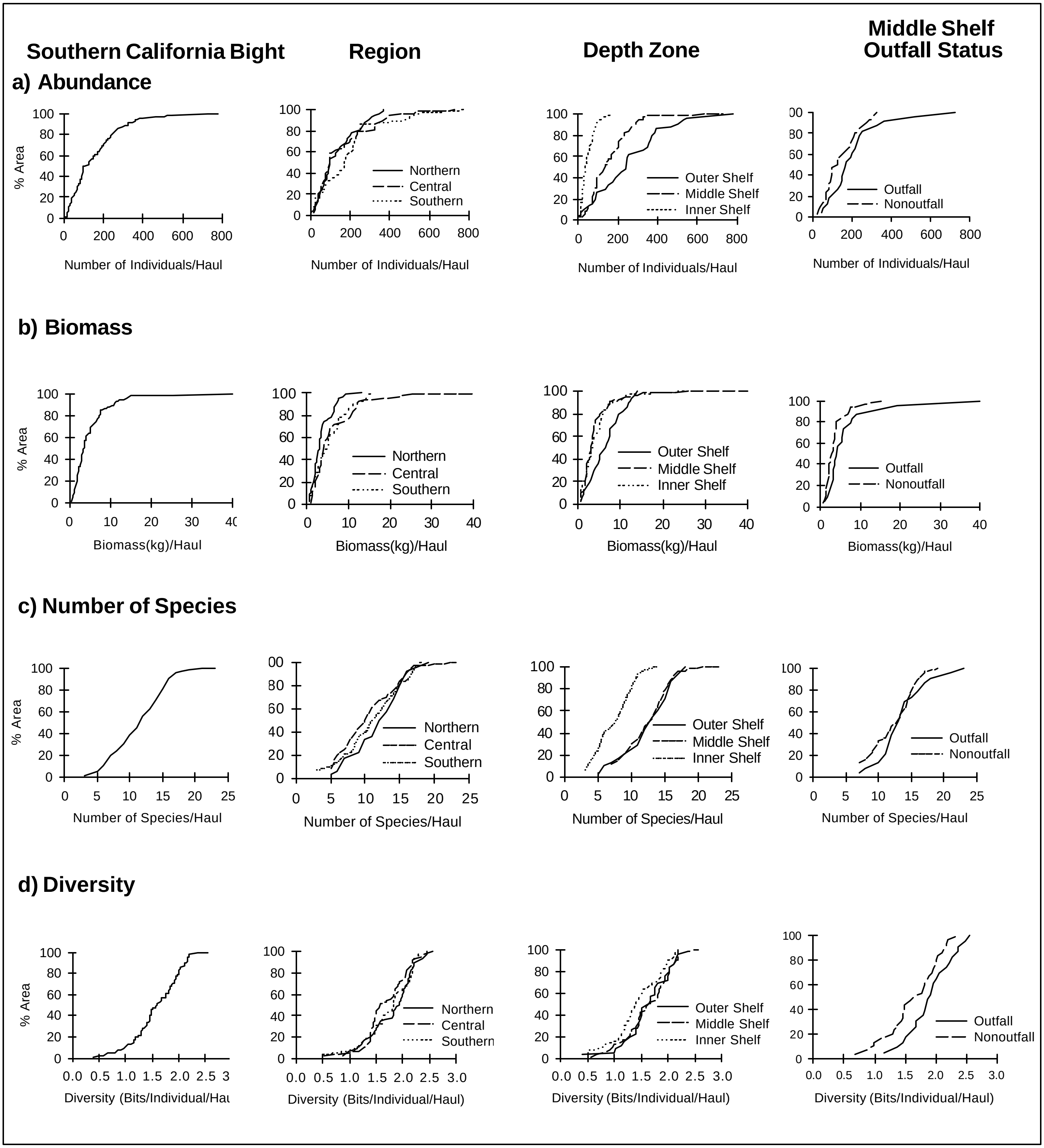

FIGURE 2. Cumulative distribution functions (CDFs) for fish abundance, biomass, number of species, and diversity per haul (2944 m²) by subpopulation in Southern California Bight Pilot Project survey, July-August 1994.

southern region on the inner shelf and the highest in the northern region on the middle shelf in the nonoutfall area. The median for the Bight as a whole was 171 individuals / haul, with subpopulation medians ranging from 17 (inner shelf) to 474 (outer shelf). Invertebrate abundance was significantly higher (less area below Bight median) in the northern region than in the central and southern regions; medians were 402, 35, and 145, respectively (Tables 4 and 5). Abundance was significantly lower on the inner shelf than on the middle and outer shelves (medians 17, 329, and 474, respectively). However, invertebrate abundance did not differ significantly between outfall and nonoutfall areas (Table 4). The CDF curve for invertebrate abundance on the inner shelf was distinctly different from those for the other depth zones (reflecting the low abundance there) (Figure 3). However the CDFs for regions, middle and outer shelf, and outfall/nonoutfall areas intertwined.

Biomass per haul. A total of 891.3 kg of invertebrates was taken during the survey (Table 5). The biomass of fish per haul ranged from 0.0 to 95.4 kg. The lowest individual value occurred in the southern region on the inner shelf at a station where no invertebrates were taken; however, values <0.1 kg occurred in all regions, on the inner and middle and outer shelves, and in outfall and nonoutfall areas (Table 5). The highest individual value (95.4 kg) occurred in the northern region on the outer shelf. The median for the Bight as a whole was 2.9 kg / haul, with subpopulation medians ranging from 0.1 (inner shelf) to 10.4 kg (outer shelf). Invertebrate biomass was significantly lower (more area below Bight median) in the central region than in the southern and northern regions (medians were 0.8, 3.3, and 3.6 kg, respectively) (Tables 4 and 5). Biomass differed significantly between each of the three depth zones and increased with increasing depth; medians were 0.1, 3.6, and 10.4 kg on the inner, middle, and outer shelf, respectively. Invertebrate biomass was also significantly higher at outfall than at nonoutfall (medians 6.1 and 3.0 kg) areas. CDF curves for invertebrate biomass were distinctly different between depth zone and outfall status subpopulations but those for regional subpopulations intertwined (Figure 3).

Number of species per haul. A total of 222 species of invertebrates was taken during the survey (Table 5). The number of invertebrate species per haul ranged from 0 to 41. Both the lowest and highest individual values occurred in the southern region, with the lowest on the inner shelf and the highest on the middle shelf, nonoutfall area. The median for the Bight as a whole was 11.7 species /haul, with subpopulation medians ranging from 6.9 (inner shelf) to 14.5 (outfall area). The number of invertebrate species did not differ significantly between regions or outfall and nonoutfall areas (Table 4). However, number of species was significantly lower (more area below Bight median) on the inner shelf than on the middle and outer shelves (6.9, 12.3 and 13.5, respectively) (Tables 4 and 5). CDF curves for number of invertebrate species intertwined for regions (Figure 3). The CDF for the inner shelf was distinctly different from middle and outer shelf curves, which intertwined on their upper ends. Outfall and nonoutfall curves were generally distinct but intertwined on their upper and lower ends.

Diversity per haul. Invertebrate diversity ranged from 0.00 to 2.42 bits/individual. The lowest individual value occurred in the southern region on the inner shelf and the highest in the northern region on the middle shelf in the nonoutfall area (Table 5). The median for the Bight as a whole was 1.05 bits/individual/haul, with subpopulation medians ranging from 0.70 (southern region) to 1.32 (central region). Invertebrate diversity was significantly higher (less area below Bight median) in the central region than in the northern or southern regions; medians were 1.32, 0.82, and 0.70, respectively (Tables 4 and 5). Diversity was significantly higher on the inner shelf than on the middle and outer shelf (1.24, 0.81, and 1.03, respectively). Invertebrate diversity was significantly higher at the outfall than in the nonoutfall area; medians were 1.15 and 0.78. Overall, CDF curves for invertebrate diversity were generally distinct in subpopulation comparisons but each curve intertwined at some point with the curve of another subpopulation (Figure 3).

Summary of invertebrate catch parameter results. In summary, invertebrate catch parameters varied by region, depth, and outfall status (Table 4). Regionally, the north had significantly higher invertebrate abundance whereas the central region had significantly lower biomass and higher diversity than the other regions. Bathymetrically, invertebrate abundance and numbers of species were significantly lower and diversity was significantly higher on the inner shelf than on the middle and outer shelves. Biomass increased with increasing depth, differing significantly between each of the depth zones. Invertebrate biomass and diversity were significantly higher in outfall than in nonoutfall areas.

DISCUSSION

Southern California Bight

Many trawl studies have been conducted in Southern California during the past 40 years, but most are focused in local areas rather than the SCB as a whole. However, two studies, Allen and Voglin (1976) and Thompson *et al.*

TABLE 5. Demersal invertebrate abundance, biomass, number of species, and diversity by subpopulation in the Southern California Bight Pilot Project survey, July-August, 1994.

Category	No. Stations	Unweighted Values[a] Total	Range (per Haul)[b] Min.	Range (per Haul)[b] Max.	Weighted Values (per Haul)[c] Median	Mean	SD	95% CL	Percent below Bight Median
Abundance (no. individuals)									
Region									
Northern	45	31758	16	11616	402	805	1970	664	41.9
Central	41	18067	4	4564	35	384	853	274	64.6
Southern	28	16508	0	2808	145	530	681	267	57.2
Depth Zone									
Inner Shelf	30	764	0	130	17	26	28	10	100.0
Middle Shelf	53	40143	13	11616	329	805	1900	612	39.7
Outer Shelf	31	25426	27	4564	474	793	931	336	27.9
Outfall Status (Middle Shelf)									
Outfall	23	15081	13	2828	348	656	803	328	38.4
Nonoutfall	30	25062	16	11616	313	835	2051	734	42.3
Total (All Stations)	114	66333	0	11616	171	631	1518	354	50.0
Biomass (kg)									
Region									
Northern	45	365.2	0.0	95.4	3.6	7.4	12.5	3.2	45.9
Central	41	358.5	0.0	45.9	0.8	7.0	11.0	3.3	65.8
Southern	28	167.6	0.0	29.9	3.3	6.2	8.0	3.7	41.0
Depth Zone									
Inner Shelf	30	11.7	0.0	2.0	0.1	0.4	0.6	0.2	100.0
Middle Shelf	53	396.7	0.0	31.8	3.6	6.4	7.4	2.2	40.1
Outer Shelf	31	482.9	1.1	95.4	10.4	15.1	17.8	6.4	13.3
Outfall Status (Middle Shelf)									
Outfall	23	226.3	0.0	31.8	6.1	9.8	8.9	3.6	28.0
Nonoutfall	30	170.4	0.0	29.9	3.0	5.7	6.8	2.5	49.0
Total (All Stations)	114	891.3	0.0	95.4	2.9	7.0	11.2	2.0	50.0
Number of Species									
Region									
Northern	45	106	7	29	11.9	12.5	3.3	0.9	47.5
Central	41	139	3	37	11.7	12.8	7.2	2.2	50.3
Southern	28	131	0	41	10.1	12.8	9.6	4.4	55.3
Depth Zone									
Inner Shelf	30	68	0	13	6.9	7.2	3.5	1.3	93.2
Middle Shelf	53	154	6	41	12.3	13.7	6.0	1.8	40.9
Outer Shelf	31	106	8	37	13.5	15.4	6.4	2.3	35.7
Outfall Status (Middle Shelf)									
Outfall	23	100	6	36	14.5	16.0	6.4	2.6	32.2
Nonoutfall	30	113	7	41	12.2	13.2	5.8	2.1	42.7
Total (All Stations)	114	222	0	41	11.7	12.6	6.4	1.3	50.0
Shannon-Wiener Diversity (bits/individual)									
Region									
Northern	45	-	0.03	2.42	0.82	1.03	0.59	0.19	55.8
Central	41	-	0.27	2.25	1.32	1.36	0.50	0.16	29.5
Southern	28	-	0.00	2.21	0.70	0.81	0.56	0.21	67.2
Depth Zone									
Inner Shelf	30	-	0.00	2.08	1.24	1.20	0.60	0.22	35.1
Middle Shelf	53	-	0.03	2.42	0.81	1.05	0.65	0.20	55.7
Outer Shelf	31	-	0.25	1.80	1.03	0.99	0.38	0.13	55.9
Outfall Status (Middle Shelf)									
Outfall	23	-	0.17	2.25	1.15	1.20	0.68	0.28	42.2
Nonoutfall	30	-	0.03	2.42	0.78	1.02	0.64	0.23	59.5
Total (All Stations)	114	-	0.00	2.42	1.05	1.07	0.59	0.12	50.0

[a]Unweighted values are catch values; weighted values are adjusted by station area weights.
[b]The average area sampled during a trawl tow was 2944 m^2.
CL = confidence limits (± value); Min = minimum; Max = maximum; No. = number; SD = standard deviation

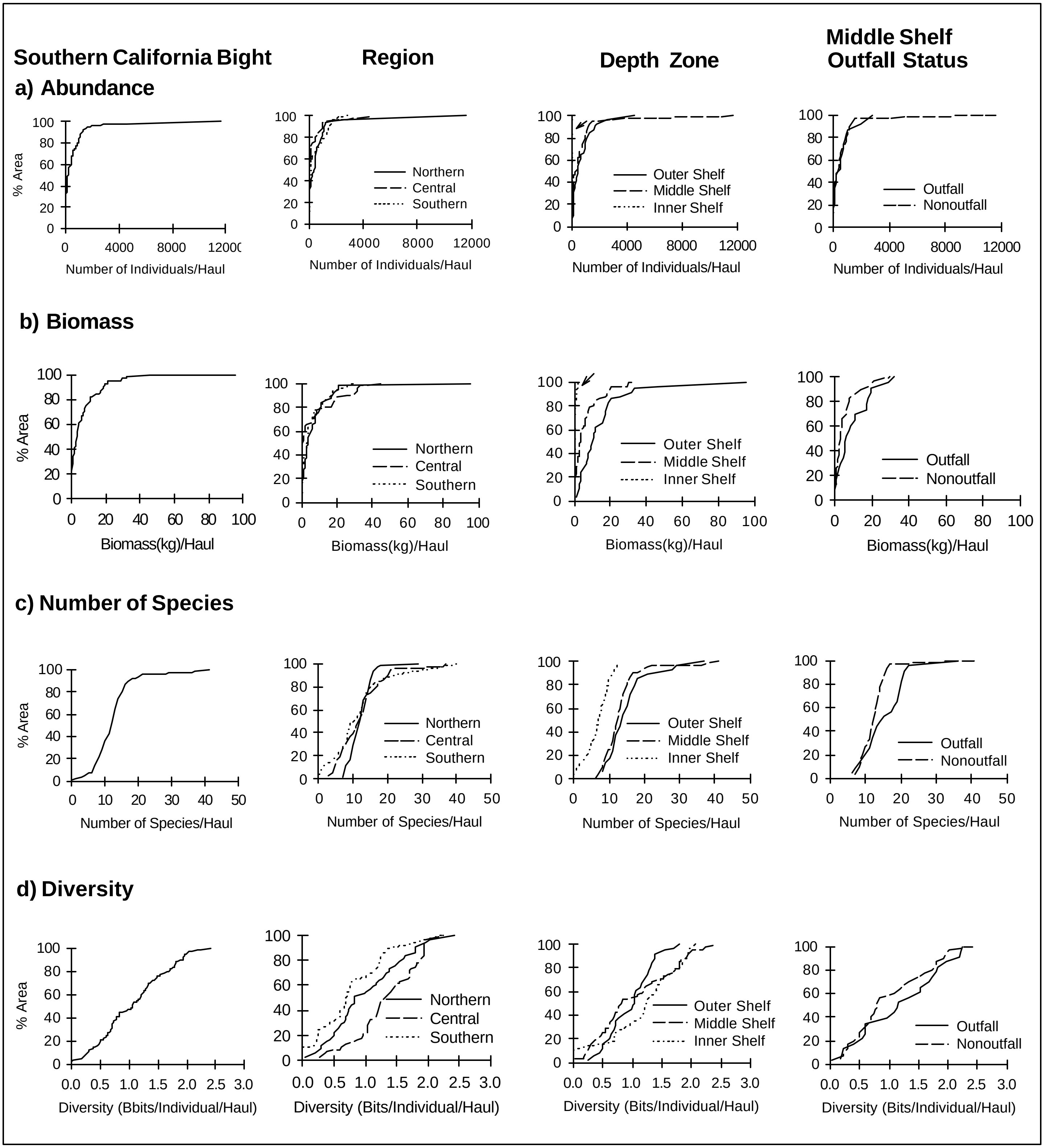

FIGURE 3. Cumulative distribution functions (CDFs) for invertebrate abundance, biomass, number of species, and diversity per haul (2944 m^2) by subpopulation in Southern California Bight Pilot Project survey, July-August 1994. Arrows show location of inner shelf CDF.

(1993) provide information on catch parameters of the SCB for fish and invertebrates, respectively.

Allen and Voglin (1976) summarized regional and local variability in fish catch parameters from 2,237 trawl samples collected on the mainland shelf and slope throughout the SCB from 1957 to 1975 at depths from 5-659 m. Of these, 2,220 were collected over the mainland shelf (5-200 m). Similarly, Thompson *et al*. (1993) summarized information on demersal (megabenthic) invertebrates from 1203 trawl samples in Southern California from 1971 to 1985 over a depth range of 10 to 915 m. Of these, 658 were collected over the mainland shelf (10-137 m). The SCBPP survey collected trawl samples from 9 to 215 m.

In general, the Bight-wide means of fish and invertebrate catch parameters in the SCBPP survey (Tables 3 and 5) were similar to the historical values (Table 6). However, a number of differences between the two studies may affect these comparisons. Although the historical fish data were predominantly collected at depths of 10-200 m, the overall depth range was greater than in the SCBPP survey. In contrast, the invertebrate data used for comparison were collected over a slightly more limited depth range. In addition, the SCBPP means were weighted in accordance to the sampling design whereas those of the historical databases were not; it is not known yet how this might affect this comparison. Also, fish diversities were calculated using the Shannon-Wiener equation (Shannon and Weaver 1949) in the SCBPP survey but by the Brillouin equation (Brillouin 1962) in Allen and Voglin (1976); although both measures are similar (Pielou 1976), this probably also affects the comparison.

Regional Variability

The SCBPP survey showed significant regional variability in median values of all fish and invertebrate catch parameters except for number of invertebrate species (Table 4). However, there was little similarity of regional patterns among the parameters. The north had significantly lower fish biomass but significantly higher numbers of fish species (than the central region) and invertebrate abundance. The central region had significantly lower fish diversity and invertebrate biomass but significantly higher invertebrate diversity. The south had significantly higher fish abundance.

Comparisons between mean catch parameters of historical and SCBPP data can be made for fish but not for invertebrates. Allen and Voglin (1976) provide some information on regional variability of fish catch parameters but the regions were divided more finely than in this study. In the historical database, mean fish abundance per haul ranged from 64 to 147 individuals in the north, from 139 to 420 in the central region, and from 97 to 192 in the south (Allen and Voglin 1976). Mean values in the SCBPP survey were 137, 159, and 197 in the northern, central, and southern regions, respectively (Table 3). Thus, it appears that highest fish abundances have shifted from the central to the southern region during the last 20 years. In the historical database, mean fish biomass per haul values were 3.5 kg in the north, 7.6 to 13.4 kg in the central region, and 5.0 to 6.2 kg in the south (Allen and Voglin 1976) whereas in the SCBPP survey, they were 3.6, 6.7, and 5.7 kg in the northern, central, and southern regions, respectively (Table 3). Thus the general regional pattern of

TABLE 6. Comparison of demersal fish and invertebrate catch parameters in historical and Southern California Bight Pilot Project data.

Southern California Bight Data Base	No. Samples	Mean/Haul[a] Abundance (No. Individuals)	Biomass (kg)	No. Species	Diversity [b] (Bits/Individual)
Fish					
Historical[c] — 1957-1975	2237	173	7.1	11.0	1.28
SCBPP — 1994	114	157	4.9	11.7	1.59
Invertebrates					
Historical[d] — 1971-1985	658	577	6.6	13.1	—
SCBPP — 1994	114	631	7.0	12.6	—

[a]SCBPP means are weighted in accordance with the SCBPP sampling design.
[b]Historical diversities were calculated using the Brillouin equation whereas those of the SCBPP were calculated from the Shannon-Wiener equation.
[c]Historical fish data from Allen and Voglin (1976).
[d]Historical invertebrate data from Thompson *et al*. (1993).
SCBPP = Southern California Bight Pilot Project.

fish biomass appeared to be similar between the two time periods, but was lower in the central region in 1994.

Historically, the mean number of fish species per haul ranged from 8.1 to 12.2 in the north, 10.0 to 16.2 in the central region, and 9.6 to 10.7 in the south (Allen and Voglin 1976). Means for the SCBPP survey were 12.2, 10.9, and 11.4 in the northern, central, and southern regions, respectively (Table 3). These were in the range of the historical means in the north and south but numbers of fish species appeared to be higher in the south in 1994 than in the past. Historically, mean Brillouin fish diversities per haul ranged from 0.91 to 1.50 in the north, 1.23 to 1.64 in the central region, and 1.27 to 1.50 in the south (Allen and Voglin 1976). In the SCBPP survey, Shannon-Wiener diversities per haul were 1.72, 1.45, and 1.47 in the northern, central, and southern regions, respectively (Table 3). If the values from the two equations are comparable, then diversity was higher in the north than it had been in the past.

Along the 60-m isobath, Word *et al.* (1977) found fish abundance higher in the north and diversity higher in the south but invertebrate abundance and number of fish and invertebrate species did not show any trend. Thus, compared with Allen and Voglin (1976) and Word *et al.* (1977), fish abundance appear to have shifted to the south and diversity to the north since the late 1970s. This is perhaps due to the general warming of the Bight since the early 1980s and the consequent reduced recruitment of northern and increased recruitment of southern species (CSDLAC 1990, MBC 1990).

Depth Variability

The SCBPP survey showed significant depth variability in median values of all fish and invertebrate catch parameters (Table 4). Unlike the regional variability, there was considerable similarity of pattern among parameters. The inner shelf was significantly lower in all but fish biomass and invertebrate diversity; it was significantly higher in the latter. The outer shelf was significantly higher in fish abundance and biomass, and invertebrate biomass. Fish abundance and invertebrate biomass increased significantly between each depth zone with increasing depth.

Variability in fish catch parameters over depths from 10 to 200 m has been summarized in more limited surveys (Allen and Mearns 1977, Word and Mearns 1977, Allen 1982, Thompson *et al.* 1987, Thompson *et al.* 1993a,b). Similar patterns of increasing fish abundance and lower numbers of fish species on the inner shelf and higher fish biomass on the outer shelf have been shown as trends in the past (Allen and Mearns 1977, Allen 1982, Thompson *et al.* 1987, Thompson *et al.* 1993b) but these had not been tested for significance. As in this study, Thompson *et al.* (1987) found a distinct increase in invertebrate biomass with depth but that study found fewer individuals on the middle shelf and more species on the inner shelf. The low catch parameters in the inner shelf zone may be related to higher daytime light levels and a more variable environment (e.g., of temperature, salinity, turbulence, and food availability).

Outfall Status Variability

In this study, outfall areas on the middle shelf had significantly higher fish abundance, biomass and diversity, and invertebrate biomass and diversity than nonoutfall areas in the same depth zone. The two areas did not differ significantly in numbers of fish and invertebrate species and invertebrate abundance. Because the shelf areas in most of the outfall areas (the Palos Verdes Shelf excepted) is broad whereas most of the shelf of the SCB is narrow, the shelf breadth may influence the higher catch parameters in the outfall areas. Further analysis is needed to resolve whether the higher catches are due to stimulation from wastewater discharge or shelf breadth.

Before the SCBPP survey, there was no regional comparison of trawl catch parameters from all of the major POTW outfall areas with those from nonoutfall areas. Mearns *et al.* (1976) compared fish catch parameters at each outfall (in the monitoring program station areas, which is much smaller than the outfall areas of the SCBPP survey) and showed differences among the outfall areas. With one exception, fish catch parameters on the Palos Verdes Shelf near the White Point outfall (County Sanitation Districts of Los Angeles County) in 1985-1986 did not differ significantly from those of reference areas in 1985 (MBC 1987, Thompson *et al.* 1987, CSDLAC 1988). However, fish biomass was significantly higher on the middle shelf of the Palos Verdes Peninsula than in reference areas.

CONCLUSIONS

Demersal fish and invertebrate populations on the mainland shelf of Southern California varied significantly by region, depth, and outfall/nonoutfall areas in 1994. Trawl catch parameters for demersal fish and invertebrates varied more consistently by depth than by region. Catch parameters were generally lower on the inner shelf and higher on the outer shelf. Regional variability occurred in almost all fish and invertebrate catch parameters but the pattern of variability differed greatly by catch parameter.

Outfall areas generally had higher catch parameter values than nonoutfall areas. Although this may be due to stimulation from wastewater discharge, it also may be related to the broader shelf in the vicinity of most outfalls relative to that of the SCB. In general, mean fish and invertebrate catch parameters were similar between the SCBPP survey of 1994 and historical surveys for the mainland shelf of the SCB. However, fish abundance and numbers of species have apparently increased to the south and fish diversity has increased to the north since the late 1970s.

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APPENDIX 1

Area-weighted Equations

Equations for area-weighted mean, variance, standard deviation, standard error, and 95% confidence limits.

Equation 1.1

$$\text{Area-weighted Mean} = \frac{\sum_{i=1}^{n} (\text{uobs}_i * \text{areawt}_i)}{\sum_{i=1}^{n} \text{areawt}_i}$$

Equation 1.2

$$\text{Area-weighted Variance} = \frac{\sum_{i=1}^{n} ((\text{uobs}_i - \text{wmean})^2 * \text{areawt}_i)}{\sum_{i=1}^{n} \text{areawt}_i}$$

Equation 1.3

$$\text{Area-weighted Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n} ((\text{uobs}_i - \text{wmean})^2 * \text{areawt}_i)}{\sum_{i=1}^{n} \text{areawt}_i}}$$

Equation 1.4

$$\text{Area-weighted Standard Error} = \sqrt{\frac{\sum_{i=1}^{n} ((\text{uobs}_i - \text{wmean}) * \text{areawt}_i)^2}{\left(\sum_{i=1}^{n} \text{areawt}_i\right)^2}}$$

Equation 1.5

Area-weighted 95% Confidence Limit = $\pm$ 1.96 * Area-weighted Standard Error

where **areawt**$_i$ = the area weight for station *i*;
n = number of stations in subpopulation.
uobs$_i$ = the indicator (e.g., no. individuals, biomass, etc.) observation at station *i* (= unweighted observation)
wmean = the area-weighted mean

Note: The equation for the sample variance would normally be multiplied by **n/n-1**. However, because the constrained SCBPP sampling design is less variable than a simple random design, the variance is overestimated; to compensate for this, the **n/n-1** term is not included (Don Stevens, ManTech Environmental Research Services, Inc., Corvallis, OR, pers. comm. Nov. 10, 1995).