Descriptive trends in Southern California Bight demersal fish assemblages, 1994-2008

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Abstract

Despite intense localized monitoring, few regional assessments of demersal fish assemblages are conducted in the Southern California Bight (SCB). The goal of this study was to describe temporal changes in regional-scale SCB demersal fish assemblages (density, biomass, size class) in relation to regional environmental changes (temperature and related climate indices). Nearly 600 small otter trawls were conducted by collaborating agencies between 3 and 200 m depth during the summers of 1994, 1998, 2003, and 2008 under a standardized sampling plan. Summer water temperature at depth between 1950 and 2008 has remained relatively stable although temperatures in 1998 and 2008 were above the long-term mean while the 1994 and 2003 temperatures were at or below the mean. Mean demersal fish density increased each survey between 1994 and 2003 before declining in 2008, while mean biomass increased each survey since 1994 reaching its maximum in 2008. Based on community similarity analyses, the 1998 survey was appreciably different than the other three surveys, with 2003 and 2008 being the most similar. This could be the result of anomalously warm-water conditions recorded during the 1997-1998 El Niño and the resultant temporary poleward expansion of numerous species. Although the sample size was limited to four regional surveys, the best predictors of mean demersal fish density and biomass were the Northern Pacific Gyre Oscillation and the Multivariate El Niño-Southern Oscillation Index. Increasing temperature, or similar patterns in environmental indices, resulted in reduced density and biomass. Furthermore, habitat valuation revealed a trend of increasing value with depth and latitude with

the southern inner shelf areas scoring the lowest habitat value. With the addition of more data, regional surveys such as these surveys provide a good foundation on which to analyze changes in demersal fish assemblages.

Introduction

Southern California Bight (SCB) shelf demersal fish assemblages are commonly monitored by dischargers in compliance with state and federal regulatory requirements (Mearns 1979, Love *et al.* 1986, Stull and Tang 1996). Nearly 12,000 samples are collected annually along this 300 km coastline to assess the health of demersal fish assemblages in response to discharges (Schiff *et al.* 2002). Despite this level of effort, few studies have documented trends in these assemblages beyond site-specific programs. For instance, Stull and Tang (1996) identified changes in demersal fish assemblages near one outfall in Los Angeles linked to improving wastewater effluent quality and natural environmental variability.

The challenge of interpreting trends in local-scale data is that regional influences can have an enormous effect on local results. Regional scale information provides the context for local trends, helping discern true differences from background stimuli. Such spatially robust studies potentially reveal significant information including wholesale population declines (Holbrook *et al.* 1997), generalized overfishing impacts (Myers and Worm 2003), site-specific anthropogenic discharge impacts (or lack of impacts, Conversi and McGowan 1994), influence of hypoxic conditions (Bograd *et al.* 2008, McClatchie *et al.* 2010), and/or climatic forcing (Perry *et al.* 2005,

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Genner *et al.* 2010). Disentangling interactions of regional scale natural influences from local anthropogenic stressors often requires the use of spatiotemporally extensive, fisheries-independent data (Hsieh *et al.* 2008, Hsieh *et al.* 2009, Genner *et al.* 2010).

In the SCB, there are two monitoring programs that can be used to evaluate regional trends over the last fifteen years. The first is the SCB Regional Marine Monitoring (Bight), completed regional surveys in 1994, 1998, 2003, and 2008 (Allen *et al.* 2007, Miller and Schiff 2011). The second is the California Cooperative Oceanic Fisheries Investigation (CalCOFI). CalCOFI measures the hydrography of the SCB water column (Bograd and Lynn 2003) and provides environmental data from a spatial scale relevant to the Bight program, thereby filling data gaps for measurements not collected during the Bight surveys. Together, the CalCOFI hydrographic series and the Bight Program provide data sets with sufficient spatial similarity to warrant a review of the relationship between the demersal fish assemblages of the SCB shelf and physical environmental changes.

This study aims to describe and quantify temporal changes in SCB demersal fish assemblages and, to the extent possible, in relation to regional environmental variability. Such an endeavor has not been attempted in southern California since Mearns (1974) evaluated fish community responses to seasonal dissolved oxygen patterns. The temporal changes in SCB demersal fish assemblages will be assessed by spatial dimensions of known importance including depth and latitude. Fish community characteristics include species distributions, abundance, biomass, fish length, and habitat value. Environmental changes include temperature and various climate indices including the Northern Pacific Gyre Oscillation (NPGO; Di Lorenzo *et al.* 2008), the Pacific Decadal Oscillation (PDO; Mantua *et al.* 1997), and the Multivariate El Niño-Southern Oscillation Index (MEI; Wolter and Timlin 2012).

METHODS

Bight Sampling for Demersal Fish

The Bight Program uses a stratified probabilistic survey design (Stevens 1997). Three strata were sampled in each survey: 5 to 30 m = inner shelf (IS); 31 to 120 m = middle shelf (MS), and 121 to 200 m = outer shelf (OS). In addition, three latitudinal strata were sampled in each survey: 33.6 to 34.2° N = Northern SCB; 33.3 to 33.6° N = Central SCB; and 32.3 to 33.3° N = Southern SCB. Each station was sampled once per survey by a consortium of participating agencies (publicly-owned treatment works, academics, and consultants) during the summer (July–September) with a standardized 7.6-m head-rope semi-balloon otter trawl net with a 1.25-cm cod-end mesh. Trawls were towed parallel to the target isobaths at each station for ≈ 10 minutes at 0.8-1.0 m/second. The difference between the start and stop fishing GPS coordinates recorded on the deck of the towing vessel was used to calculate the distance trawled. Two assumptions were used: 1) the net retained contact with the bottom during the entire designated fishing period, and; 2) the GPS coordinates acted as a proxy for the net's relative position. Upon retrieval, trawl catches were sorted, identified to species and measured to nearest cm (standard length [SL], total length [TL] or disc width [DW], where appropriate). All recorded lengths were rounded up to the next size class (e.g. a 6.1 cm fish = 7 cm size class).

CalCOFI Sampling for Hydrography

CalCOFI conducts quarterly hydrographic surveys of the California Current hydrography. Methods used by CalCOFI are summarized in Bograd and Lynn (2003). CalCOFI uses a fixed grid sampling design, of which data from four transects from San Diego to Point Conception (lines 83 - 93) from stations numbering less than 50 on each line corresponding to approximately the same sampling frame as the Bight Program were used.

Data Analysis

Abundance and biomass data were standardized to the area swept. Underwater measurements by EQA -MBC (1975) determined the 7.6-m otter trawl net spread 4.9 m on average while under tow and fishing. Thus, the area swept in this analysis represents the distance trawled (m) x 4.9 m. The Shannon-Wiener Diversity Index was calculated for each depth strata by year using the derived densities. A raw density-weighted mean latitude and depth of each survey year's catch was calculated using the coordinates (depth) where fishing started. No density or biomass transformations were made prior to weighting. Environmental indices reviewed in the analysis include mean summer temperature (°C), PDO (Mantua *et al.* 1997), NPGO (Di Lorenzo *et*

al. 2008), and the MEI (Wolter and Timlin 2012). Mean extended summer (June-September) values for each index encompass the survey year and the preceding four years. Water temperature at 70 m recorded by CalCOFI (2011) for the survey year and the preceding four years was used. Temperatures were compared against the mean latitude, depth, and overall catch for all fishes, all fishes after removing the two most common species (no *Citharichthys*), and each of the two most common species individually. Climate indices were only compared against density and biomass independent of latitude or depth of capture. Low statistical power (β <0.80) resulting from our small sample size (n = 4 surveys) precluded advanced, significance-testing, regression modeling. Therefore, conclusions were restricted to comparing coefficients of determination (R^2) rather significance at α = 0.05 level. The sensitivity of these results to fluctuations in the dominant species were evaluated by excluding the abundant species and examining them individually as well as examining the entire catch as a whole.

Based on the probabilistic design of the Bight Program, density by stratum was area-weighted using the ratio estimator approach following Thompson (1992):

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

where:
m = Area-weighted mean density for stratum j.
p_i = Parameter value (e.g., density) at station i.
w_i = Area weight for station i.
n = Number of stations in population j.

The standard error of the mean was calculated using the following equation:

$$\text{Standard error (SE)} = \sqrt{\frac{\sum_{i=1}^{n}((p_i - m) * w_i)^2}{\left(\sum_{i=1}^{n} w_i\right)^2}}$$

where:

m = Area-weighted mean concentration for population j.
p_i = Parameter value (e.g., density) at station i.
w_i = Area weight for station i.
n = Number of stations in population j.

Similarities in overall community composition, as indicated by the species abundance distribution, were examined using percent similarity index (PSI;

Whittaker 1952) using the equation:

$$PSI = 100 - 0.5 * \sum |A_i - B_i|$$

where:

A_i and B_i are the percentages of species i in samples A and B, respectively.

Fish length frequency distributions and mean lengths for each survey year were examined for shifts in the overall size structure of the whole catch and each of the four most commonly measured species. Abundance-weighted mean lengths were calculated for each comparison (i.e., year, latitude, depth). Annual mean lengths across all stations were compared using a Friedman Rank Sum Test. Furthermore, the annual total mean lengths were compared against the overall mean across all four Bight surveys to place each annual value into a long-term context. The mean length by 0.2°N latitude and 20-m depth bins were also analyzed for all species combined, and the most common species separately, to identify possible spatial variability in the catch.

Habitat values were calculated for each stratum in each year based on fish guilds described in Bond *et al.* (1999) and further supplemented by Pondella (2009) using a modification of the Bond *et al.* (1999) equation:

$$HV = \sum_{24}^{1} (mean\ length * F * D)^{0.5}$$

where:

F = proportional frequency of occurrence on a scale of 0-1 and

D = density (count/hectare).

The habitat valuation analysis focused on the demersal assemblages. Therefore, pelagic and midwater fishes (e.g., northern anchovy *Engraulis mordax*) were excluded as their catches likely represent sampling during midwater deployment or retrieval (Biagi *et al.* 2002). A listing of the 74 species was used in the habitat valuation analysis (Appendix A in Supplemental Information (SI) available at ftp://ftp.sccwrp.org/pub/download/ DOCUMENTS/AnnualReports/2012AnnualReport/ ar12_10SI.pdf). Habitat value differences by year, strata, and latitudinal region were compared separately using a Kruskall-Wallis (KW) analysis of variance with a Bonferroni multiple comparison test (Sokal and Rohlf 1995).

Results

A total of 597 tows completed during the four Bight surveys (Table 1) caught 131,961 fish weighing a total of 3541 kg and representing 160 demersal species (Appendix B in SI). Sampling effort was greatest in 1998 and least in 2008. Distribution of sampling sites among the three shelf strata was the most equitable in 2008 when 29 (±3, standard error) stations were sampled in each shelf stratum. The sampling distribution in 1998 was the most variable with 81 (±25) stations sampled in each zone. Sampling was consistently most intense along the middle shelf followed by the inner shelf and the outer shelf, in descending order.

The 15 most common species averaged 79% of the total abundance and 77% of the total biomass across the four surveys (Table 2 and 3). These patterns were most heavily influenced by the density and biomass of Pacific sanddab (*Citharichthys sordidus*), which ranked first in abundance and biomass overall. Pacific sanddab, longspine combfish (*Zaniolepis latipinnis*), and English sole (*Parophrys vetulus*) were the only species taken in all years and depth zones among the 15 most common species. Of the species ranking second through fifth in density, only halfbanded rockfish (*Sebastes semicinctus*) and stripetail rockfish (*S. saxicola*) ranked among the top ten in biomass at fifth and ninth, respectively. English sole and California halibut (*Paralichthys californicus*) ranked second and third in biomass, respectively, but English sole was only the 14th most common fish taken while California halibut was not among the 15 most commonly caught species. Not unexpectedly, highly abundant species tended to be smaller fishes as compared to those species with high biomass.

Observed differences in species abundance distributions may reflect changes in the local physiochemical structure of the waters overlying the SCB shelf. Mean annual summer seawater temperatures recorded at 50 m, 100 m, and 200 m were significantly correlated (p <0.05), with correlation coefficients (r) ranging between 0.29 (50 m vs 200 m) and 0.71 (50 m and 100 m; Figure 1). Summer seawater temperatures at 50 m since 1949 averaged 11.3ºC while temperatures in survey years (1994, 1998, 2003, and 2008) were both above and below the mean with 11.2ºC, 13.2ºC, 10.7ºC, and 12.3ºC, respectively. A similar pattern was observed at 100 m, albeit with less variation and mean summer temperatures of 9.4ºC, 10.4ºC, 9.1ºC, and 10.6ºC,

Table 1. Number of successful trawl events by shelf stratum in each of the four Bight monitoring surveys (1994, 1998, 2003, and 2008).

Shelf Strata	1994	1998	2003	2008	Total
Inner (5 - 30 m)	32	77	43	32	184
Middle (31 - 120 m)	58	126	86	33	303
Outer (121 - 200 m)	20	40	27	23	110
Survey total	110	243	156	88	597

respectively. Lastly, at 200 m, temperatures were least variable over time and each survey year was near the long-term average (8.4ºC) except 2008 when the temperature was 1.0ºC warmer at 9.4ºC. The seawater temperature during the survey year, however, often misrepresented conditions that dominated the intervening years. For example, 2008 temperatures were above average while temperatures since the 2003 survey were predominantly below average. Therefore, temperature analyses focused on the mean across the years since the previous survey to better account for intervening conditions. This same principle was applied to the climate indices NPGO, PDO, and MEI.

Comparisons of the species abundance distributions via the PSI indicated a high degree of similarity (≈ 80%) between the 2003 and 2008 catches (Figure 2). Less similarity was observed between the 2003 and 2008 surveys and the 1994 and 1998 surveys (Figure 2). The 1998 survey results were the most unique at <55% similarity to any of the other three surveys. Comparisons among the relative density of the 15 most common species helps explain the similarities and differences among Bight surveys (Figure 2). For example, Pacific sanddab accounted for ≈ 23% of total catch in all but the 2003 survey when it accounted for >30% of the catch. The most distinct difference between earlier and later surveys pertains to plainfin midshipman (*Porichthys notatus*), which was commonly taken in 1994 but not in 2003 or 2008. Catches of species ranked 6 – 14 were markedly higher in 1998 than the remaining years, thus resulting in the greater PSI differences.

Mean demersal fish density along the continental shelf increased slightly through 2003 before declining again in 2008, although 2008 remained above the mean density recorded in 1994 and 1998 (Figure 1; Tables 2 and 3). Similarly, mean biomass increased in 2003 and 2008 from 1998. Comparisons

Table 2. Mean area-weighted and unadjusted (raw) density (count/1000 m²) by year and depth zone for the 15 most common species taken during the Bight program demersal surveys, 1994, 1998, 2003, and 2008.

Area-Weighted Density

Species	1994 IS	1994 MS	1994 OS	1994 Tot.	1998 IS	1998 MS	1998 OS	1998 Tot.	2003 IS	2003 MS	2003 OS	2003 Tot.	2008 IS	2008 MS	2008 OS	2008 Tot.
Citharichthys sordidus	0.2	16.8	6.7	11.2	0.4	13.1	26.6	12.9	1.3	55.6	33.4	39.4	2.5	22.9	31.3	18.2
Citharichthys stigmaeus	6.9	1.7	-	2.7	3.3	4.1	-	3.3	31.5	8.6	0	12.8	24.2	3	-	8.8
Icelinus quadriseriatus	0.3	4.1	0	2.5	0	4.7	0	3.1	1.7	9.6	-	6.3	1.9	17.7	-	10.1
Sebastes semicinctus	-	0.8	0.2	0.5	-	0.6	0.5	0.4	0	16.1	3.2	10.4	-	9.7	2.2	5.6
Sebastes saxicola	0	1.6	4.7	1.7	-	0.7	2.1	0.8	0	10	17.9	8.8	-	2.5	10.4	3
Zaniolepis latipinnis	0.2	2.6	0	1.6	0	2.1	0.4	1.4	0.8	11.1	0.3	7	5.4	0.6	3
Lyopsetta exilis	-	0.3	15.1	2.4	-	0.2	14.8	2.5	-	0.2	20.8	3.2	-	0.2	26.5	4.4
Porichthys notatus	0	4.3	14.8	4.8	-	2.2	2.4	1.8	0.4	2	1.8	1.6	0.1	2.3	2.2	1.6
Citharichthys xanthostigma	0.7	3.3	-	2.2	0.5	5.7	0	3.8	0.5	3	0	1.9	0.2	3	0.1	1.7
Microstomus pacificus	-	2.1	6.5	2.2	-	1.7	6.7	2.2	0	4.9	5.4	3.8	-	1.2	3.7	1.3
Zalembius rosaceus	0.8	2.1	0.1	1.5	0	1.1	0.4	0.8	3.8	1.9	0.4	2.1	1.3	6.1	1.5	4
Genyonemus lineatus	2.3	-	-	0.6	25.1	1.6	-	5.7	2.2	0	-	0.5	0.2	0	-	0.1
Zaniolepis frenata	-	0.4	2.4	0.6	-	0.6	10.3	2	-	1.5	10.1	2.4	-	1	8.1	1.8
Parophrys vetulus	0.5	0.5	0.2	0.5	0.4	0.4	1.3	0.6	1.8	1.3	1.4	1.4	1.7	5.9	2.8	4.2
Synodus lucioceps	0.6	0.5	0.1	0.5	5.2	5.6	0	4.7	0.8	0.2	-	0.3	1.1	0.5	-	0.6
All species combined	17	50	71	45	47	54	76	56	53	140	115	115	40	93	102	79
Number of Species	38	65	39	86	54	90	59	129	55	83	56	109	50	56	44	93
Species Diversity	2.3	2.5	2.4	2.9	1.8	2.8	2.2	3	1.9	2.33	2.34	2.6	1.8	2.5	2.17	2.8

Raw Density

Species	1994 IS	1994 MS	1994 OS	1994 Tot.	1998 IS	1998 MS	1998 OS	1998 Tot.	2003 IS	2003 MS	2003 OS	2003 Tot.	2008 IS	2008 MS	2008 OS	2008 Tot.
Citharichthys stigmaeus	0.1	2.5	0.8	3.3	0.1	0.9	1.5	2.5	0.3	3.7	1.7	5.7	0.4	2.2	2.1	4.7
Genyonemus lineatus	0.1	1.7	0.0	1.9	0.0	1.6	0.0	1.6	0.6	4.6	-	5.2	0.5	5.4	-	5.9
Sebastes saxicola	1.1	0.3	-	1.4	0.4	0.3	-	0.7	4.5	0.9	0.0	5.5	3.6	0.7	-	4.4
Lyopsetta exilis	0.4	-	-	0.4	10.5	0.2	-	10.7	0.2	0.0	-	0.2	0.1	0.0	-	0.1
Sebastes semicinctus	0.0	0.4	1.0	1.4	-	0.3	0.8	1.1	0.0	2.0	2.9	5.0	-	0.6	2.2	2.7
Porichthys notatus	-	0.2	1.6	1.8	-	0.1	2.0	2.1	-	0.0	2.9	2.9	-	0.1	2.7	2.8
Microstomus pacificus	-	0.2	0.1	0.2	-	0.4	0.2	0.3	0.0	3.3	0.3	3.5	0.1	1.1	0.5	1.6
Zaniolepis latipinnis	0.0	0.8	1.4	2.2	0.8	1.7	0.0	2.5	0.1	0.4	0.2	0.7	-	0.5	0.4	0.9
Zalembius rosaceus	-	0.4	0.7	1.1	0.1	1.2	0.0	1.3	0.0	0.7	0.7	1.5	0.0	0.3	0.6	0.9
Zaniolepis frenata	0.1	0.6	0.0	0.7	0.1	0.2	0.3	0.5	0.2	1.6	0.1	2.0	0.4	0.9	0.2	1.2
Synodus lucioceps	0.1	0.5	0.0	0.6	0.0	0.3	0.2	0.6	0.2	0.6	0.1	1.2	-	1.2	0.4	2.0
Citharichthys xanthostigma	-	0.1	0.5	0.6	0.1	0.4	0.2	0.6	0.6	0.2	1.1	1.3	0.2	0.2	1.1	1.4
Parophrys vetulus	0.3	0.2	0.0	0.5	0.1	0.5	0.3	1.0	0.2	0.3	0.3	1.0	0.4	0.5	0.4	0.7
All species combined	4.3	11.9	10.6	26.7	16.3	11.5	10.5	38.4	9.9	24.1	15.1	49.1	8.3	18.5	14.3	41.2

Note: "-" = none taken; 0.0 = <0.05

Table 3. Mean area-weighted and unadjusted (raw) biomass (kg/1000 m²) by year and depth zone for the 15 most common species taken during the Bight program demersal surveys, 1994, 1998, 2003, and 2008.

Area-Weighted Biomass

Species	1994				1998				2003				2008			
	IS	MS	OS	Tot.	IS	MS	OS	Tot.	IS	MS	OS	Tot.	IS	MS	OS	Tot.
Citharichthys sordidus	0.01	0.23	0.29	0.18	0.01	0.41	1.01	0.43	0.04	0.93	1.22	0.76	0.04	0.44	2.45	0.65
Parophrys vetulus	0.07	0.07	0.03	0.06	0.03	0.05	0.12	0.05	0.08	0.14	0.09	0.12	0.06	0.30	0.22	0.22
Paralichthys californicus	0.56	0.04	-	0.16	0.29	0.04	-	0.08	0.20	0.03	-	0.07	0.14	-	-	0.04
Citharichthys xanthostigma	0.05	0.11	-	0.08	0.02	0.14	0.00	0.09	0.03	0.14	0.00	0.10	0.01	0.11	0.00	0.06
Sebastes semicinctus	-	0.02	0.00	0.01	-	0.00	0.01	0.00	0.00	0.09	0.10	0.07	-	0.37	0.07	0.21
Pleuronichthys verticalis	0.12	0.06	-	0.06	0.10	0.05	0.00	0.05	0.07	0.09	0.02	0.08	0.12	0.13	0.03	0.11
Lyopsetta exilis	-	0.00	0.29	0.04	-	0.01	0.24	0.04	-	0.00	0.42	0.06	-	0.00	0.51	0.09
Genyonemus lineatus	0.19	-	-	0.05	0.44	0.11	-	0.15	0.12	0.00	-	0.03	0.01	0.00	-	0.01
Sebastes saxicola	-	0.02	0.16	0.03	-	0.02	0.07	0.02	0.00	0.08	0.43	0.11	-	0.04	0.27	0.06
Citharichthys stigmaeus	0.05	0.01	-	0.02	0.04	0.04	-	0.03	0.21	0.07	0.00	0.09	0.23	0.02	-	0.08
Microstomus pacificus	-	0.06	0.21	0.07	-	0.03	0.16	0.05	0.00	0.08	0.13	0.07	-	0.03	0.17	0.04
Porichthys notatus	-	0.09	0.31	0.10	-	0.05	0.07	0.04	0.02	0.05	0.10	0.05	-	0.03	0.09	0.03
Zaniolepis latipinnis	0.01	0.06	-	0.04	-	0.05	0.01	0.03	0.03	0.15	0.01	0.10	0.00	0.09	0.02	0.05
Scorpaena guttata	0.04	0.11	-	0.08	0.01	0.04	0.00	0.03	0.04	0.08	0.02	0.06	0.02	0.05	0.01	0.03
Synodus lucioceps	0.05	0.15	0.02	0.11	0.07	0.07	0.00	0.06	0.02	0.01	-	0.01	0.03	0.02	-	0.02
All species combined	1.43	1.31	1.73	1.40	1.47	1.52	2.27	1.63	1.19	2.56	3.49	2.37	0.83	2.00	4.42	2.05

Raw Biomass

| Species	1994				1998				2003				2008			
	IS	MS	OS	Tot.	IS	MS	OS	Tot.	IS	MS	OS	Tot.	IS	MS	OS	Tot.
Citharichthys sordidus	0.01	0.29	0.28	0.58	0.00	0.24	0.87	1.11	0.06	0.90	1.05	2.01	0.04	0.44	2.45	2.93
Lyopsetta exilis	-	0.00	0.29	0.29	-	0.01	0.29	0.30	-	0.01	0.56	0.56	-	0.00	0.51	0.51
Genyonemus lineatus	0.33	-	-	0.33	1.09	0.11	-	1.20	0.07	0.00	-	0.08	0.03	0.00	-	0.04
Paralichthys californicus	0.57	0.09	-	0.66	0.28	0.15	-	0.43	0.26	0.06	-	0.31	0.14	-	-	0.14
Parophrys vetulus	0.07	0.08	0.03	0.17	0.01	0.06	0.12	0.20	0.07	0.16	0.14	0.36	0.06	0.30	0.22	0.57
Sebastes saxicola	-	0.02	0.17	0.19	-	0.03	0.09	0.11	0.00	0.07	0.42	0.49	-	0.04	0.27	0.31
Microstomus pacificus	-	0.06	0.24	0.30	-	0.03	0.15	0.18	0.00	0.08	0.13	0.21	-	0.03	0.17	0.20
Porichthys notatus	-	0.12	0.30	0.42	-	0.06	0.07	0.13	0.01	0.05	0.08	0.15	-	0.03	0.09	0.12
Citharichthys xanthostigma	0.05	0.14	-	0.19	0.01	0.23	0.01	0.26	0.07	0.17	0.00	0.24	0.01	0.11	0.00	0.12
Pleuronichthys verticalis	0.12	0.07	-	0.19	0.05	0.07	0.00	0.13	0.09	0.11	0.02	0.22	0.12	0.13	0.03	0.27
Citharichthys stigmaeus	0.05	0.01	-	0.07	0.02	0.02	-	0.04	0.24	0.05	0.00	0.28	0.23	0.02	-	0.26
Zaniolepis frenata	-	0.01	0.06	0.07	-	0.01	0.11	0.12	-	0.04	0.18	0.22	-	0.01	0.18	0.19
Sebastes semicinctus	-	0.02	0.00	0.03	-	0.00	0.02	0.02	0.00	0.07	0.05	0.12	-	0.37	0.07	0.44
Scorpaena guttata	0.05	0.09	-	0.14	0.00	0.06	0.00	0.07	0.04	0.15	0.01	0.20	0.02	0.05	0.01	0.08
Synodus lucioceps	0.05	0.12	0.03	0.20	0.05	0.14	0.00	0.19	0.01	0.02	-	0.03	0.03	0.02	-	0.04
All species combined	1.58	1.47	1.80	4.84	2.58	1.73	2.13	6.44	1.28	2.62	3.30	7.20	0.91	2.00	4.42	7.33
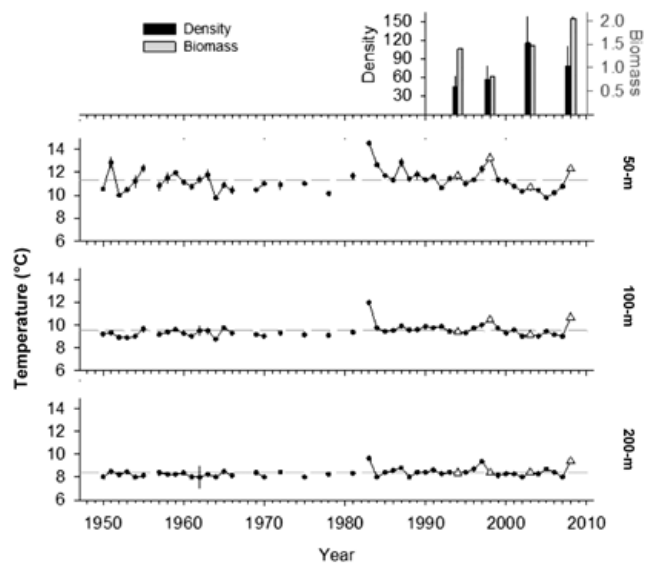
Figure 1. Mean annual demersal fish density (count/100 m² ±SE) and biomass (kg/100 m² ±SE) recorded during the 1994, 1998, 2003, and 2008 surveys at stations on the inner shelf, middle shelf, and outer shelf. Mean summer water temperature recorded during the CalCOFI hydrographic surveys at stations located inshore of Station 50 along survey lines 83.3, 86.7, 90.0, and 93.3 at the 50-, 100-, and 200-m depth strata. The four Bight Regional Monitoring survey years are denoted by the open triangles in each plot. Dashed line in each plot represents the long-term (1949-2008) mean temperature at each depth.

Figure 2. Percent similarity index (PSI) comparing the assemblages and the proportional catch by species between the four Southern California Bight demersal fish surveys (1994, 1998, 2003, and 2008) along the inner, middle, and outer shelves. Numbers represent the years compared against the base year listed on the x-axis. 2003 and 2008 overlap for the comparisons with 1994 and 1998. Species distribution of the 15 most common species, listed in order of decreasing abundance, across all four surveys, combined, plotted by survey: 1994, 1998, 2003, and 2008.

between fish density and biomass against the average temperature at 70 m for the intervening years resulted in a pattern of decreasing density and biomass with increasing temperature (Figure 3). For all species combined, the R^2 was 0.70 for density and 0.85 for biomass. To determine the effect of the highly abundant species on this relationship, data were re-analyzed after filtering out both Pacific sanddab and speckled sanddab (*Citharichthys stigmaeus*), and then for each of these dominant species individually to examine their impact on the relationship. There was an effect of these dominant species on the overall relationship as the R^2 for both density and biomass increased with their exclusion. Speckled sanddab density and biomass exhibited a relationship with temperature similar to that described for all species. Pacific sanddab density and biomass, however, exhibited a substantially reduced relationship with temperature. Given its consistent first ranking in density across all surveys, this likely accounted for the improved relationship observed between density or biomass with temperature after removing Pacific sanddab.

The three climate indices also had relationships to regional fish density or biomass (Table 4). The direction of each relationship was consistent with the general productivity characterizations of each climate index. For example, negative NPGO or positive PDO equated to low productivity periods and resulted in lower demersal fish density and biomass. Of the three climate indices, the MEI and the NPGO were the most correlated with patterns in fish community metrics; mean R^2 were 0.81 and 0.80, respectively. The PDO was the least descriptive climate index with the lowest mean $R^2 = 0.70$, but also the second
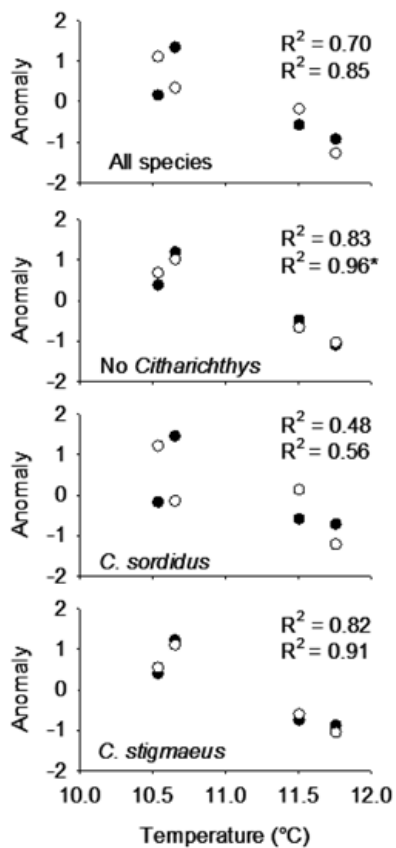
Figure 3. Standardized anomalies of annual mean density (count/100 m²; black circles - ●) and biomass (kg/100 m²; white circles - ○) versus the ~5-year running mean temperature at 70 m for all species combined, all species after excluding *Citharichthys sordidus* and *C. stigmaeus*, *C. sordidus*, and *C. stigmaeus*. Coefficient of determination (R²) for the linear regression through each set is presented. Top R² reflects density and bottom R² reflects biomass.

highest standard error consistent with the wide variation among analysis-specific values. The NPGO was the most explanatory index for density with a R^2 >0.90 for all four community metrics. Temperature was the least explanatory with a $R^2 \leq 0.83$ for all four fish community metrics. Patterns in biomass, however, were best described by temperature and the MEI, including a nearly straight-line relationship between the MEI and the no *Citharichthys* group of demersal fishes. In all cases, no clear relationship between Pacific sanddab and environmental indices were observed and these comparisons consistently yielded the lowest coefficient of determination in each analysis.

Demersal fish community density and biomass generally shifted southward with increasing water temperature (Figure 4). In 1994 and 1998, the

Table 4. Coefficient of determination (R²) of the trendline describing the relationship between each environmental index and each abundance index. Density refers to the area-weighted mean count/1000 m² and biomass represents the area-weighted mean kg/1000 m². No *Citharichthys* data set represents the data for each abundance metric after removing *C. sordidus* and *C. stigmaeus*. NPGO = North Pacific Gyre Oscillation, PDO = Pacific Decadal Oscillation, MEI = Multivariate ENSO Index, and temp = mean water temperature at 70 m. See Methods section for description of the mean calculation for each environmental index.

Metric	Index			
	NPGO	PDO	MEI	Temp
Density				
All species	0.99	0.92	0.85	0.70
No Citharichthys	0.98	0.79	0.94	0.83
C. sordidus	0.90	0.73	0.66	0.48
C. stigmaeus	0.99	0.92	0.93	0.82
Biomass				
All species	0.47	0.39	0.74	0.85
No Citharichthys	0.92	0.86	1.00	0.96
C. sordidus	0.17	0.12	0.41	0.56
C. stigmaeus	0.96	0.85	0.98	0.91
Mean	0.80	0.70	0.81	0.76
SE	0.11	0.10	0.07	0.06

relatively warmer periods, density and biomass were centered between 33.5 and 33.6 °N latitude. In 2003 and 2008, the relatively cooler periods, density and biomass were centered between 33.6 and 33.7°N latitude. These latitudinal relationships using all species ($R^2 = 0.92$ for density and 0.81 for biomass) were largely driven by movement in Pacific sanddab ($R^2 = 0.83$) populations. Depth patterns in demersal fish density and biomass were variable and exhibited fewer relationships with latitude than observed for temperature. For example, a modest ($R^2 = 0.50$) relationship was observed between speckled sanddab biomass depth and latitude.

The OS demersal fish community consistently had more fish per unit area (density and biomass) than either the IS or the MS (Tables 2 and 3). Diversity and species richness, however, was typically greatest along the MS compared to the IS or OS. In nearly every survey, the IS recorded the lowest density, biomass, diversity, and species richness.

The seven most abundant species taken from all four surveys combined accounted for ≥ 69% of the
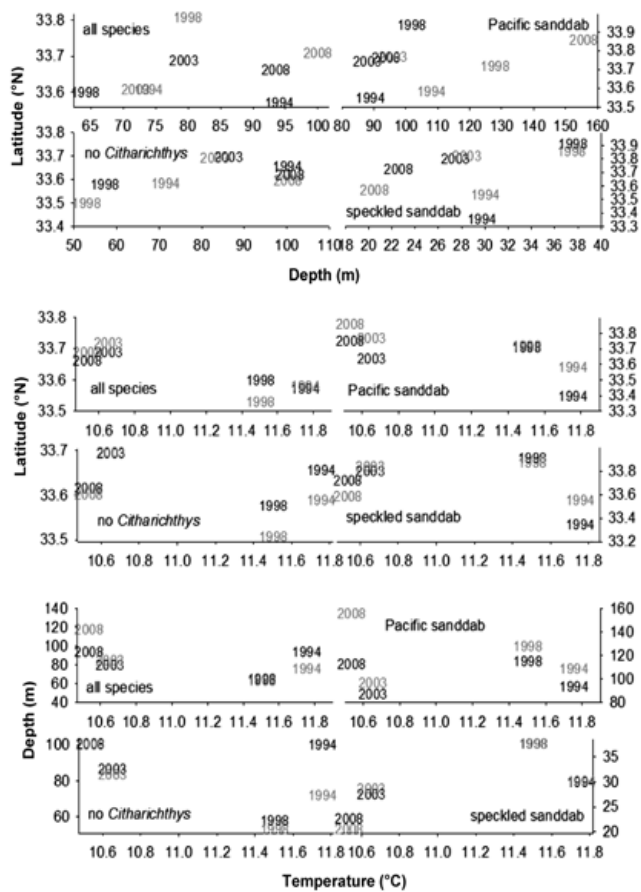
Figure 4. Area-weighted mean density (count/100 m²) and biomass (kg/100 m²) centers of distribution by latitude, depth, and latitude per temperature at 70 m. Grey = biomass and black = density. The survey year is overlaid on the data point in each figure.
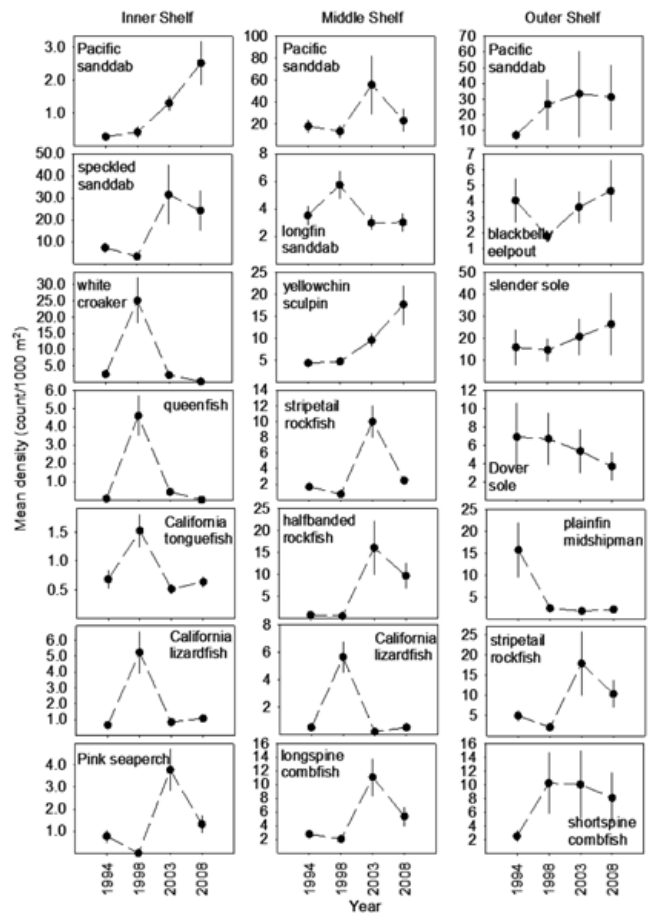

Figure 5. Mean annual density (count/1000 m² ±SE) for the seven species most commonly taken during otter trawls in each shelf strata during the four Bight monitoring surveys (1994, 1998, 2003, and 2008).

total catch regardless of depth stratum (Figure 5). Eleven species-stratum combinations had increasing trends while 10 species-stratum combinations declined over time. Species with substantially increasing densities during the four surveys included Pacific sanddab and speckled sanddab along the IS, yellowchin sculpin and halfbanded rockfish along the MS, and Pacific sanddab, slender sole (*Lyopsetta exilis*), and stripetail rockfish along the OS. Decreasing densities were most noticeable in many species along the IS, California lizardfish (*Synodus lucioceps*) along the MS, and plainfin midshipman and Dover sole (*Microstomus pacificus*) along the OS.

In total, all four surveys were dominated by demersal fishes in the 6 to 14 cm size classes (Figure 6). Average demersal fish lengths in 1994 and 1998 did not change much (10.5 cm and 10.7 cm, respectively). Demersal fish length frequencies were generally consistent between 1994 and 1998, with a subtle size-class mode shift from 6- and 7-cm size

classes in 1994 to 7- to 10-cm size classes in 1998. In 2003, however, the mean fish length declined over 1 cm (9.5 cm) due to the influence of fishes ≤7 cm. This pattern reversed in 2008 as the catch increased in size to an average of 11.0 cm with few individuals in smaller size classes, particularly those ≤6 cm. These differences were statistically significant (Friedman Rank Sum, $\chi^2 = 27.45$, df = 3, p < 0.001). Differences in fish length between survey years were reflected in size class distributions for the most common species (Figure 7). In Pacific sanddab for instance, between 3 and 8% of the population was ≤4 cm size class in each of the three earliest surveys, but comprised only 2% in the 2008 survey. In contrast, 13% of the Pacific sanddab population was ≥20 cm size class in 2008, while only 6 to 10% of the population was ≥20 cm size class in each of the three earliest surveys. Similarly, length-frequency distributions in each of the four common demersal fish species exhibited smaller size classes in 2008 than
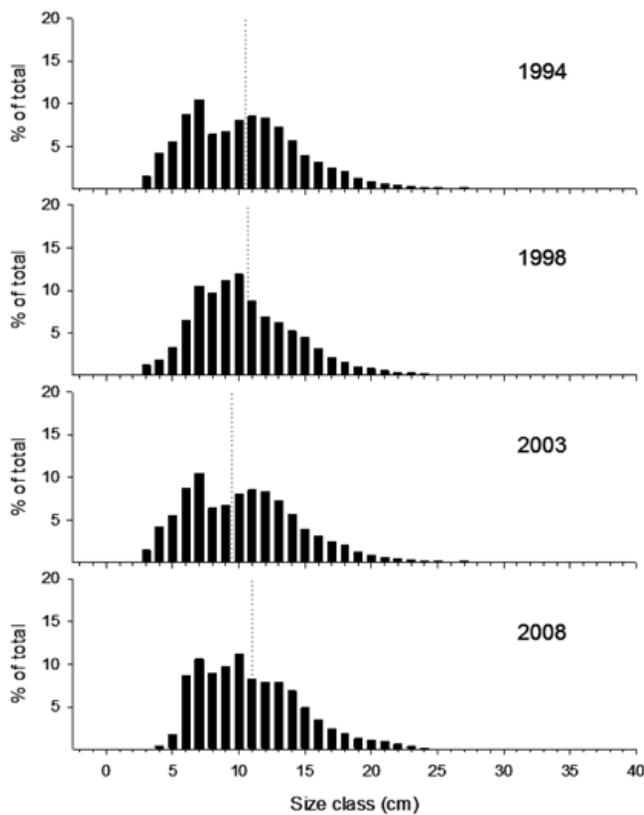
Figure 6. Length frequency distribution of all fishes (up to the 40 cm size class) taken by survey year with the mean length indicated by the vertical dashed line.

was taken in 2003. Even extending to the 12 most common species, mean length in 2008 was greater than, or equal to, the grand mean length observed across all four survey years (Appendix C in SI).

Mean fish length varied with latitude and depth across surveys (Figure 8). During most survey years, the minimum mean length was taken at the southern latitudes (≤33.0°N) and then increased with increasing latitude. For example, Pacific sanddab lengths were generally >10 cm north of 33.6°N while the opposite was observed south of 33.6°N. Unlike length:latitude comparisons, the distribution of lengths by depth differed between all species combined and the dominant demersal fish species, Pacific sanddab. The maximum mean fish length occurred at the shallowest and deepest depths for all species combined consistently across surveys, with the mid-depth sampling recording the lowest mean fish length. In contrast, maximum average Pacific sanddab lengths typically increased with increasing depth consistently across surveys.

The habitat value analysis revealed differences among most years (KW, H = 67.28, df = 3, p <0.01) (Figure 9). Mean habitat values derived for 1998 and 2008 were different from all other years, while those for 1994 and 2003 were different only from 1998 and
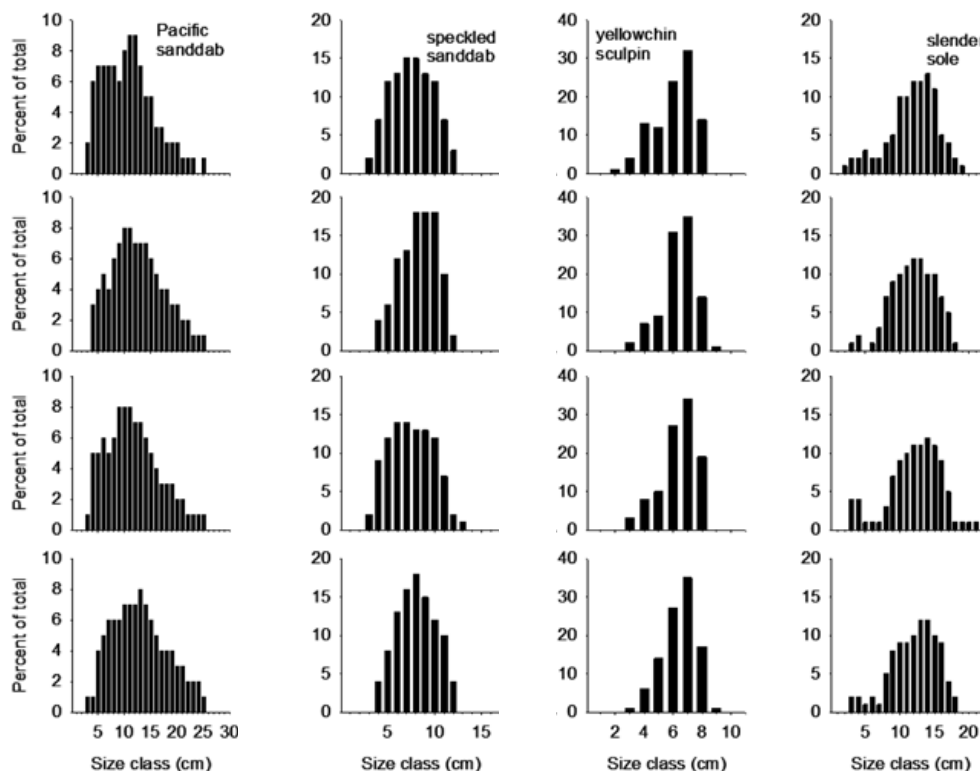

Figure 7. Length frequency histograms for the four most common species taken across all four surveys. Top row = 1994 survey; second row = 1998 survey, third row = 2003 survey, last row = 2008 survey.
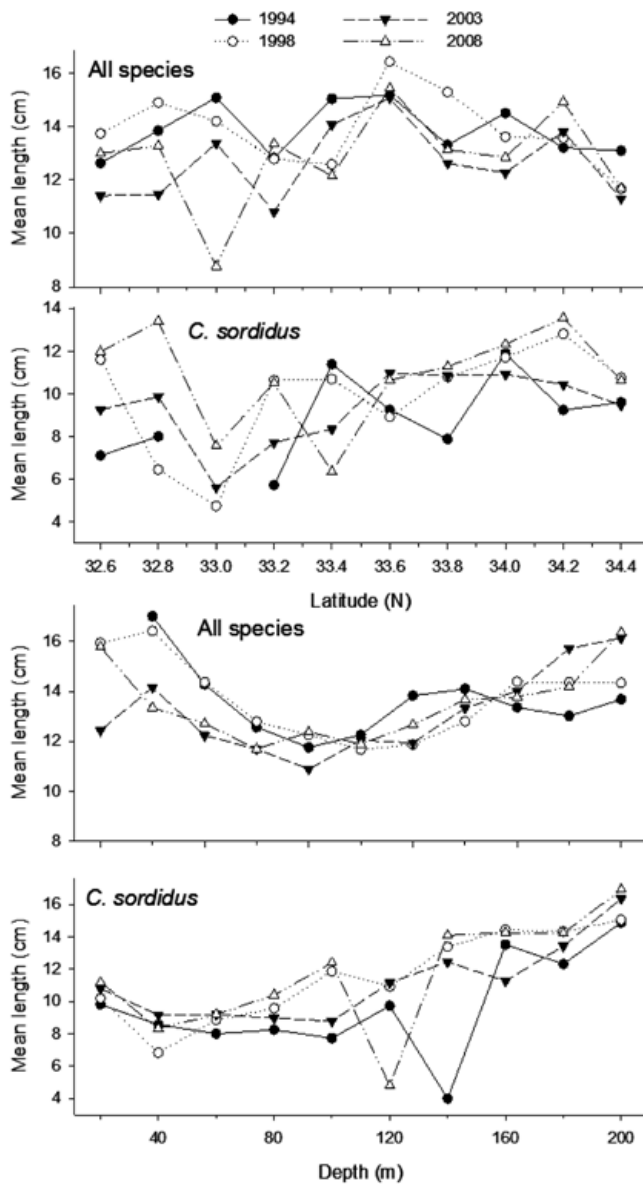
Figure 8. Abundance-weighted mean lengths by latitude and depth for all species combined and *Citharichthys sordidus* by survey year: 1994, 1998, 2003, and 2008.
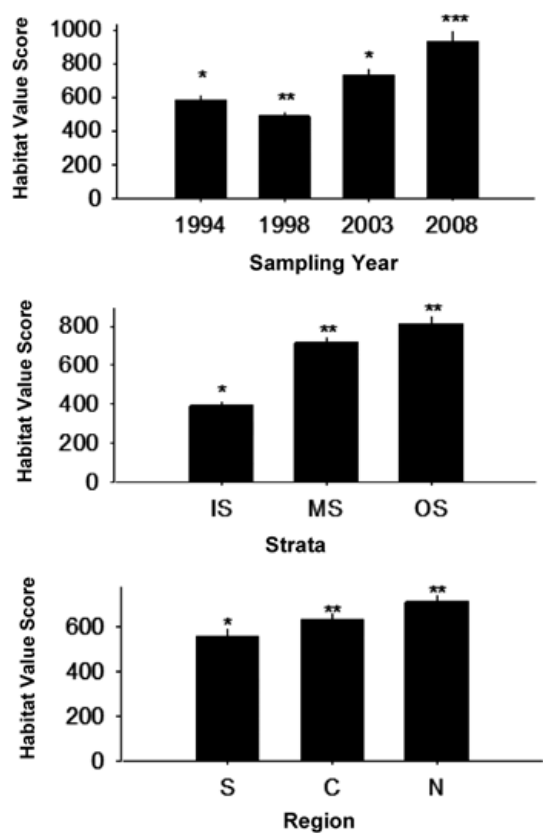

Figure 9. Mean (±SE) habitat value by sampling year (all regions and shelf strata combined), by strata (all regions and years combined), and by region (all years and shelf strata combined). Asterisks denote significant differences.

2008 but not each other. Examination by depth found the IS habitat value was significantly lower than the remaining two areas, with no significant difference between the MS and OS (KW, H = 79.07, df = 2, p <0.01). Finally, the southern area exhibited a significantly lower habitat value than either the central or northern areas (KW, H = 12.37, df = 2, p <0.01).

DISCUSSION

In the SCB regional surveys between 1994 and 2008, 160 species were identified including several new to the area (Allen and Groce 2001, Groce *et al.* 2001, Lea *et al.* 2009). Comparing the regional surveys clearly indicated that these demersal fish assemblages are dynamic, changing in species composition, abundance, and biomass over time. The significance of these periodic, regionalized surveys cannot be underestimated. Localized trawl monitoring programs typically find far fewer species (Stull and Tang 1996). The regional surveys not only revealed bightwide variability in abundance of selected species, but that population movements either in latitude or depth are common, both of which could result in mistaken assumptions about species shifts at local-scale impact-based monitoring programs.

Large scale temporal changes in the demersal fish community were evident during the SCB regional surveys. The 1998 survey was appreciably different from the other three surveys, with 2003 and 2008 being the most similar. Anomalous oceanographic conditions existed in 1998 as a result of the 1997-1998 El Niño and the resultant temporary poleward expansion of numerous species (Lea and Rosenblatt 2000). In addition, many of the species that were

comparatively common in 1998 were often minimally represented in the remaining surveys. Moreover, numerically dominant species during 1994, 2003, and 2008 such as Pacific and speckled sanddabs, had reduced abundance in 1998. Arguably, the fish assemblage sampled during the 1998 survey was reflective, at least partially, of the El Niño conditions.

Density, biomass and mean fish length also indicated differences between regional surveys. The 2008 survey had the second greatest bightwide density and the single greatest biomass for any of the four surveys. What precipitated this pattern is perhaps the most pressing question resulting from this analysis. Did the assemblage change resulting in this shift? The PSI indicates no appreciable change in the assemblage's species composition, with the exception of the influx of tourist species in 1998. Therefore, the increased biomass with reduced density is not likely caused by a change in the species structure, e.g. phenotypically larger fishes have not replaced smaller fishes. If the same species are there, just fewer individuals weighing more, did the average fish size change? Species-specific length analyses were consistent with a generalized increase in size across the assemblage as the 2008 mean length was larger than the preceding surveys. More importantly, reduced abundances in the smallest size classes suggest poor larval settlement (ecological recruitment) occurred between 2003 and 2008. No change in sampling protocols has occurred and the aforementioned consistency in species assemblage across surveys reinforce that these measures were not artifacts of sampling or species replacements. The SCB demersal fish assemblage information collected during the Bight surveys indicates a shift to bigger, likely older, individuals of the same suite of species that was present in 2003, and likely before, due to depressed larval settlement.

Region-wide changes in demersal fish density and biomass were correlated with environmental conditions. The NPGO and MEI were the most predictive environmental indices and the PDO was the least predictive of the demersal fish assemblage metrics. The PDO is derived from sea surface temperature (SST) anomalies (Mantua *et al.* 1997), and therefore correlates with only SST in the SCB with little or no relationship to other oceanographic variables in the area (Di Lorenzo *et al.* 2008). In response, Di Lorenzo *et al.* (2008) developed the NPGO from sea surface height data and found it correlated with several oceanographic variables in the

SCB. The MEI represents a compilation of several disparate oceanographic metrics, including sea level pressure, SST, surface air temperature, etc. (Wolter and Timlin 2012). The inclusion of measures beyond temperature in the calculation of NPGO and MEI may be responsible for the improved correlations in our analyses of a mixed stock (species and age-structure) fish community. Each species likely responds best to a unique set of environmental conditions that is encapsulated by metrics beyond SST.

One limitation of our study is the small sample size of only four regional surveys. This hinders our statistical power to detect trends, so caution should be used when interpreting results. More data is clearly needed for a detailed account of autocorrelation and robust trends analysis. Despite these important limitations, however, the climate-demersal fish assemblage relationships we observed herein were similar to relationships observed by others examining both extensive temporal (Holbrook *et al.* 1997, Perry *et al.* 2005) and spatial scales (Mearns 1974, Juan-Jorda et al 2009).

While several unique patterns were identified with the SCB regional demersal fish surveys, at least two well-known patterns were re-affirmed. The first was depth-related spatial patterns. Depth is a well-established principal factor segregating the SCB demersal fish community (Mearns 1979, Young *et al.* 1980, Juan-Jorda *et al.* 2009, Toole *et al.* 2011) and the analysis of SCB regional surveys reflects this spatial pattern (Allen and Pondella 2006, Miller and Schiff 2011). The second re-affirmation was the general lack of demersal fish community impacts due to offshore discharges of treated wastewater, particularly in the MS region. Neither abundance nor biomass appeared to be degraded in the MS region. Receiving the majority of wastewater discharge, impacts from these discharges would be expected to be most clearly manifested along the MS, but no such evidence was detected. This is consistent with local trend data near the discharge outfalls that have indicated fish community recovery after increased wastewater treatment (Stull and Tang 1996) and the lack of tumors, lesions and fin rot in comparison to conditions prior to treatment upgrades near the outfalls (Cross 1986).

Habitat value scores based on fish feeding guilds calculated during the regional surveys were dissimilar among years, depths, and latitudes. Temporal differences likely reflected the elevated density and larger mean size of fishes taken in 2008 compared to

the other survey years. Lower habitat value scores in shallower, southern waters were likely due to less dense assemblages of smaller individuals relative to the MS and OS. The fact that the IS is in closer proximity to fishermen (commercial and sport) and stormwater discharges warrants further consideration (Dotson and Charter 2003, Allen 2006, Love 2006). With the notable exceptions of Pacific sanddab, English sole, California halibut, and Dover sole (*Microstomus pacificus*), the small otter trawls used in these regional surveys do not target harvested populations (Leet *et al.* 2001). The harvesting effect may be one cause of the lack of any definable relationship between Pacific sanddab abundance indices and climate indices. Further analysis is needed on this question.

Stormwater discharges are known to contain pollutants that accumulate in both nearshore and offshore sediments (Schiff and Bay 2003) and stormwater plumes are known to extend over large areas, often many kilometers from shore (Nezlin *et al.* 2005). However, the duration of these offshore plumes is short, at most lasting several days, and storm-discharged pollutants are rapidly diluted with most toxics comprising only a small fraction of the plume extent (Reifel *et al.* 2009). Thus, the relative impacts of both fishing and water quality on nearshore demersal fishes remain uncertain and cannot be accurately described by our data.

While the magnitude of current fishing and stormwater pollution impacts are uncertain, the future effects of large-scale oceanographic forces could be demonstrable. The SCB regional surveys identified substantial changes in demersal fish abundance and biomass seemingly correlated to subtle changes in climate. This is likely due to the fine-tuned bioenergetics of demersal species in response to declining food availability with increasing depth, especially those occupying the deeper habitats (Vetter and Lynn 1997). The ecological ramifications of oceanographic warming in cold-adapted fishes was reviewed by Pörtner *et al.* (2008) who found altered physiological performance in fishes including heart rate, fecundity, and growth rate. Therefore, the subtle changes in environmental conditions at depth in the SCB observed by CalCOFI may have reduced the demersal fish community's resiliency, perhaps manifesting itself in the significant shift in size structure observed by the Bight surveys. Ocean warming, even temporary, has been demonstrated to cause substantial faunal changes and biogeographic

shifts to avoid physiological penalties, including in demersal/benthic assemblages (Genner *et al.* 2004, Schiel *et al.* 2004, Perry *et al.* 2005, Miller *et al.* 2011). Future renditions of the SCB regional demersal fish survey may provide critical data to evaluate these patterns.

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Acknowledgements

Supplemental Information

Supplemental Information is available at ftp:// ftp.sccwrp.org/pub/download/DOCUMENTS/ AnnualReports/2012AnnualReport/ar12_10SI.pdf