DEMERSAL FISHES OF THE UPPER CONTINENTAL SLOPE OFF SOUTHERN CALIFORNIA

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ABSTRACT

This study covers the composition, distribution, and abundance of fishes collected by otter trawl and longline between 290 m and 625 m. Fifty-four species of fish were collected: 42 species were caught in trawls, and 30 species were caught on longlines. Only 18 species were caught by both types of gear. The number of species decreased with increasing depth in the trawls but not on the longlines. There were no depth-related trends in abundance or biomass for either gear. Fewer fish were caught during the summer by both types of gear.

Trawl catches were dominated by *Sebastolobus alascanus, Sebastolobus altivelis, Sebastes diploproa, Microstomus pacificus, Glyptocephalus zachirus,* and *Lyopsetta exilis*. Composition of the trawl catches was consistent between areas, seasons, and years.

Longlines were used on mud and banks. Catches on the mud were dominated by *Sebastolobus alascanus, Anoplopoma fimbria,* and *Sebastolobus altivelis*. Catches on the banks were dominated by *Anoplopoma fimbria, Sebastes melanostomus,* and *Sebastolobus alascanus*.

RESUMEN

Este estudio examina la composición, distribución, y abundancia de peces colectados con red de arrastre y espinel entre 290 y 625 m. Cincuenta y cuatro especies de peces fueron colectadas, de las cuales 42 fueron capturadas en redes y 30 en rastras. Solamente 18 especies fueron capturadas con ambos métodos. El número de especies disminuyó con el aumento en profundidad en las redes pero no en las espineles. No hubo una relación entre abundancia o biomasa y profundidad para cualquiera de las técnicas.

Las capturas de las redes estuvieron dominadas por *Sebastolobus alascanus, Sebastolobus altivelis, Sebastes diploproa, Microstomus pacificus, Glyptocephalus zachirus,* y *Lyopsetta exilis*. La composición de la captura por las redes fue consistente entre áreas, estaciones, y años.

Los espineles fueron usadas sobre lodo y bancos. Las capturas en el lodo estuvieron dominadas por *S. alascanus, Anoplopoma fimbria,* y *S. altivelis*. Las capturas en los bancos estuvieron dominadas por *A. fimbria, Sebastes melanostomus,* y *S. alascanus*.

[Manuscript received December 8, 1986.]

INTRODUCTION

The demersal fish fauna from depths greater than 200 m off southern California is not well known (Horn 1980). The fishes were first sampled by beam trawl from the steamer *Albatross* during U.S. Fish Commission surveys from 1888 to 1911 (Fitch and Lavenberg 1968; Allen and Mearns 1977). Few surveys have been conducted and published since then. Four otter trawl samples were taken between 439 m and 658 m off Catalina Island (Fitch 1966). Fifteen otter trawl samples were taken between 200 m and 610 m (Allen and Mearns 1977), and eight were taken between 550 m and 915 m off Los Angeles (Mearns et al. 1979). Deepwater fishes off southern California have also been photographed by baited and unbaited cameras (Isaacs and Schwartzlose 1975; Edwards 1985) and observed from submersibles (Barham et al. 1967; Smith and Hamilton 1983).

This paper presents the results of extensive otter trawl and longline fish collections on the upper continental slope off southern California. The objective of the study was to summarize the composition, distribution, and abundance of fishes on the upper slope.

METHODS

Trawl samples were taken with a single-warp semiballoon otter trawl with a 7.6-m headrope, 8.8-m footrope, 4.1-cm body mesh (stretched), and 1.3-cm cod-end liner (stretched). The net was towed along a depth isobath at approximately 2.5 knots for 10 min (measured from the time the cable was completely deployed to the start of its retrieval) at scope ratios between 2:1 and 3:1. At sea,

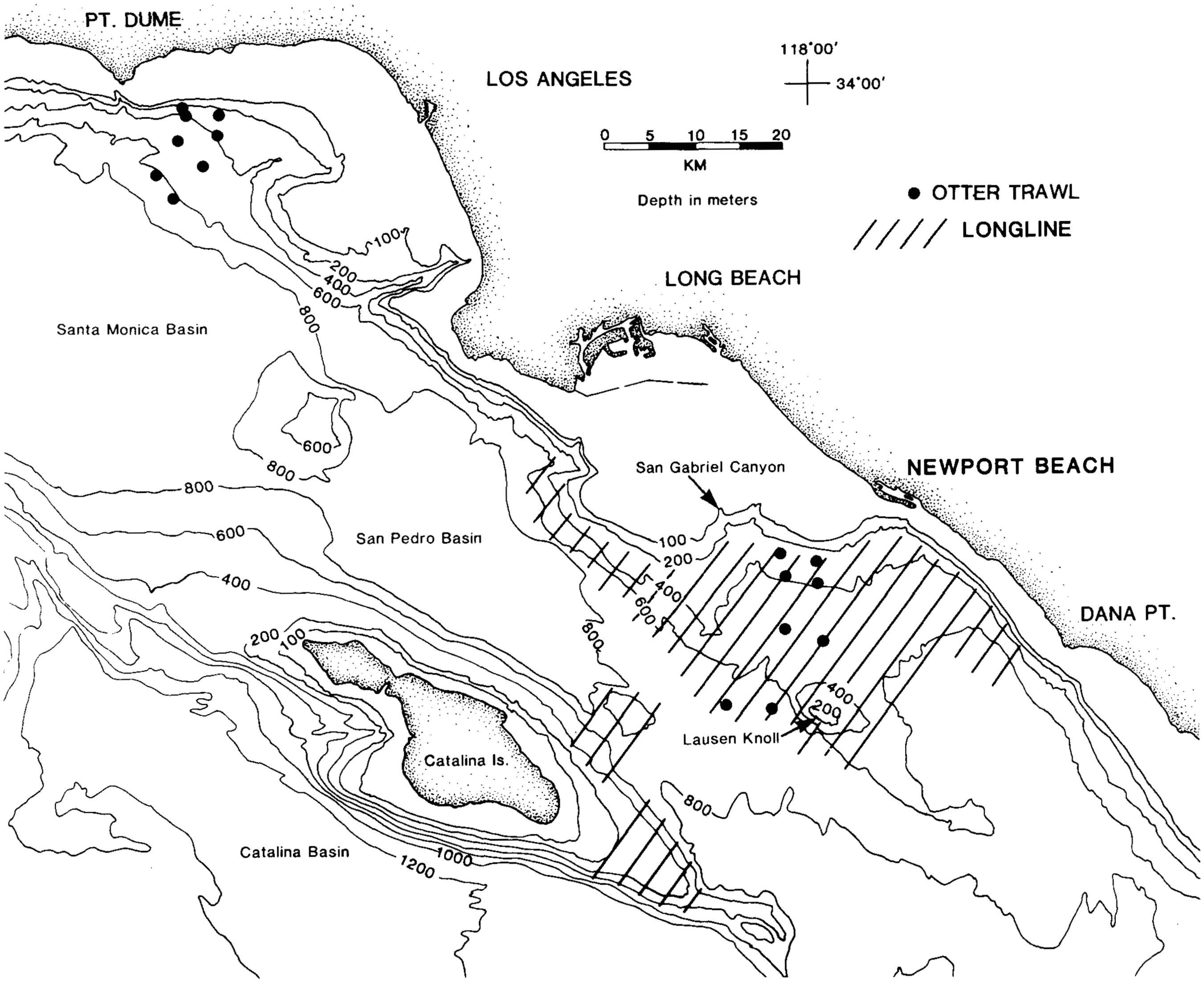

Figure 1. Map of the study area.

the fishes were identified, counted, measured to the nearest mm total length (TL), and weighed by species to the nearest 0.1 kg.

Trawl samples were taken during the day at four stations along each of two lines off Newport Beach and off Point Dume (Figure 1). One sample was taken at each station during each sampling period. Off Newport Beach, 8 trawl samples were taken in winter (Dec.-Jan.) and 8 in summer (July-Aug.) for two consecutive years (1981–82 and 1982–83) for a total of 32 trawls. Off Point Dume, 8 trawl samples were taken in winter and 8 in summer of 1982–83 for a total of 16 trawls.

Data were also obtained from longline catches of commercial fisherman. Their gear consisted of a groundline comprising three to six separate lines of no. 72 twisted cord. Each line of the groundline was approximately 650 m long and, after baiting, was coiled in a wooden tub. (During the set, the individual lines were tied end-to-end.) Hooks (4/0 and 5/0 rockcod) were tied on short leaders and spaced about 1 m apart. Salted pieces of *Engraulis mordax*, and to a lesser extent *Scomber japonicus*, were used as bait.

Sinking and floating longline sets were made. On sinking sets, weights (bricks) were tied to the groundline at the beginning or end of each tub. On floating sets, weights and floats (soda bottles) were alternately tied to the groundline; the distance between two weights encompassed 50–60 hooks. Anchors and buoy lines were attached to each end of the groundline.

Seventy-one trips were made with the commercial fishermen from June 1983 to November 1984. The lines were usually set between 1000 and 1400 hrs and pulled between 0600 and 1000 hrs the following day. Most lines were set within 20 km of Newport Beach, although trips of 50 km were not unusual (Figure 1). The catch of each tub of line was recorded separately. Each fish was measured to the nearest mm TL, and randomly selected individuals were weighed to the nearest 0.1 kg at sea. Weight-length regressions were determined for each species. Weights of fish not weighed were estimated from the regressions, and the weight of the total catch was reconstructed.

Data Analyses

A unit of effort for the otter trawl was one trawl. The number of species, number of individuals, and weight of fish caught in trawls off Newport Beach in 1981–82 and 1982–83 were compared in a three-way fixed-effects analysis of variance (ANOVA; SAS Institute Inc. 1985) with year, depth, and season as the main effects. The number of species, number of individuals, and weights of fish caught in trawls off Newport Beach and Point Dume in 1982–83 were compared in a three-way fixed-effects ANOVA with area, depth, and season as the main effects. The data were transformed to $\log_{10}(x + 1)$ to stabilize the variance. Cell sizes were equal for all analyses. Parallel analyses of raw and transformed data produced qualitatively similar results.

A unit of effort for the longline was one tub of line fished overnight (soak time generally 18 to 20 hrs). For each set, the average catch per tub was determined by averaging the catches of the constituent tubs. The number of species, number of individuals, and weight of fish caught per tub were compared by analysis of covariance (ANCOVA; SAS Institute Inc. 1985) with habitat and season as the main effects and depth as the covariate. The data were transformed to $\log_{10}(x + 1)$ to stabilize the variance. Cell sizes were unequal. Parallel analyses of raw and transformed data produced qualitatively similar results.

Catch parameter means were calculated from all trawls and longline sets taken at specified depths, times, or habitats. Individual species' catch means were calculated from all trawls and sets taken at specified depths, times, or habitats. Percent frequency of occurrence means were calculated from all trawls and sets taken at specified depths and times.

Parametric correlations between individual fish size and depth of capture were determined for the common species. Fish size distributions were compared by the Kolmogorov-Smirnov two-sample test (Siegel 1956). The size-depth relationship for *Sebastolobus alascanus* was examined.

STUDY AREA

Sediments of the upper continental slope are predominantly green silty clays. Sand content was fairly constant downslope (mean = 12% by dry weight); areas around the offshore banks and the shoulders of the submarine canyons were sandier (25%–50% by dry weight). Organic content increased from 5%–7% (as total volatile solids) at 290 m, to 11%–14% at 625 m (SCCWRP 1983).

The longline fishermen recognize two habitats on the slope: hard substrate banks and soft, relatively featureless (on a fathometer) mud bottom. Surface sediments on the banks are a mixture of coarse sand and calcareous organic debris with occasional rocks. Banks, as used herein, include isolated mounds as small as a few hundred meters across and 20–30 m high, shoulders of submarine canyons, and submerged mountains. The mud habitat is the green silty clay described above and is the predominant habitat on the slope.

Temperature, dissolved oxygen, and salinity measured in the water column over the slope off Newport Beach showed weak and decreasing gradients with increasing depth. The mean annual temperature was 8.2°C (SD = 0.4, N = 21, min = 7.5, max = 9.1) at 300 m, and 6.5°C (SD = 0.2, N = 17, min = 6.0, max = 6.9) at 500 m. Mean annual dissolved oxygen was 1.22 ppm (SD = 0.26, N = 18, min = 0.76, max = 1.94) at 300 m, and 0.47 ppm (SD = 0.10, N = 16, min = 0.31, max = 0.72) at 500 m. Some of the variation in these parameters resulted from seasonal changes related to upwelling. In the spring, temperature and dissolved oxygen decreased and salinity and density increased in water shallower than 350 m (SCCWRP 1983).

RESULTS

Fifty-four species of fish were collected during the study (Table 1). Eighteen species were collected by both otter trawl and longline.

Otter trawls collected 42 species; *Sebastolobus alascanus, Sebastolobus altivelis, Sebastes diploproa, Glyptocephalus zachirus, Microstomus pacificus,* and *Lyopsetta exilis* dominated the catches (Table 1). Twenty-four species occurred only in trawls—these were generally small demersal species (agonids and zoarcids), small nektobenthic

TABLE 1
Fishes Collected by Otter Trawl (*n* = 48) and Longline (*n* = 71) off Southern California between 290 and 625 m

		Otter trawl		Longline	
Family	Scientific name	Number collected	Percent frequency of occurrence	Number collected	Percent frequency of occurrence
Myxinidae	*Eptatretus deani*	87	33	486	80
	Eptatretus stoutii	1	2	139	59
Chimaeridae	*Hydrolagus colliei*	23	25	138	62
Hexanchidae	*Hexanchus griseus*			1[a]	—
Scyliorhinidae	*Apristurus brunneus*	4	6	475	70
	Parmaturus xaniurus	2	2	223	75
Squalidae	*Squalus acanthias*			148	41
	Somniosus pacificus			2	1
Torpedinidae	*Torpedo californica*			1	1
Rajidae	*Bathyraja kincaidi*	7	15	14	7
	Raja inornata	2	4	1	1
	Raja rhina			20	14
Nettastomatidae	*Facciolella gilberti*	4	6		
Alepocephalidae	*Alepocephalus tenebrosus*	2	2	2[a]	—
Moridae	*Physiculus rastrelliger*	19	19		
Merlucciidae	*Merluccius productus*	62	35	306	63
Macrouridae	*Nezumia stelgidolepis*	24	23	177	46
Bythitidae	*Cataetyx rubrirostris*	57	19		
Batrachoididae	*Porichthys notatus*	19	6		
Scorpaenidae	*Sebastolobus alascanus*	1405	98	2830	99
	Sebastolobus altivelis	3063	52	979	80
	Sebastes aleutianus			3	3
	Sebastes aurora	6	6	588	87
	Sebastes babcocki			1	1
	Sebastes diploproa	403	58	297	18
	Sebastes elongatus	2	4		
	Sebastes gilli			2	3
	Sebastes goodei	5	4	1	1
	Sebastes helvomaculatus			102	7
	Sebastes hopkinsi	1	2		
	Sebastes jordani	32	6		
	Sebastes levis	1	2		
	Sebastes melanostomus			1279	65
	Sebastes paucispinis	3	4		
	Sebastes phillipsi			5	4
	Sebastes rosenblatti	7	10		
	Sebastes rufus	52	15	1	1
	Sebastes saxicola	41	4		
Anoplopomatidae	*Anoplopoma fimbria*	104	58	3799	99
Zaniolepididae	*Zaniolepis frenata*	1	2		
Agonidae	*Bathyagonus pentacanthus*	15	13		
	Xeneretmus latifrons	38	19		
	Xeneretmus triacanthus	1	2		
Cyclopteridae	*Careproctus melanurus*	7	10		
Zoarcidae	*Bothrocara brunneum*	1	2		
	Lycodapus fierasfer	5	4		
	Lycodes pacificus	92	46		
	Lyconema barbatum	3	6		
Bothidae	*Citharichthys sordidus*	1	2		
Pleuronectidae	*Eopsetta jordani*			6	4
	Glyptocephalus zachirus	324	54		
	Lyopsetta exilis	737	50	2	3
	Microstomus pacificus	590	94	49	28
	Parophrys vetulus	11	13		
Total		7,264		12,074	

[a]Caught during the study but on a trip in which I did not participate; not counted in totals.

species (scorpaenids), and some larger demersal species (pleuronectids).

Longlines collected 30 species; *Sebastolobus alascanus, Sebastolobus altivelis, Sebastes melanostomus,* and *Anoplopoma fimbria* dominated the catches (Table 1). Twelve species occurred only on

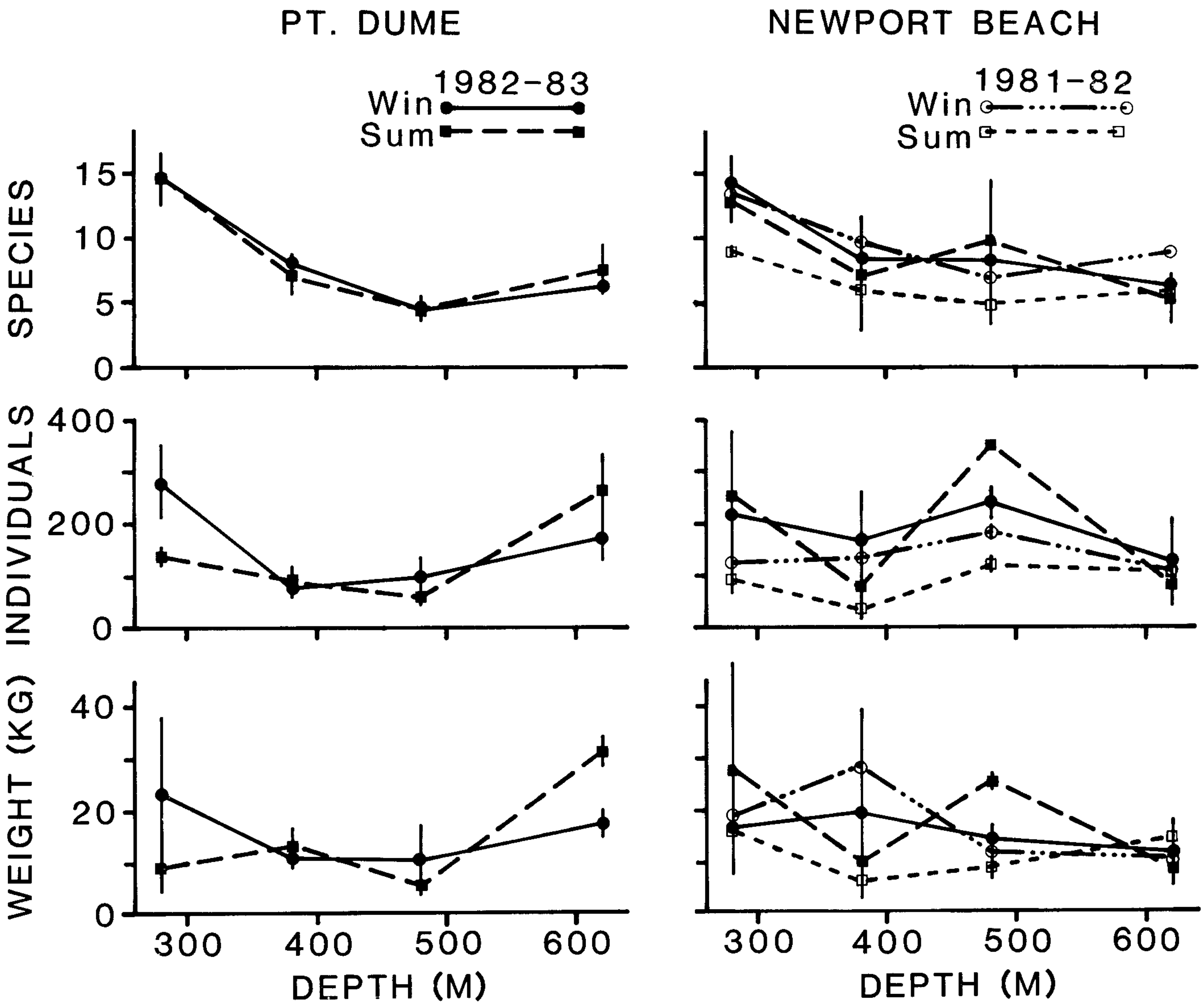

Figure 2. Mean number of fish species, number of individuals, and weight of fish per 10-min trawl off Newport Beach and Point Dume by season, year, and depth. Vertical bars are one standard deviation.

longlines—these were generally large, mobile species (squalids and scorpaenids).

Otter Trawls

The number of species collected per trawl varied with depth and season. Significantly more species were collected at 290 m than at the deeper stations in both areas (ANOVA, $P < 0.05$; Figure 2). Significantly more species were collected during the winter than during the summer off Newport Beach (ANOVA, $P < 0.05$; Figure 2).

The number of individuals collected per trawl varied with depth, year, and season (Figure 2). Off Newport Beach, catches were significantly larger in the winter than in the summer, and catches in 1982–83 were significantly greater than in 1981–82 (ANOVA, $P < 0.05$).

Weight of the catch was the most variable of the three catch parameters and the least consistent between seasons and areas (Figure 2).

Of the six dominant species in trawl catches, all except *Sebastolobus alascanus* showed significant trends in abundance with depth (ANOVA, $P < 0.05$; Figure 3). *Lyopsetta exilis, Microstomus pacificus,* and some *Sebastes* spp. decreased in abundance downslope. *S. alascanus* and *Glyptocephalus zachirus* were more abundant at mid-depths than either shallower or deeper. *Sebastolobus altivelis* increased in abundance downslope.

S. alascanus, M. pacificus, and *L. exilis* were

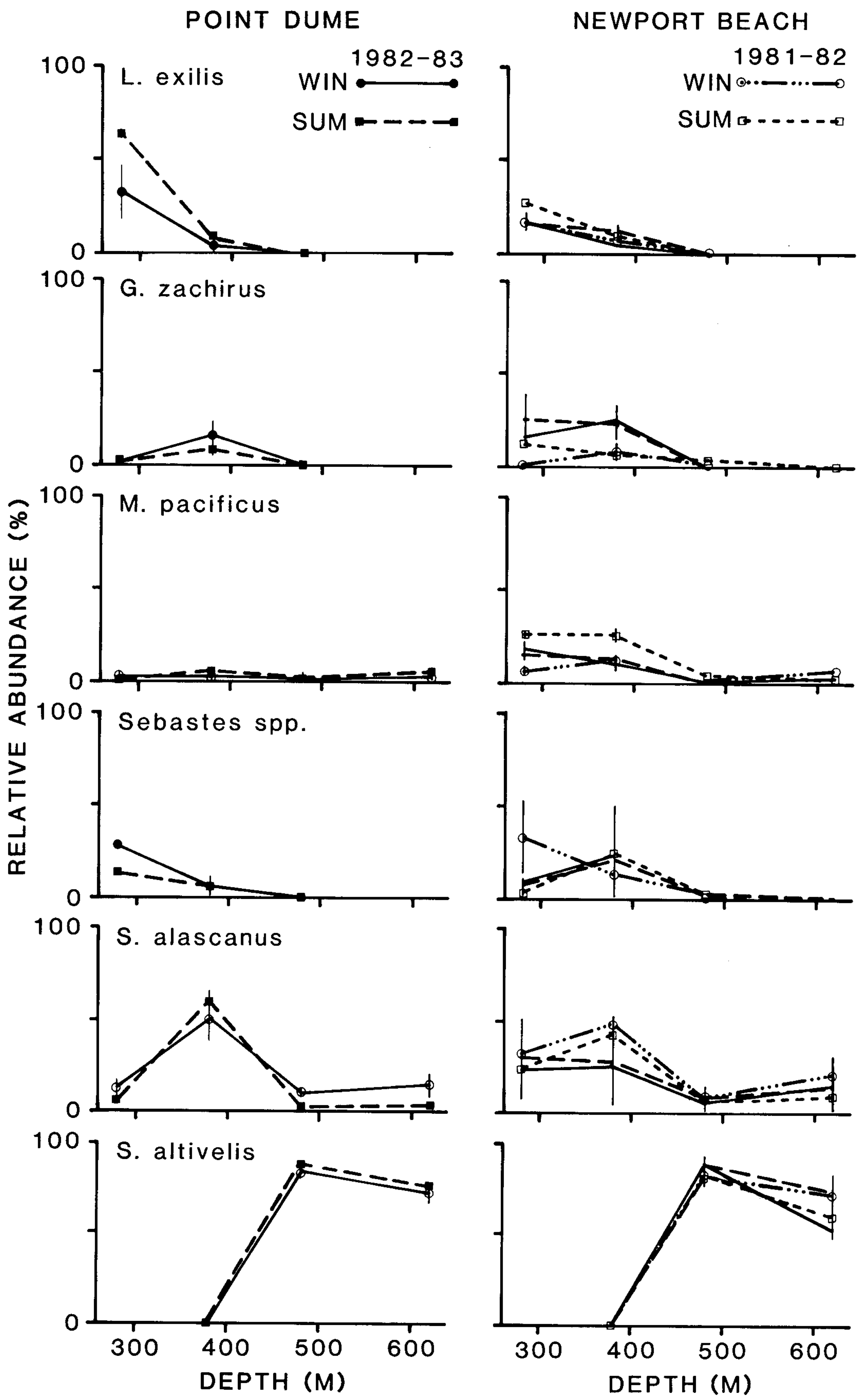

Figure 3. Mean percent abundance of the dominant fish species in trawls off Newport Beach and Point Dume by season, year, and depth. Vertical bars are one standard deviation.

TABLE 2
Composition of Trawl Catches between 290 and 380 m (*n* = 24) and between 480 and 625 m (*n* = 24)

	290–380 m			480–625 m		
	PO	No	Wt	PO	No	Wt
Eptatretus deani	17	0.4	<0.1	50	3.2	0.4
Hydrolagus colliei	42	0.8	0.3	8	0.1	<0.1
Physiculus rastrelliger	38	0.8	<0.1	0	—	—
Merluccius productus	63	2.5	0.8	8	0.1	<0.1
Nezumia stelgidolepis	4	<0.1	<0.1	42	1.0	0.1
Cataetyx rubrirostris	0	—	—	42	2.4	<0.1
Sebastolobus alascanus	100	42.6	3.6	96	15.9	2.6
Sebastolobus altivelis	4	<0.1	<0.1	100	127.5	6.7
Sebastes diploproa	92	16.1	1.8	25	0.7	0.3
Sebastes rufus	29	2.2	0.4	0	—	—
Anoplopoma fimbria	42	0.8	0.8	71	3.5	2.1
Bathyagonus pentacanthus	21	0.6	<0.1	0	—	—
Xeneretmus latifrons	38	1.6	<0.1	0	—	—
Lycodes pacificus	75	3.3	0.4	17	0.5	0.1
Glyptocephalus zachirus	96	12.9	2.5	13	0.6	0.2
Lyopsetta exilis	100	30.7	0.7	0	—	—
Microstomus pacificus	100	19.5	3.8	88	5.1	1.8
Parophrys vetulus	25	0.5	0.1	0	—	—

These species constituted more than 97% of the number and weight of fish caught. PO = percent frequency of occurrence; No = mean number per 10-min trawl; Wt = mean weight (kg) per 10-min trawl.

more abundant in 1982–83 than in 1981–82, and *S. alascanus* and *G. zachirus* were more abundant off Point Dume than off Newport Beach. Despite differences in catches, the relative abundances of the dominant species were consistent between areas and years (Figure 3).

The composition of otter trawl catches changed markedly between 380 m and 480 m (Table 2). Of the 42 species caught by trawls, only 12 were collected at all four depths. Thirty-four species were caught at 290 m and 380 m; 22 occurred only between those depths. Twenty species were caught at 480 m and 625 m; 8 occurred only between those depths.

Longlines

There were no trends in the number of species caught per tub with depth, and there were no differences between bank and mud sets, but the number of species was significantly lower in the summer (ANCOVA, $P < 0.05$; Figure 4). There were no trends in the number of fish caught per tub over depth, and there were no differences between habitats, but the catch was significantly lower in the summer (ANCOVA, $P < 0.05$). There were no trends in weight per tub with depth, but weight was significantly higher on bank sets than on mud sets and was significantly lower in the summer (ANCOVA, $P < 0.05$).

Of the 30 species of fish caught on longlines, 27 were caught on banks and 20 were caught on mud.

TABLE 3
Composition of Longline Catches from Mud (*n* = 38) and Bank (*n* = 33) Habitats

	Bank			Mud		
	PO	No	Wt	PO	No	Wt
Eptatretus deani	70	1.3	0.1	90	2.9	0.4
Eptatretus stoutii	46	0.2	<0.1	71	1.0	<0.1
Hydrolagus colliei	73	0.9	0.5	53	0.5	0.3
Apristurus brunneus	61	1.4	0.5	79	2.9	1.1
Parmaturus xaniurus	73	1.4	0.4	76	0.8	0.3
Squalus acanthias	39	0.9	2.1	42	0.5	1.0
Merluccius productus	85	2.0	1.7	45	0.9	0.6
Nezumia stelgidolepis	12	0.1	<0.1	76	1.5	0.4
Sebastolobus alascanus	97	5.6	2.9	100	20.2	11.2
Sebastolobus altivelis	58	1.7	0.1	100	7.4	0.8
Sebastes aurora	88	2.7	1.0	87	2.8	1.4
Sebastes diploproa	36	2.5	1.0	3	0.2	<0.1
Sebastes melanostomus	100	15.2	17.8	34	0.6	0.9
Anoplopoma fimbria	97	21.1	24.2	100	17.0	20.3
Microstomus pacificus	39	0.2	0.1	40	0.2	0.1

These species constituted more than 97% of the number and biomass of fish caught. PO = percent frequency of occurrence; No = mean number per tub; Wt = mean weight (kg) per tub.

Catches on banks were dominated by *Anoplopoma fimbria, Sebastes melanostomus,* and *Sebastolobus alascanus* (Table 3). Catches on mud were dominated by *Sebastolobus alascanus, Anoplopoma fimbria,* and *Sebastolobus altivelis.* Ten species, including seven *Sebastes* spp., were caught only on banks; three species were caught only on mud.

Size of Fish

Nine of 12 trawl-caught species and 6 of 13 longline-caught species showed significant positive size-depth correlations (Table 4). *Sebastes diploproa* showed a positive correlation for trawl captures

TABLE 4
Correlation between Individual Fish Size and Depth of Capture

	Otter trawl			Longline		
	r	*p*	*n*	*r*	*p*	*n*
Hydrolagus colliei	−.369	ns	23	.013	ns	114
Apristurus brunneus				.062	ns	408
Parmaturus xaniurus				.263	**	167
Squalus acanthias				−.187	ns	92
Merluccius productus	.567	**	59	.054	ns	175
Nezumia stelgidolepis				−.112	ns	142
Cataetyx rubrirostris	−.070	ns	49			
Lycodes pacificus	.586	**	69			
Sebastolobus alascanus	.199	**	1240	.167	**	2361
Sebastolobus altivelis	.178	**	2648	.240	**	882
Sebastes aurora				.541	**	469
Sebastes diploproa	.446	**	384	−.157	*	182
Sebastes rufus	.402	*	52			
Sebastes melanostomus				.234	**	843
Anoplopoma fimbria	−.001	ns	73	.140	**	3015
Glyptocephalus zachirus	.341	**	292			
Lyopsetta exilis	.300	**	738			
Microstomus pacificus	.485	**	603	.233	ns	34

r = correlation coefficient; *p* = probability; *n* = number of fish; * = significant at 0.05; ** = significant at 0.01; ns = not significant

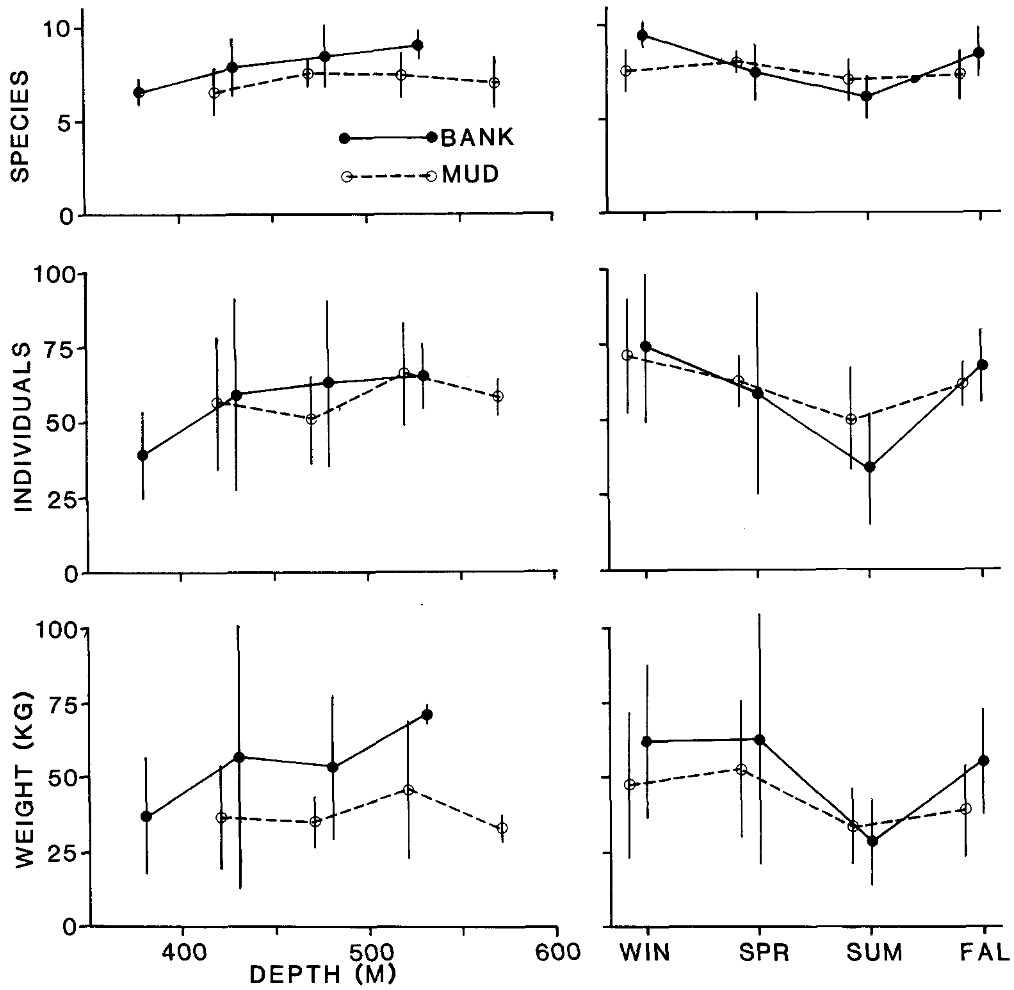

Figure 4. Mean number of fish species, number of individuals, and weight per tub of longline by depth and season. Vertical bars are one standard deviation.

and a negative correlation for longline captures. The remaining species showed no significant size-depth relationships.

The size distributions of eight species were significantly different between trawls and longlines (Kolmogorov-Smirnov two-sample test, $P < 0.05$). In each case, the otter trawl collected smaller individuals (Figure 5).

Trawl collections on the upper slope encompassed most of the vertical range commonly occupied by *Sebastolobus alascanus* (Moser 1974), and captured fish ranged in size from transforming benthic juveniles (< 50 mm TL) to adults (> 400 mm TL). Recently settled individuals were most abundant at the deepest and shallowest stations (Figure 6). Midsized individuals were more abundant at the shallower stations, and large individuals were more abundant at the deeper stations.

DISCUSSION

Gear selectivity substantially affected catch composition. Only 18 (33%) of the 54 species collected were caught by both types of gear. Large mobile fishes dominated longline catches, and small sedentary fishes dominated trawl catches. Small trawls are ineffective samplers of large demersal fishes (Day and Pearcy 1968; Haedrich et al. 1975). Avoidance of the otter trawl is suggested by the larger size of individuals captured by longline.

Otter Trawls

The total number of species collected, the number of species per trawl, and the number of fish per trawl were lower on the upper slope, 290–625 m, than on adjacent areas on the outer shelf, 130–230 m (Table 5). Catch weight per trawl was similar on the upper slope and outer shelf.

All trawl-catch parameters on the slope were higher than those in the adjacent basins, 715–915 m[1] (Table 5). The low number of species, number

[1]Trawl catch parameters for the basins probably are overestimates. Assuming the net continues to fish for some time after retrieval begins, distance fished during deeper tows probably is underestimated compared to shallower tows.

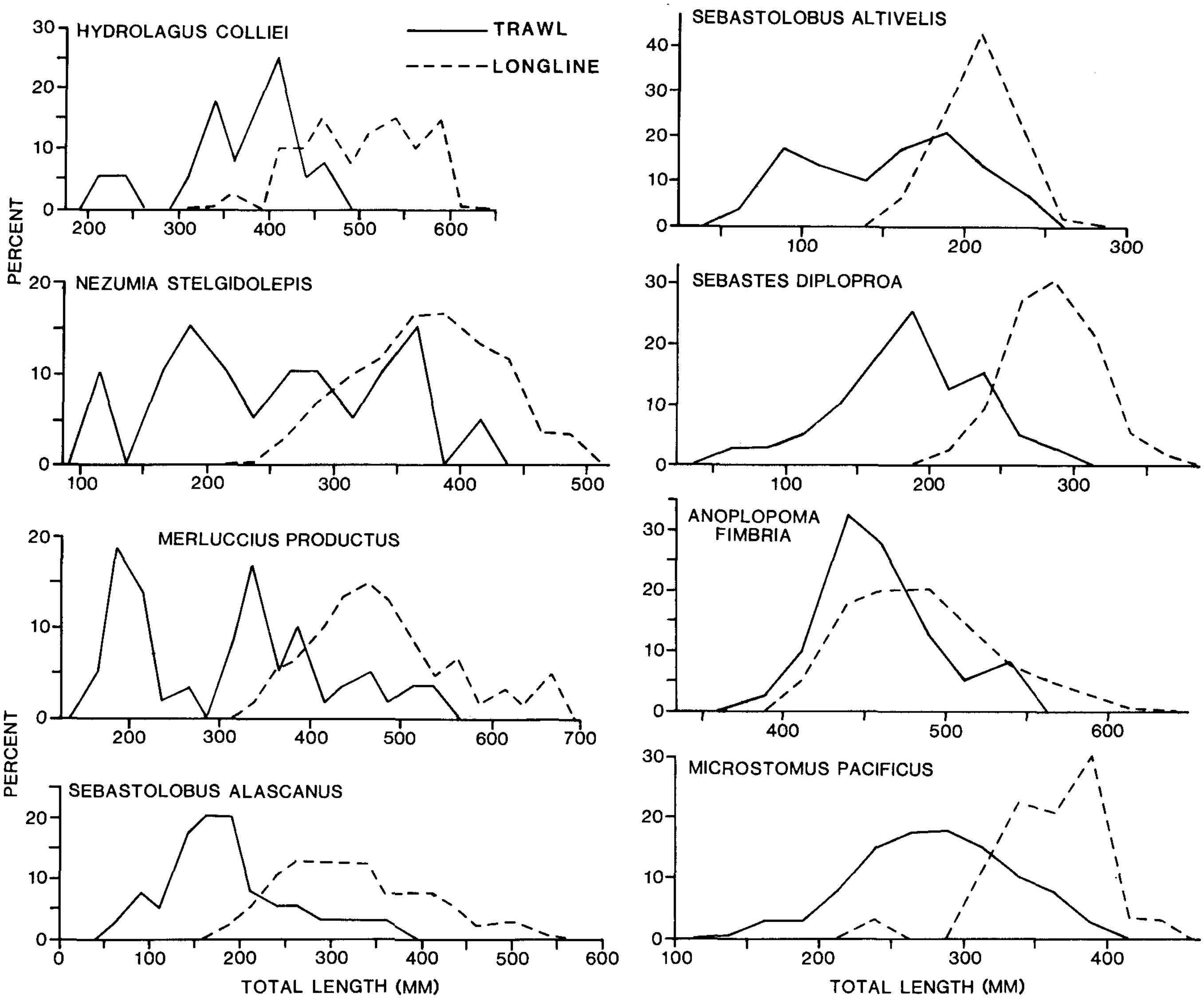

Figure 5. Size distribution of eight species collected by trawl and longline.

of individuals, and weight of fish in the San Pedro and Santa Monica basins is probably related to low dissolved-oxygen levels. Water entering the basins at the depth of the sills (about 700 m) comes from the oxygen minimum layer (0.3 ml l^{-1}) in the ocean waters to the southeast. The oxygen content of the water in the basins ranges from less than 0.1 to 0.3 ml l^{-1} with a mean of about 0.2 (U.S. Department of Interior 1968). The abundance of animals in the bottom of the basins parallels the abundance of oxygen (Rittenberg et al. 1955). Macrofauna and megafauna are scarce in the San Pedro and Santa Monica basins and very abundant in the Catalina Basin, an offshore basin with an average oxygen content about twice that of the nearshore basins (Hartman 1955; Emery 1960; U.S. Department of Interior 1968; Smith and Hamilton 1983).

Estimates of fish abundance (3.4–3.8 fish 100 m^{-2}) and biomass (3.5–3.9 g m^{-2}) on the upper continental slope off southern California (Table 5) are higher than estimates obtained from a 3-m beam trawl (0.6–1.1 fish 100 m^{-2} and 2.0–2.9 g m^{-2}) fished between 515 m and 805 m off Oregon (Pearcy et al. 1982), and lower than biomass estimates obtained from a 23-m trawl (approximately 6–11 g m^{-2}) fished between 250 m and 750 m off Oregon (Alton 1972; Fig. 6 in Pearcy et al. 1982). Differences among net types and accuracy of area-swept estimates preclude anything but a casual comparison.

Longlines

Among the longline catches, the number of species and biomass per tub were higher on banks than

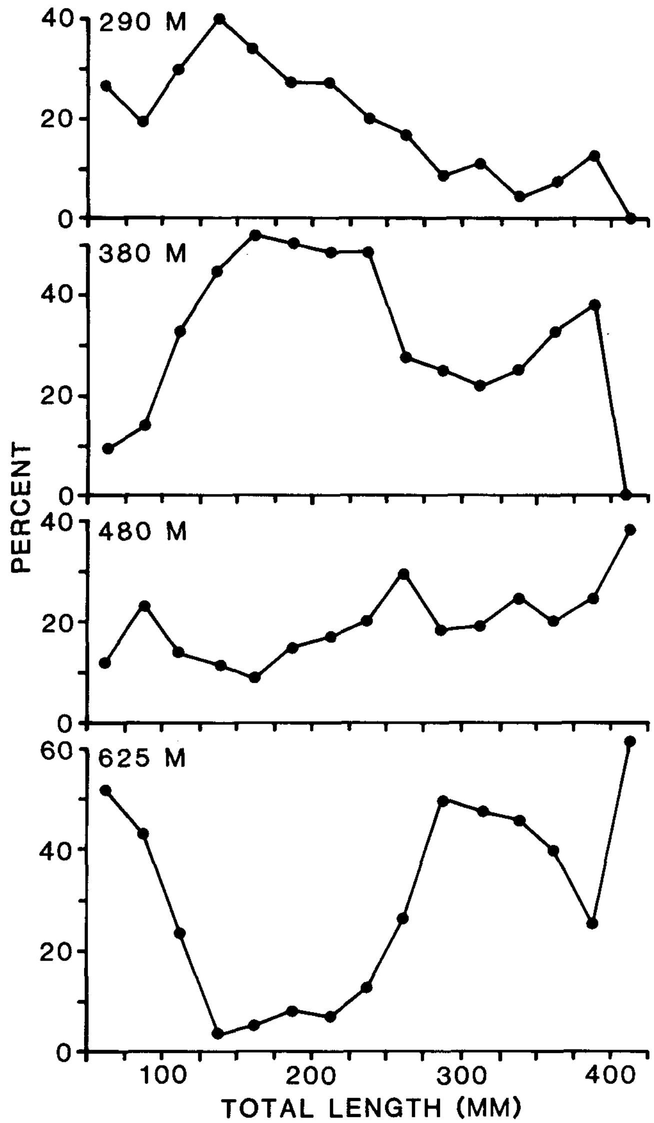

Figure 6. Percent of trawl-caught *Sebastolobus alascanus* in 25-mm TL size class intervals by depth. For example, 52% of the 50–74-mm fish were collected at 625 m, 12% at 480 m, 9% at 380 m, and 27% at 290 m.

mud. The higher number of species on bank sets is probably related to topographic complexity. Because banks provide the only vertical relief on an otherwise featureless habitat, they may attract and concentrate nektobenthic fishes. This hypothesis is supported by the distribution of *Sebastes* species between the two habitats. Ten species of *Sebastes* were caught on the banks, accounting for 34% of the species and 36% of the individuals collected. Three species of *Sebastes* were caught on the mud, accounting for 16% of the species and 7% of the individuals collected. The greater catch-weight of bank sets was due primarily to the abundance of *Sebastes melanostomus* and their large average size (Table 3).

The upper continental slope off southern California is not a uniform habitat. Faunal differences between bank and mud habitats might have been greater if the longlines had been shorter (groundlines were generally 1.5 to 2.0 km long). On several sets on smaller banks, species composition of some tubs was typical of mud sets.

TABLE 5
Otter Trawl Catch Parameter Means for the Outer Continental Shelf (130–230 m)[a], the Continental Slope (290–625 m), and the Nearshore Basins (715–915 m)[b] off Southern California

	Depth (m)			
	130–230	290–380	480–625	715–915
Number of trawls	18	24	24	10
Total species	46	32	20	11
Species per trawl	15.4	10.6	6.8	3.3
Fish per trawl	514	138	156	58
[c]Fish 100 m^{-2}	12.5	3.4	3.8	0.7
Biomass (kg) per trawl	15.6	15.8	14.3	2.3
[c]Biomass (g) m^{-2}	3.8	3.9	3.5	0.3

[a]County Sanitation Districts of Orange County, P.O. Box 8172, Fountain Valley, CA 92728; unpublished data.
[b]Southern California Coastal Water Research Project, 646 W. Pacific Coast Hwy., Long Beach, CA 90806; unpublished data.
[c]Estimated area swept 4,100 m^2 assuming effective net opening of 5.3 m (0.6 x 8.8-m footrope length) and distance covered of 772 m (2.5 knots for 10 min).
All trawls were made with a 7.6-m (headrope) net and were 10 min in duration, except between 715 m and 915 m, which were 20 to 25 min. Trawls from 130 m to 230 m and from 715 m to 915 m were made between 1981 and 1985.

Seasonal and Annual Variation

Summer catches of fish on the slope were generally smaller than during the rest of the year. Among otter trawl catches, fewer species and individuals were caught off Newport Beach during summer than winter. Among longline catches, fewer species and individuals and less weight were caught in both habitats in the summer than during the rest of the year. The seasonal catch patterns may be due, in part, to changes in the bathymetric distributions of some of the fishes. *Microstomus pacificus,* for example, are more abundant on the shelf off southern California in spring and summer than in fall and winter (Cross 1985). In northern California and Oregon, *M. pacificus* move onto the shelf in summer to feed, and move back onto the slope in winter to reproduce (Hagerman 1952; Alton 1972).

Winter catches of fish on the outer continental shelf and upper slope (91–411 m) off Oregon were smaller than those in summer (Alton 1972). Alton attributed this to bathymetric movements of some species (e.g., *M. pacificus* and *Anoplopoma fimbria*) and latitudinal movements of other species (e.g., *Merluccius productus*) related to feeding and reproduction.

Microstomus pacificus, Lyopsetta exilis, and *Sebastolobus alascanus* were significantly more abundant in trawl catches in 1982–83 than in 1981–82. The increase in numbers was not a result of increased recruitment; there were no significant differences in size distributions between years (Kolmogorov-Smirnov two-sample test, $P > 0.05$).

Size

The size of several species captured by both types of gear increased with increasing depth. More species caught in trawls (9 of 12) than on longlines (6 of 13) had significant positive size-depth correlations; the difference, however, was not significant ($x^2 = 1.13$, $P > .25$).

The "bigger-deeper" phenomenon has been observed in several studies (Haedrich and Rowe 1977; Polloni et al. 1979; Haedrich et al. 1980), although the relationship does not always hold for the same species in different areas (Wenner and Musick 1977; Snelgrove and Haedrich 1985) or the same species in the same area on different types of gear (*Sebastes diploproa* in this study). The relationship may also be confounded by sampling gear bias and differing depth distribution of adults and juveniles.

Small trawls are biased against large demersal fishes (Day and Pearcy 1968; Haedrich et al. 1975), a bias that apparently changes with depth. Pearcy (1978) and Pearcy et al. (1982) found a large disparity in species composition and estimates of biomass between a 3-m beam trawl and a 23-m (footrope) commercial otter trawl fished on the continental shelf off Oregon; the disparity did not exist below 1,000 m.

Differences in the distribution of adults and juveniles may be responsible for apparent bigger-deeper relationships. Immature individuals may concentrate at the shallow end of the depth range while adults distribute across the depth range (Snelgrove and Haedrich 1985).

The depth distribution of *Sebastolobus alascanus* (Figure 6) suggests that settling individuals head for the bottom regardless of depth. It is not surprising that some settle in deep water; time spent in the water column from spawning to settling is about a year, and larvae can occur more than 300 km offshore (Moser 1974). If *S. alascanus* settle in deep water, they move up the slope. As they grow, they move into deeper water.

Zonation

Otter trawl collections suggest a faunal break between 380 m and 480 m. The ranges of 22 species ended, and the ranges of 8 species began between these depths. *Sebastolobus alascanus, Lyopsetta exilis, Microstomus pacificus, Glyptocephalus zachirus,* and *Sebastes diploproa* dominated trawl collections between 290 m and 380 m. Juveniles of these species constituted about half of the individuals collected in trawls on the outer shelf (130–230 m). *Sebastolobus altivelis* dominated trawl collections between 480 m and 625 m and in the basins (715–915 m).

Pearcy et al. (1982) noted a rapid change in the benthic fish fauna between 400 m and 900 m on the continental slope off Oregon. The ranges of 34 shelf and upper slope species ended, and the ranges of 24 slope species began between these depths.

Temperature, dissolved oxygen, and salinity decrease with increasing depth on the slope off southern California. Dissolved oxygen drops below 1 ppm between 380 m and 480 m (SCCWRP 1983). The higher respiration rates of active shallow-water fishes may restrict them to depths with higher dissolved oxygen (cf. Sullivan and Somero 1980; Siebenaller et al. 1982).

There are no obvious physical discontinuities between 380 m and 480 m on the slope off southern California. Sediment grain size decreases and organic content increases with increasing depth over the slope (Thompson and Jones 1987). Macroinvertebrate assemblages on the slope off southern California show a similar zonal pattern. Polychaetes dominate the infauna between 161 m and 632 m. Small molluscs and crustaceans dominate the infauna between 480 m and 851 m (Thompson and Jones 1987). The absence of suitable polychaete prey deeper on the slope may restrict polychaete-feeders, such as the pleuronectids[2], to shallower depths.

The causes of species replacements among the macrofauna and megafauna are not well understood but probably include a variety of physical and biotic factors that change gradually and continuously with depth (Rex 1981).

El Niño

A major California El Niño occurred during 1982–83, causing increased sea-surface and subsurface temperatures, a depressed thermocline, and reduced upwelling. Temperature anomalies were, however, small at upper-slope depths off southern California (Lynn 1983; Simpson 1983, 1984).

[2]Cross, J.N. Food habits of the demersal fishes of the upper continental slope off southern California. Manuscript in preparation.

During El Niño years, tropical species frequently move into southern California, and species from southern California often move into northern California and beyond (Radovich 1961). No tropical fishes were collected on the upper continental slope off southern California during the study. Two species that range south of Baja California were more abundant during the El Niño year: 3 of the 4 *Facciolella gilberti* and 18 of the 19 *Physiculus rastrelliger* were collected in 1982–83. Also present in trawl catches in 1982–83 but not in 1981–82 was *Pleuroncodes planipes*. During past El Niño events, this galatheid crab extended its range from Baja California into southern California (Radovich 1961; Longhurst 1967).

Zoogeography

The fish assemblage of the upper continental slope off southern California is dominated by fishes with northern affinities. (Most ranges were obtained from Miller and Lea [1972]; additional ranges were obtained from Fitch and Lavenberg [1968], Hart [1973], and Pearcy et al. [1982]). Of the 54 species collected during the study, 42 have northern range endpoints off British Columbia or Alaska and southern range endpoints off southern California or northern Baja California. Twenty-nine of these species accounted for 98% of the individuals collected in trawls. Twenty-three of these species accounted for 88% of the individuals collected on longlines. *Sebastolobus alascanus, Sebastolobus altivelis, Anoplopoma fimbria, Microstomus pacificus,* and *Eptatretus deani* constituted 72% of the individuals in 48 trawls on the upper slope off southern California and 86%–90% of the individuals in 49 trawls on the upper slope off Oregon (Pearcy et al. 1982).

Nine of the 54 species collected during the study have ranges that do not extend north of California: *Parmaturus xaniurus, Facciolella gilberti, Physiculus rastrelliger, Sebastes gilli, Sebastes hopkinsi, Sebastes levis, Sebastes phillipsi, Sebastes rosenblatti,* and *Sebastes rufus*. Three of the 54 species have ranges that extend south of Baja California: *Facciolella gilberti, Alepocephalus tenebrosus,* and *Physiculus rastrelliger.* Two species have antitropical distributions: *Hexanchus griseus* and *Squalus acanthias*.

Previous deepwater (200–915 m) trawl studies off southern California produced species lists and dominance rankings nearly identical to the present study (Fitch 1966; Allen and Mearns 1977; Mearns et al. 1979). For the studies that included catch lists, only two species—*Embassichthys bathybius* (Pleuronectidae; Fitch 1966) and *Gnathophis catalinensis* (Congridae; Mearns et al. 1979)—were not collected during the present study.

ACKNOWLEDGMENTS

This study was supported in part by a contract from the County Sanitation Districts of Orange County (CSDOC). H. Stubbs, B. Thompson, and M. Moore (SCCWRP) and T. Pesich (CSDOC) assisted in trawl collections aboard R/V *Vantuna* and R/V *Westwind*. Special thanks go to the dory fishermen of Newport Beach for their cooperation. R. N. Lea, California Department of Fish and Game, identified *Sebastes aleutianus*, and Y. Jiminez translated the abstract. Early versions of the manuscript were reviewed by J. Allen, M. Horn, A. Mearns, W. Pearcy, D. Somerton, and two anonymous referees; their comments improved the manuscript and are appreciated.

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