DIEL VARIATION IN CATCH PARAMETERS FOR FISHES SAMPLED BY A 7.6-M OTTER TRAWL IN SOUTHERN CALIFORNIA COASTAL WATERS

EDWARD E. DeMARTINI[1] AND LARRY G. ALLEN[2]
Marine Science Institute
University of California
Santa Barbara, California 93106

ABSTRACT

The species composition, diversity, numerical and biomass abundances, and length-frequency distributions of the fishes caught with a 7.6-m otter trawl (1.25-cm stretch mesh cod-end liner) were compared for 13 pairs of day and night samples. Monthly cruises were made from May 1980-May 1981, at two (18-m, 30-m) depths in the region of San Onofre-Oceanside.

The basic diel pattern found was of greater total numbers, total biomass, and species richness at night. Larger catches were made at night for 12 (numbers) and 9 (biomass) of the 20 most abundant species (total trawls). Average weight per fish (all species) and the length-frequency distributions of five of seven species, however, did not differ meaningfully between day and night samples. Nighttime estimates of the grand mean number of species and total fishes (numbers) per tow varied much less (average CVs of 13% and 31%, respectively) than did daytime estimates (CVs of 34% and 83%).

Many nearshore fishes are less contagiously distributed at night, hence samples are more precise. We conclude that, for otter trawls of the specified design towed at 2.3 knots, catch efficiency is greater during the night, even at shallow (18-m, 30-m) depths in turbid coastal waters. Nighttime trawls also provide more data on a greater number of species per unit of effort than daytime trawls. We feel that these advantages of nighttime surveys warrant their extra cost and suggest that night sampling be adopted in future trawl monitoring of fishes in the Southern California Bight.

RESUMEN

Cruceros mensuales, desde Mayo de 1980 hasta Mayo de 1981, se efectuaron con red de arrastre de 7.6 m (copo con malla de 1.20 cm), explorando la zona que se extiende desde San Onofre hasta Oceanside, California, abarcando profundidades de 18 m y 30 m.

En total se realizaron 26 arrastres, 13 de noche y 13 de día. Los peces capturados sirvieron de base para estudios comparativos sobre su distribución, frecuencia de tallas, conjunto de especies, índice de diversidad, abundancia y biomasa.

El patrón diario observado indica capturas nocturnas de mayor magnitud en cuanto a número total, biomasa total y abundancia de especies. Las capturas fueron más abundantes durante la noche para 12 (abundancia numerica) y 9 (biomasa) especies respectivamente, de las 20 especies mas abundantes, considerando todos los arrastres. El peso promedio de los peces (incluyendo todas las especies) y la frecuencia de longitud en cinco de las siete especies consideradas, no presentaron diferencias notables entre las capturas diurnas y nocturnas. Estimaciones del número promedio de especies y número total de peces por arrastre presentan menor variación en las pescas nocturnas (C.V. 13% y 31% respectivamente) que en las diurnas (C.V. 34% y 83% respectivamente).

Muchos peces costeros muestran distribuciones menos congregadas durante la noche, siendo así estas muestras más precisas. Estos resultados señalan que las redes de arrastre del diseño indicado, remolcadas a 2.3 nudos presentan una mayor eficiencia de captura durante la noche, aun a poca profundidad (18 m y 30 m) en aguas costeras y turbias. Los arrastres nocturnos, ademas proporcionan más información sobre un mayor número de especies por unidad de esfuerzo. Se considera que las ventajas proporcionadas por las exploraciones nocturnas compensan el costo adicional. Un programa de arrastres nocturnos es sugerido para las futuras observaciones regulares sobre los peces de la Bahía del Sur de California.

INTRODUCTION

Demersal fishes of the Southern California Bight have been extensively censused with otter trawls over the past two decades (for reviews see SCCWRP 1973 and LACSD 1981). Most trawl data, however, have been restricted to fishes of the outer shelf and slope (SCCWRP 1973) and harbors and embayments (Stephens et al. 1974; Horn and Allen 1981). Undoubtedly this past emphasis has been due to the interest of government agencies in environmental effects caused by waste discharges at deepwater outfalls, and impacts resulting from harbor construction and other

[1]Present address: Marine Review Committee Research Center, 531 Encinitas Boulevard, Encinitas, California 92024
[2]Present address: Department of Biology, California State University, Northridge, California 91330
[Manuscript received September 3, 1983.]

shoreline development. Relatively little is known of the distribution and abundance of the benthic fishes of shallow (<30 m) coastal waters within the bight (Allen 1982).

Gear and sampling techniques have been generally inconsistent among the studies performed by various monitoring agencies. Despite these inconsistencies, several studies (SCCWRP 1973; Mearns 1974; Allen 1976; LACSD 1981) have noted the larger size and more species-rich nature of night catches versus day catches in southern California waters. Numerous studies in other regions have indicated diel differences in the composition, species richness, and numbers of fishes in trawl catches (Roessler 1965; Hoese et al. 1968; Livingston 1976). Other studies have identified many factors, both environmental and related to gear design and technique, contributing to the diel variation (Parrish et al. 1964; Woodhead 1964; Beamish 1966; Blaxter 1970; Sissenwine and Bowman 1978; Bowman and Bowman 1980). To date no one has examined in detail the type and magnitude of diel variation in trawl catches for shelf fishes of the Southern California Bight.

Seasonal phenomena, differences in species composition and abundance with depth, and the interactions of these factors with diel patterns are not elaborated on in this report. A multiple-year diel trawl study of the benthic fishes encountered at six depths between 5 and 100 m off Bolsa Chica (Orange County) should provide a more comprehensive evaluation of biological patterns (M. H. Horn, California State University, Fullerton, pers. comm.).

Our specific objectives in this report are to (1) evaluate the nature and extent of diel differences in the catches of fishes, based on a series of paired, day and night otter trawls made at shallow shelf depths; (2) wherever possible, relate observed differences to plausible factors influencing catchabilities; and (3) discuss the implications of these differences for future coastal monitoring programs in the bight.

MATERIALS AND METHODS

Sampling Design

Thirteen pairs of diel cruises were made over the 13-month interval from May 1980 through May 1981. The two cruises of each pair were 36 hours apart in 11 cases, 60 hours apart in one case, and 10.5 days apart in one case. "Day" samples were made between sunrise and sunset; "night" samples were made between sunset and sunrise. On each cruise four trawl tows were made at each of two (18-m, 30-m) bottom depths, at two longshore locations (Table 1). Longshore locations were 18 km distant, off San Onofre (33°20′N, 117°30′W) and off Stuart Mesa (33°10′N, 117°20′W), upcoast of Oceanside, San Diego County. (See Plummer et al. 1983 for a chart of the sampling locations.)

We attempted to make all trawl tows a standard distance; length of tow was determined from a combination of permanently moored spar buoys and Motorola Mini-Ranger III signals from a temporarily moored auxiliary craft. Each tow in a series of four trawls thus provided relative abundance (catch per unit of effort, CPUE) data that we could consider as a statistical replicate. Two of the four tows in each series were directed upcoast along the isobath; the other tows were directed downcoast in order to sample any variation in catchability caused by relative directions of the tow and longshore water current. Direction (upcoast, downcoast) and relative speed (nil, mild, strong) of surface current were noted for each trawl. Replicate tows were shifted slightly inshore and offshore in order to avoid resampling trawl tracks. Average duration of tow (time net on the bottom) was 3.5 ± 0.06 (SE) min, and average trawling speed was 2.3 knots for the 104 series of four replicate tows (locations, depths, and diel periods pooled). Mean tow distance was 248 ± 4 (SE) m for the 104 series of tows. Distance of tow was evaluated during a January-April 1980 pilot study in which we determined the shortest distance practical (see Discussion), based on minimizing zero catches of major species.

Gear Design

All samples were taken using the type and size of otter trawl recommended by Mearns and Allen (1978) for biological monitoring in southern California coastal waters. We used a single-warp Marinovitch-type otter trawl, with a 25-ft (7.6-m) headrope and a 29-ft (8.9-m) chain-rigged footrope, manufactured by J. Willis. Body mesh was 1.5 inch (3.8 cm), and the cod-end was fitted with a 0.5-inch (1.25-cm) liner of no. 15 thread nylon. (All measurements are stretch-mesh.) Length of bridles was three times the headrope length. Scope ratio was 5:1 for tows at 18- and 30-m depths.

Types of Data and Analysis Design

Numbers of individual fishes were recorded, by species, for each trawl tow. Biomass (wet weight) also was determined aboard ship for the aggregate of each species in each tow. Weights were recorded to ± 10 g for catches < 1 kg and to ± 0.1 kg for catches > 1 kg.

In addition, various species were selected for determination of length-frequency composition (at one or both trawl depths). Species were one small round-

TABLE 1
Summary of Sampling Effort for the Thirteen Paired Cruises

Longshore location	Depth (m)	No. trawl tows				
		Day		Night		Day & night
		Per cruise	Total	Per cruise	Total	total
San	18	4	52	4	52	104
Onofre	30	4	52	4	52	104
Stuart	18	4	52	4	52	104
Mesa	30	4	52	4	52	104
Both locations	Both depths	16	208	16	208	416

fish—the white croaker, *Genyonemus lineatus* (18, 30 m)—and three species of "small" (10-15 cm standard length, SL) demersal flatfishes—speckled sanddab, *Citharichthys stigmaeus* (18 m); longfin sanddab, *C. xanthostigma* (18, 30 m); and Pacific sanddab, *C. sordidus* (30 m). Also measured were three species of "medium-sized" (15-30 cm SL) flatfishes: fantail sole, *Xystreurys liolepis* (18, 30 m); California halibut, *Paralichthys californicus* (18, 30 m); and hornyhead turbot, *Pleuronichthys verticalis* (18, 30 m). Species were selected because of their numerical dominance in trawls made during the 1980 pilot study.

Standard lengths were recorded to the nearest millimeter aboard ship for a random sample of a maximum of 50 individuals of each selected species present in the four replicate tows. The length-distribution of catches of > 50 individuals was standardized to the total catch. Length data were later sorted and analyzed by 5-mm classes.

The length-frequency distributions of day and night sample fish were compared by Kolmogorov-Smirnov (K-S) two-sample test (Siegel 1956). The mean numerical and biomass abundances of day and night catches were compared for the most common and abundant species using Hotelling's T^2 (Morrison 1976). Additional diel comparisons were made for the CPUE of each of the top 20 ranked species (in day and night samples pooled) and for the aggregate of all fishes trawled. For particular species, we used either Wilcoxon's matched-pairs signed-ranks test (Siegel 1956), or paried t-test (Sokal and Rohlf 1969). Mean species CPUE (8-tow basis if longshore locations could be pooled, 4-tow if they could not) were transformed to common logarithms to normalize distributions before calculating paired t-tests. If transformation did not normalize a distribution, we used Wilcoxon's rank test. We compared relative abundances among species within day and night assemblages by Kendall rank correlation (Siegel 1956). We used either parametric or nonparametric paired comparison tests, as appropriate, for diel contrasts of several representative types of species diversity and evenness indices. We chose indices to provide a basis for comparison with prior analyses of trawl catches in the bight. In addition to species richness (S), indices used included Gleason's d, Shannon's H', Pielou's J', Simpson's D (the complement of lambda; Peet 1974), and Hill's (1973) numbers and ratios. We further characterized day and night sample assemblages by cluster analysis based on "ecological distance" (Bray-Curtis Index of Dissimilarity; Clifford and Stephenson 1975) of species CPUE, following square root transformation of CPUE to reduce the bias of disproportionately abundant species. All analyses were done using the Statistical Analysis System (Helwig and Council 1979).

RESULTS

General Patterns

Average total catch (numbers and biomass) of all fishes and the numbers of different species per tow did not differ (all $P > 0.10$) between tows made against or with surface currents. Therefore we ignored trawl direction relative to current velocity in the analysis.

On average, a greater number of individual fishes (Tables 2 and 3) whose aggregate weighed more (Tables 2 and 4) were caught in nighttime trawls. Most species were relatively more numerous at night (18 m: Wilcoxon's test, $z = 3.0$, $P = 0.001$; 30 m: $z = 1.75$, $P = 0.04$; Table 3), when catches were heavier (18 m: $z = 2.8$, $P < 0.003$; 30 m: $z = 2.0$, $P = 0.02$; Table 4). Greater mean numbers of species per tow were present in nighttime samples (18 m: $t = -8.1$, $P < 0.001$; 30 m: $t = -5.2$, $P < 0.001$; Table 5). Species richness scaled for the effect of number of individuals in samples (Gleason's index) was greater at night only at 30-m depth off San Onofre (Table 5). Shannon's H', a diversity index that emphasizes the equitability of moderately abundant species (Peet 1974), varied insignificantly ($P > 0.05$) between diel periods at either depth (Table 5). Day samples, however, were significantly ($P < 0.05$) more diverse

TABLE 2
General Catch Statistics and Results of Paired T-Test (or Wilcoxon Matched-Pairs Signed-Ranks Test) Comparisons of Diel Effects on Mean (Median) Numbers, Biomass, and Average Body Weight of Fishes Present in Single Trawl Tows

			Day		Night			
Category	(Depth)	Longshore location(s)	x̄	SE	x̄	SE	Test statistic	P
Total numbers	18	Pooled	27	8	95	10	Paired t = −5.50	<0.001*
	30	Pooled	90	16	190	14	Paired t = −6.15	<0.001*
Total biomass (kg)	18	Pooled	3.4	0.6	8.5	1.0	Paired t = −4.33	0.001*
	30	San Onofre	3.5	1.0	9.1	1.1	Paired t = −4.69	<0.001*
	30	Stuart Mesa	6.8	1.1	13.6	1.5	Paired t = −4.10	0.001*
Average body weight (g)	18	Pooled	199	21	99	8	Paired t = 4.83	<0.001*
	30	San Onofre	59	11	52	6	Wilcoxon T = 37	>0.1(NS)
	30	Stuart Mesa	85	12	67	4	Paired t = 2.69	0.16 (NS)

Sample size for paired comparisons was 13 cruises in all cases. Grand means are based on cruise means comprising either four (or eight, if locations were pooled) tows per cruise. Data for the two longshore locations were pooled only if locations were indistinguishable ($P>0.05$) using the more appropriate paired comparison test. T-test comparisons were made based on raw data, as cumulative frequency distributions of the deltas of raw data were indistinguishable from a normal distribution (K-S tests, $P>0.17$), for all categories except average body weight (San Onofre, 30 m).
*Paired comparison significant at $P \leqslant 0.05$.

at 18-m (but not at 30-m) depth, based on a number of other indices examined (Table 5). These included Simpson's index and both Hill's (1973) N_1 and N_2. At 18-m depth, daytime collections had a significantly ($P < 0.05$) more even distribution of individuals among species, whether measured by Pielou's J' or Alatalo's (1981) modified ratio of Hill's N_2 to N_1 (Table 5).

Diel differences in species composition were mainly due to the marked dissimilarity in the day-versus-night catches of several fishes (basketweave cusk eel, *Ophidion scrippsae*; plainfin midshipman, *Porichthys notatus*; and California tonguefish, *Symphurus atricauda*) that were typically present or abundant only in night trawls (Tables 3 and 4).

Despite these diel differences in species composition, day and night assemblages (characterized by the top 20 species in total trawls, Tables 3 and 4) were statistically similar for numbers and frequency of occurrence (per cruise) at the two depths (Table 6). However, diel similarity in total biomass was marginal at both depths. The basic numerical similarities of the assemblages sampled at both depths are illustrated by cluster diagrams based on the ecological distance between species within day and night samples (Figure 1).

Abundances of Selected Species

Despite the similar rank abundances of fishes in day and night trawls (Table 6), the mean catches of most of the top 20 species were greater in nighttime tows at each depth and location (numbers: Hotelling's T^2, all $P < 0.005$; biomass: all $P < 0.03$). The average catches of 12 (numbers) or 9 (biomass) of the top 20 species were significantly greater in night samples (Tables 7 and 8). Daytime catches were larger than nighttime samples for another three (numbers) and two (biomass) species, while catches varied little between diel periods for five and seven species. The species that contributed most to larger nighttime catches were *Genyonemus lineatus*; pink seaperch (*Zalembius rosaceus*); *Ophidion scrippsae*; *Citharichthys xanthostigma*; queenfish (*Seriphus politus*); *Symphurus atricauda*; shovelnose guitarfish (*Rhinobatos productus*); and California skate (*Raja inornata*). Overall, more of the top 20 species were caught in greater abundance during the night at one or the other depth or location than expected by chance alone (numbers: $p = q = 0.5$, P [4 or fewer out of 24 significant cases] $= 0.001$; biomass: P [4 or fewer out of 20] $= 0.006$; binomial test, Siegel 1956). A virtually identical pattern was shown for numbers and biomass (Tables 7 and 8), and, in fact, numerical and biomass rankings were strongly correlated within diel samples at each depth (Kendall's tau, all $P < 0.01$).

Size-Composition of Fishes

The average size of fishes present in day and night samples was similar for all except several of the most common and abundant species at the two depths (Wilcoxon test, both $P > 0.05$; Table 9). This was also generally true for average fish weight in total catches at 30 m (Table 2). At 18 m, the average weight of total fishes caught was greater during the day, primarily because of the somewhat larger body sizes (Table 9) and slightly more numerous daytime catches of *Paralichthys californicus*, a relatively large species (Table 3). The data on average fish weight (Table 9) suggest that the length-frequency distributions of most species

TABLE 3
Composition of Day and Night Trawl Catches Ranked by Numerical Abundances at the Two Sampling Depths

	Numbers			
	18 m		30 m	
	Day	Night	Day	Night
Genyonemus lineatus	1,237	4,028	1,770	5,958
Zalembius rosaceus	1	21	2,629	4,690
Ophidion scrippsae	1	2,871	—	1,754
Citharichthys xanthostigma	253	499	1,064	1,891
Citharichthys sordidus	3	19	1,799	1,766
Seriphus politus	305	1,138	225	1,063
Symphurus atricauda	13	152	182	908
Citharichthys stigmaeus	226	301	370	322
Zaniolepis latipinnis	—	—	424	349
Pleuronichthys verticalis	96	196	124	172
Paralichthys californicus	154	148	69	23
Cymatogaster aggregata	19	70	201	102
Xystreurys liolepis	82	51	122	66
Phanerodon furcatus	196	22	31	22
Porichthys notatus	—	6	17	221
Raja inornata	4	15	37	127
Hippologlossina stomata	—	1	85	91
Hyperprosopon argenteum	100	52	—	—
Icelinus quadriseriatus	3	—	63	86
Rhinobatos productus	16	54	6	20
Synodus lucioceps	27	21	39	9
Paralabrax nebulifer	28	37	17	11
Scorpaena guttata	—	8	10	35
Parophrys vetulus	15	7	16	6
Pleuronichthys ritteri	28	11	—	1
Microstomus pacificus	—	—	12	22
Merluccius productus	—	1	—	28
Hydrolagus colliei	1	4	6	16
Porichthys myriaster	2	5	7	13
Myliobatis californica	5	12	1	—
Menticirrhus undulatus	3	14	—	—
Urolophus halleri	4	9	—	—
Lepidogobius lepidus	—	—	5	3
Damalichthys vacca	2	—	3	2
Hypsopsetta guttulata	4	3	—	—
Chilara taylori	—	—	—	6
Eptatretus stouti	—	—	—	6
Leptocottus armatus	—	—	—	3
Sebastes auriculatus	—	—	—	3
Torpedo californica	—	1	2	—
Paralabrax clathratus	—	1	—	1
Pleuronichthys decurrens	1	1	—	—
Squalus acanthias	1	1	—	—
Sebastes paucispinis	—	—	1	—
Mustelus henlei	—	1	—	—
Pleuronichthys coenosus	—	1	—	—
Stereolepis gigas	—	1	—	—
Brachyistius frenatus	—	1	—	—
Caulolatilus princeps	—	1	—	—
Chitonotus pugetensis	—	—	—	1
Platyrhinoidis triseriata	—	1	—	—
Atractoscion nobilis	—	—	—	1
Total fishes	2,830	9,843	9,337	19,798
Mean total fishes trawl^{-1}	27	95	90	190
Total species	30	40	30	37

Data are the total numbers of individuals of each species caught in 104 trawls depth^{-1} diel period^{-1} pooled over the 13 pairs of monthly cruises. Species are ranked according to their total numerical abundances in all 416 (day, night) trawls pooled. Total number of different species caught is also noted.

TABLE 4
Composition of Day and Night Trawl Catches Ranked by Wet Weight

	Biomass (kg)			
	18 m		30 m	
	Day	Night	Day	Night
Genyonemus lineatus	96.0	318.7	178.7	545.2
Paralichthys californicus	100.00	89.8	52.4	25.8
Ophidion scrippsae	<0.1	173.4	—	88.2
Citharichthys xanthostigma	20.3	38.9	57.1	106.2
Zalembius rosaceus	<0.1	0.3	50.1	92.8
Rhinobatos productus	22.1	63.6	9.2	45.6
Seriphus politus	14.9	40.1	13.1	58.3
Pleuronichthys verticalis	17.6	39.1	20.8	25.3
Raja inornata	3.8	13.6	16.6	41.7
Citharichthys sordidus	<0.1	0.5	28.6	28.8
Xystreurys liolepis	13.2	8.7	17.3	10.5
Symphurus atricauda	0.6	5.5	4.6	28.7
Paralabrax nebulifer	9.0	10.1	11.2	8.4
Torpedo californica	—	13.6	17.4	—
Myliobatis californica	7.1	22.6	0.6	—
Zaniolepis latipinnis	—	—	14.1	10.7
Phanerodon furcatus	15.4	1.4	4.5	2.4
Hippoglossina stomata	—	0.2	9.4	9.2
Scorpaena guttata	—	2.9	4.0	11.4
Hydrolagus colliei	0.8	3.4	4.0	10.0
Synodus lucioceps	6.9	5.6	3.8	1.8
Citharichthys stigmaeus	3.5	4.3	3.7	3.8
Parophrys vetulus	4.8	1.8	6.1	1.5
Cymatogaster aggregata	0.6	1.6	5.0	3.1
Urolophus halleri	2.4	5.4	—	—
Hyperprosopon argenteum	4.5	3.1	—	—
Pleuronichthys ritteri	4.8	1.6	—	0.3
Atractoscion nobilis	—	—	—	5.9
Menticirrhus undulatus	0.6	5.1	—	—
Porichthys myriaster	0.7	2.2	0.4	1.4
Porichthys notatus	—	0.2	0.3	3.9
Squalus acanthias	0.9	3.2	—	—
Microstomus pacificus	—	—	1.3	2.2
Merluccius productus	—	<0.1	—	3.3
Damalichthys vacca	0.6	—	1.3	0.5
Sebastes auriculatus	—	—	—	1.7
Hypsopsetta guttulata	0.9	0.5	—	—
Icelinus quadriseriatus	<0.1	—	0.5	0.6
Eptatretus stouti	—	—	—	0.7
Paralabrax clathratus	—	0.2	—	0.2
Pleuronichthys decurrens	0.1	0.2	—	—
Mustelus henlei	—	0.2	—	—
Platyrhinoidis triseriata	—	0.2	—	—
Stereolepis gigas	—	0.2	—	—
Pleuronichthys coenosus	—	0.1	—	—
Lepidogobius lepidus	—	—	<0.1	<0.1
Chilara taylori	—	—	—	<0.1
Brachyistius frenatus	—	<0.1	—	—
Chitonotus pugetensis	—	—	—	<0.1
Leptocottus armatus	—	—	—	<0.1
Sebastes paucispinis	—	—	<0.1	—
Caulolatilus princeps	—	<0.1	—	—
Total biomass (kg)	352.3	882.4	536.2	1,180.2
Mean total biomass (kg) trawl^{-1}	3.4	8.5	5.2	11.3

Data are the total biomass of each species caught in 104 trawls depth^{-1} diel period^{-1} pooled over the 13 pairs of monthly cruises. Species are ranked according to their total biomass in all 416 (day, night) trawls pooled.

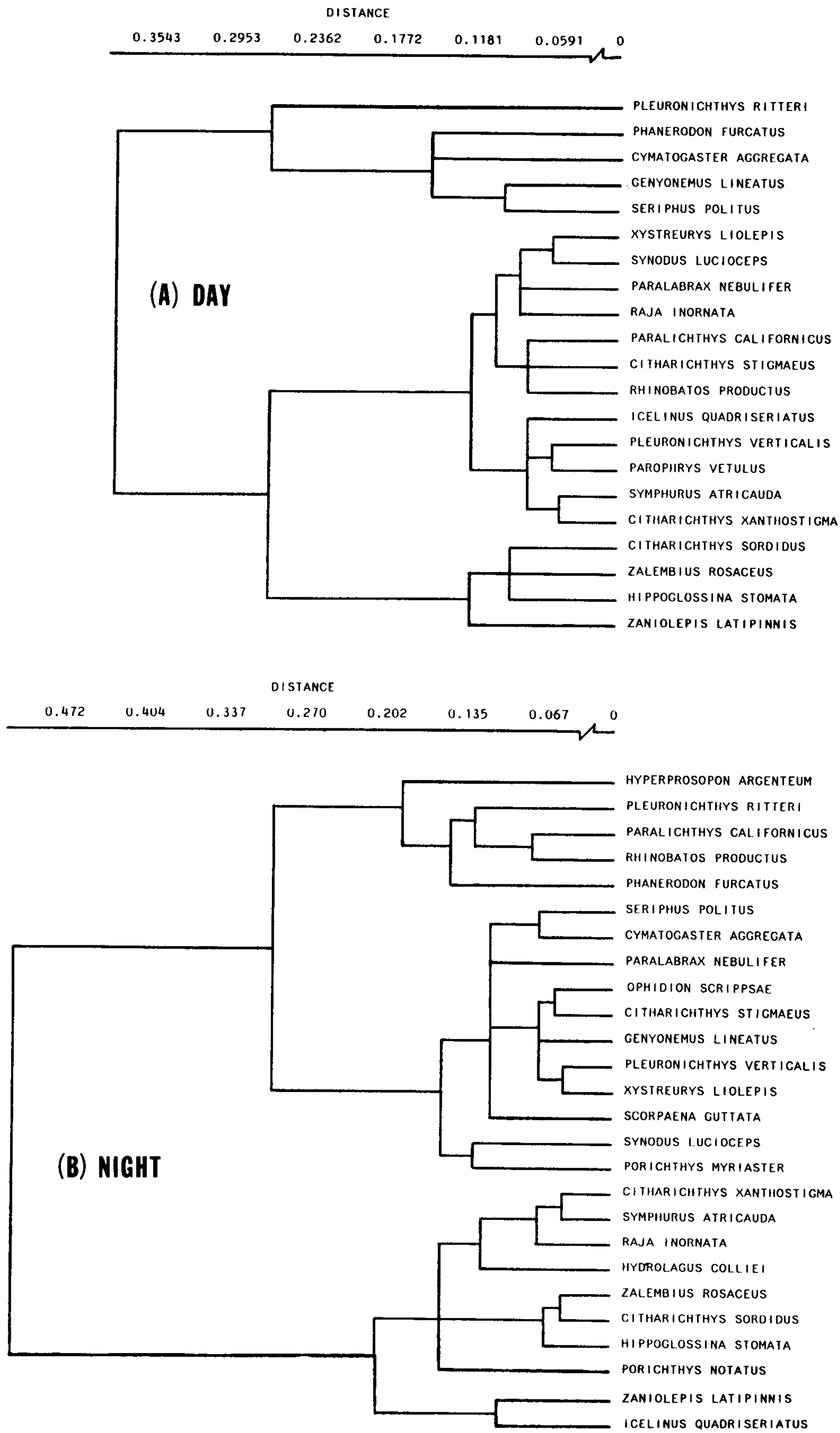

Figure 1. Cluster diagram based on a measure of ecological distance (Bray-Curtis dissimilarity, see text) for fishes present in (*A*) day and (*B*) night trawls. Numerical data for the two (18-m, 30-m) sampling depths are combined (Table 3) to illustrate species clusters representative of each depth. Analysis is based on species that occurred in a minimum of ten trawls during one or the other diel period. Note the absence of *Ophidion scrippsae* and *Porichthys notatus* in day trawls.

TABLE 5
Diversity of Fishes Present in Trawls as Represented by Nine Different Measures of Sample Species Diversity

Index	Depth	Location(s)	Day	Night
Species richness, S	18	San Onofre	5.0 ± .6	8.0 ± .5*
		Stuart Mesa	5.8 ± .5	9.5 ± .3*
	30	Pooled	9.1 ± .7	12.5 ± .3*
Gleason's d	18	San Onofre	2.0 ± .11	2.1 ± .13
		Stuart Mesa	2.5 ± .12	2.4 ± .15
	30	San Onofre	2.2 ± .15	2.6 ± .08*
		Stuart Mesa	2.6 ± .06	2.6 ± .07
Shannon's H'	18	San Onofre	1.6 ± .08	1.5 ± .08
		Stuart Mesa	1.8 ± .08	1.6 ± .09
	30	Pooled	1.9 ± .03	1.9 ± .04
Pielou's J'	18	Pooled	0.7 ± .04*	0.5 ± .02
	30	Pooled	0.6 ± .02	0.6 ± .02
D = (1-Simpson's λ)	18	Pooled	0.8 ± .03*	0.7 ± .02
	30	Pooled	0.8 ± .01	0.8 ± .01
Hill's N_1 = (exp H')	18	San Onofre	5.2 ± .38	4.7 ± .40
		Stuart Mesa	6.5 ± .48*	5.1 ± .52
	30	Pooled	6.6 ± .21	7.0 ± .29
Hill's N_2 = (1/λ)	18	Pooled	5.6 ± .63*	3.4 ± .21
	30	Pooled	4.8 ± .20	4.9 ± .29
Hill's ratio = (N_2/N_1)	18	Pooled	0.8 ± .04*	0.7 ± .01
	30	Pooled	0.7 ± .02	0.7 ± .02
Modified Hill's ratio	18	Pooled	0.7 ± .05*	0.6 ± .01
= {(N_2 − 1)/(N_1 − 1)}	30	Pooled	0.7 ± .02	0.6 ± .02

Indices tested were Gleason's index of species dominance; Shannon's index of diversity; Pielou's evenness; the complement of Simpson's index of concentration; Hill's N_1 and N_2; Hill's ratio (Peet 1974); and modified Hill's ratio (Alatalo 1981). Means ± one standard error (n = 13) are provided for each index. The data for each cruise are either the sum of 8 or 4 trawls, depending on whether data for the two longshore locations were indistinguishable ($P > 0.05$) with a diel period at a depth and thereafter pooled or not.
*$P \leq 0.05$ that measure is not more diverse or even during the particular diel period.

measured did not differ between day and night samples; and this was, in fact, the case (Table 10). The size-composition of day and night sample fish did not vary meaningfully for any of the three species of "small" or for two of the three "medium-sized" flatfishes that we measured (Figures 2 and 3). Large sample sizes (great power), however, allowed detection of real, but trivial (3%) cumulative differences in length-frequency distributions for two species of sanddabs (Figure 2, Table 10). *Paralichthys californicus* caught at 18 m differed little in size between day and night samples (Figure 4, Table 10). At 30 m, however, *P. californicus* > 40 cm SL were more common (2 x 4 x^2 = 38.6, 3 df, $P < 0.001$) in night versus day samples than were halibut < 40 cm SL (Figure 4), even though meager data made evaluation based on small length intervals impractical using K-S tests. Diel size-frequency data for *Genyonemus lineatus* were trivially (1%) different at 18-m depth, but length-frequencies differed by a cumulative 10% at 30 m (Figure 5, Table 10). Greater nighttime catches of *G. lineatus* < 14 cm reversed (Table 9) the otherwise larger average body size of *G. lineatus* caught at 30 m during the night (Figure 5).

TABLE 6
Results of Kendall's Rank Correlation between the Relative (Rank) Abundances and Frequency of Occurrence of Fishes in Day Versus Night Trawls

Measure of abundance	Depth (m)	Locations	Kendall's tau	N	P
Numbers	18	Pooled	0.40	20	0.01*
	30	Pooled	0.52	20	0.001*
Biomass	18	Pooled	0.29	20	0.07
	30	Pooled	0.26	20	0.10
Frequency of	18	Pooled	0.54	27	0.0002*
occurrence	30	Pooled	0.57	33	<0.0001*

Analysis (numbers and biomass) limited to the 20 most abundant species (longshore locations and diel periods pooled) at each sampling depth. Analysis (frequency occurrence $depth^{-1}$ $cruise^{-1}$) limited to species that occurred in samples collected on ≥3 cruises during either or both diel periods. Longshore locations were pooled in all cases because rankings were invariably concordant ($P < 0.05$) between locations.
*Significant at $P \leq 0.05$.

Precision of the Trawl Estimates

Table 11 lists the coefficients of variation (CV = standard deviation $mean^{-1}$; Sokal and Rohlf 1969) of the grand arithmetic means of numerical and biomass CPUE for total fishes present in day and night trawls. For total fishes, CVs averaged 63% and 40% smaller for numbers and biomass, respectively, during night

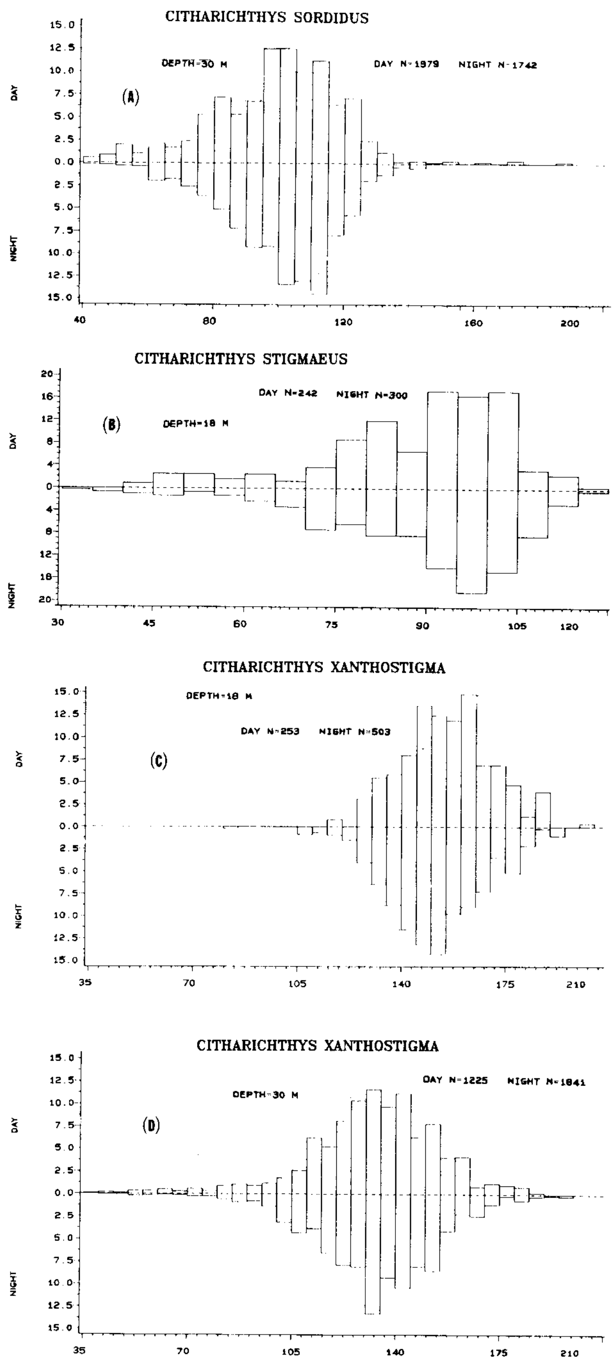

Figure 2. Length-frequency distributions of each of three species (*Citharichthys sordidus, C. stigmaeus, C. xanthostigma*) of "small" (10-15 cm SL) demersal flatfishes present in day and night trawls.

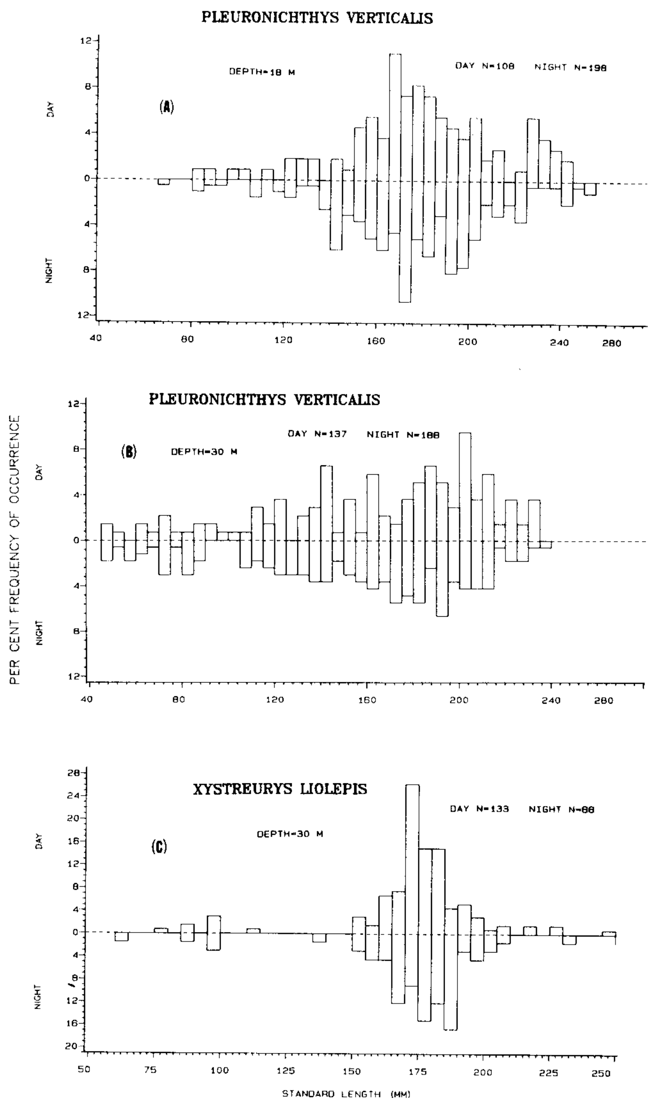

Figure 3. Length-frequency distributions of each of two species (*Pleuronichthys verticalis, Xystreurys liolepis*) of medium-sized (15-30 cm SL) demersal flatfishes present in day and night trawls.

versus day trawls. The CVs of mean weight per fish averaged 38% smaller for night trawls. The CVs of nighttime trawl CPUE were consistently smaller for 12 and 9 of the top 20 species, based on numbers and biomass, respectively. The number of instances in which nighttime catches had smaller CVs than day samples was greater than expected ($p = q = 0.5$, binomial test) based on chance alone for numbers (P [11 or fewer out of 38 nominally different cases] < 0.01), but not for biomass (P [15 or fewer out of 34] > 0.30). On average, the CVs of nighttime trawl samples for the top 20 species were 16% (numbers) and 11% (biomass) smaller than the CVs of corresponding daytime samples.

Estimates of diversity also were more precise when based on night trawl data. The CVs of numbers of species per tow (species richness) averaged 62% smaller for nighttime trawls (Table 11). The CVs of the remaining eight indices (Table 5) ranged from about 70% smaller to 40% larger for night compared to daytime trawl data.

TABLE 7
Paired T-Test (or Wilcoxon Matched-Pairs Signed-Ranks Test) Comparisons of Diel Effects on the Mean (Median) Numerical Catch per Trawl for 20 Species

			Diel differences in catch (numbers)			
Species	Depth	Location(s)	Test statistic	*N*	*P*	Conclusion
Cymatogaster	18	Pooled	Paired t = −2.7	13	0.02*	N>D
aggregata	30	San Onofre	Wilcoxon T = 5.5	7	>0.10	N=D
		Stuart Mesa	Paired t = 1.3	13	0.21	N=D
Citharichthys sordidus	30	Pooled	Paired t = −1.2	13	0.26	N=D
Citharichthys	18	Pooled	Paired t = −2.4	13	0.03*	N>D
stigmaeus	30	San Onofre	Paired t = 1.1	13	0.30	N=D
		Stuart Mesa	Paired t = 1.3	13	0.21	N=D
Citharichthys	18	San Onofre	Paired t = 0.03	13	0.97	N=D
xanthostigma		Stuart Mesa	Paired t = −4.9	13	<0.001*	N>D
	30	San Onofre	Paired t = −3.0	13	0.01*	N>D
		Stuart Mesa	Paired t = −3.9	13	0.002*	N>D
Genyonemus	18	Pooled	Paired t = −4.3	13	0.001*	N>D
lineatus	30	San Onofre	Paired t = −6.4	13	<0.001*	N>D
		Stuart Mesa	Paired t = −2.9	13	0.01*	N>D
Hyperprosopon	18	San Onofre	Paired t = −0.1	13	0.95	N=D
argenteum		Stuart Mesa		—insufficient data—		
Hippoglossina stomata	30	Pooled	Paired t = −0.4	13	0.67	N=D
Icelinus	30	San Onofre	Wilcoxon T = 9	6	>0.10	N=D
quadriseriatus		Stuart Mesa	Paired t = 0.3	13	0.74	N=D
Ophidion	18	Pooled	Paired t = −28.5	13	<0.001*	N>D
scrippsae	30	Pooled	Paired t = −19.5	13	<0.001*	N>D
Paralichthys	18	Pooled	Paired t = 0.6	13	<0.56	N=D
californicus	30	Pooled	Paired t = 3.2	13	0.008*	D>N
Phanerodon	18	Pooled	Paired t = 3.8	13	0.003*	D>N
furcatus	30	Pooled	Paired t = 1.4	13	0.20	N=D
Porichthys notatus	30	Pooled	Paired t = −4.8	13	<0.001*	N>D
Pleuronichthys	18	San Onofre	Paired t = −5.2	13	<0.001*	N>D
verticalis		Stuart Mesa	Paired t = −0.6	13	0.57	N=D
	30	Pooled	Paired t = −1.8	13	0.10	N=D
Raja inornata	30	Pooled	Paired t = −7.8	13	<0.001*	N>D
Rhinobatos productus	18	Pooled	Paired t = −2.6	13	0.02*	N>D
Symphurus	18	Pooled	Paired t = −4.1	13	0.001*	N>D
atricauda	30	San Onofre	Paired t = −2.2	13	0.04*	N>D
		Stuart Mesa	Paired t = −6.4	13	<0.001*	N>D
Seriphus	18	Pooled	Paired t = −3.7	13	0.003*	N>D
politus	30	Pooled	Paired t = −4.9	13	<0.001*	N>D
Xystreurys	18	Pooled	Paired t = 2.1	13	~0.05*	D>N
liolepis	30	Pooled	Paired t = 4.6	13	<0.001*	D>N
Zaniolepis latipinnis	30	Pooled	Wilcoxon T = 31.5	12	>0.10	N=D
Zalembius	30	San Onofre	Paired t = −3.5	13	0.004*	N>D
rosaceus		Stuart Mesa	Paired t = −1.5	13	0.17	N=D

Species selected are the top 20 ranked in terms of numbers in the total of 416 trawls made at both depths and locations, during both diel periods.
*Significant at $P \leq 0.05$.

DISCUSSION

Diel Variations in Species Composition and Richness

The conspicuous absence of certain species in daytime trawls was one of the more notable diel differences that we observed. *Ophidion scrippsae* was virtually absent in our daytime trawl catches (Tables 3 and 4; Figure 1). Two species of midshipman, particularly the smaller and more numerous *Porichthys nota-*

TABLE 8
Paired T-Test (or Wilcoxon Matched-Pairs Signed-Ranks Test) Comparisons of Diel Effects on the Mean (Median) Catch (Biomass) per Trawl for 18 Species

			Diel differences in catch (biomass)			
Species	Depth	Location(s)	Test statistic	*N*	*P*	Conclusion
Citharichthys sordidus	30	Pooled	Paired t = −1.2	13	0.26	N=D
Citharichthys xanthostigma	18	San Onofre	Wilcoxon T = 17	8	>0.10	N=D
		Stuart Mesa	Paired t = −5.4	13	<0.001*	N>D
	30	San Onofre	Paired t = −2.5	13	0.03*	N>D
		Stuart Mesa	Paired t = −3.1	13	0.009*	N>D
Genyonemus lineatus	18	Pooled	Paired t = −4.3	13	0.001*	N>D
	30	San Onofre	Paired t = −5.0	13	<0.001*	N>D
		Stuart Mesa	Paired t = −2.6	13	0.02*	N>D
Hippoglossina stomata	30	Pooled	Paired t = 0.5	13	0.64	N=D
Hydrolagus colliei	30	San Onofre	Wilcoxon T = 5	9	<0.05*	N>D
		Stuart Mesa	—insufficient data—			
Ophidion scrippsae	18	Pooled	Paired t = −34.3	13	<0.001*	N>D
	30	Pooled	Paired t = −38.7	13	<0.001*	N>D
Paralabrax nebulifer	18	San Onofre	Paired t = −0.2	13	0.85	N=D
	30	Stuart Mesa	Paired t = 1.2	13	0.26	N=D
		Pooled	Paired t = 0.5	13	0.60	N=D
Paralichthys californicus	18	Pooled	Paired t = 0.8	13	0.43	N=D
	30	Pooled	Paired t = 2.0	13	0.06	N=D
Phanerodon furcatus	18	Pooled	Paired t = 3.6	13	0.003*	D>N
	30	Pooled	Paired t = 2.2	13	0.04*	D>N
Pleuronichthys verticalis	18	Pooled	Paired t = −3.9	13	0.002*	N>D
	30	Pooled	Paired t = −1.2	13	0.26	N=D
Raja inornata	30	Pooled	Paired t = −2.4	13	0.03*	N>D
Rhinobatos productus	18	Pooled	Paired t = −1.7	13	0.11	N=D
Scorpaena guttata	30	Pooled	Paired t = −1.7	13	0.11	N=D
Seriphus politus	18	Pooled	Paired t = −2.0	13	0.07	N=D
	30	Pooled	Paired t = −4.1	13	0.002*	N>D
Symphurus atricauda	18	San Onofre	Wilcoxon T = 1	6	>0.05	N=D
		Stuart Mesa	Paired t = −6.4	13	0.001*	N>D
	30	San Onofre	Paired t = −6.4	13	<0.001*	N>D
		Stuart Mesa	Paired t = −5.7	13	<0.001*	N>D
Xystreurys liolepis	18	Pooled	Paired t = 2.1	13	~0.05*	D>N
	30	Pooled	Paired t = 3.6	13	0.004*	D>N
Zalembius rosaceus	30	San Onofre	Paired t = −3.2	13	0.007*	N>D
		Stuart Mesa	Paired t = −1.8	13	0.10	N=D
Zaniolepis latipinnis	30	San Onofre	Wilcoxon T = 26.5	13	>0.10	N=D
		Stuart Mesa	Paired t = 0.1	13	0.93	N=D

Species selected are 18 of the top 20 ranked in terms of biomass in the total of 416 trawls made at both depths and locations, during both diel periods. Data were statistically intractable for the remaining two species.

*Significant at $P \leq 0.05$.

tus, were also more abundant on nighttime cruises (Tables 3 and 4; Figure 1). Wenner (1983) has recently noted some striking parallels in the diel trawl catches of several ophidioids and one species of midshipman in the South Atlantic Bight. Our nighttime catches of California tonguefish (*Symphurus atricauda*) also were large relative to daytime trawls.

It is obvious that the striking differences in the day-versus-night catches of these species reflect behavior patterns that make them largely inaccessible to trawls during the day, yet very susceptible to capture at night. *Ophidion scrippsae* is a burrow-dwelling cusk eel that is active only at night and at other times when illumination near the seabed is low either because of

TABLE 9
Average Biomass (Wet Weight) Per Individual for Selected Species Present in Day Versus Night Trawls

	Average biomass (g)			
	18 m		30 m	
	Day	Night	Day	Night
Genyonemus lineatus	78	79	101	92
Zalembius rosaceus	—	—	19	20
Ophidion scrippsae	—	60	—	50
Citharichthys xanthostigma	80	78	54	56
Citharichthys sordidus	—	—	16	16
Seriphus politus	49	34	58	55
Symphurus atricauda	—	—	26	32
Citharichthys stigmaeus	16	14	10	12
Zaniolepis latipinnis	—	—	33	31
Pleuronichthys verticalis	183	200	168	147
Cymatogaster aggregata	30	24	25	30
Paralichthys californicus	649	607	759	1,123
Xystreurys liolepis	161	171	142	158
Phanerodon furcatus	79	62	144	107
Porichthys notatus	—	—	16	18
Raja inornata	—	—	448	328
Hyperprosopon argenteum	45	60	—	—
Icelinus quadriseriatus	—	—	8	7
Hippoglossina stomata	—	—	111	101
Paralabrax nebulifer	323	274	—	—
Rhinobatos productus	1,382	1,178	—	—
Synodus lucioceps	255	268	—	—

Only species represented by ⩾ 15 individuals per diel period in trawls made at the respective sampling depth are included. Absence of *Ophidion scrippsae* from nearly all daytime trawls precluded comparison for this species.

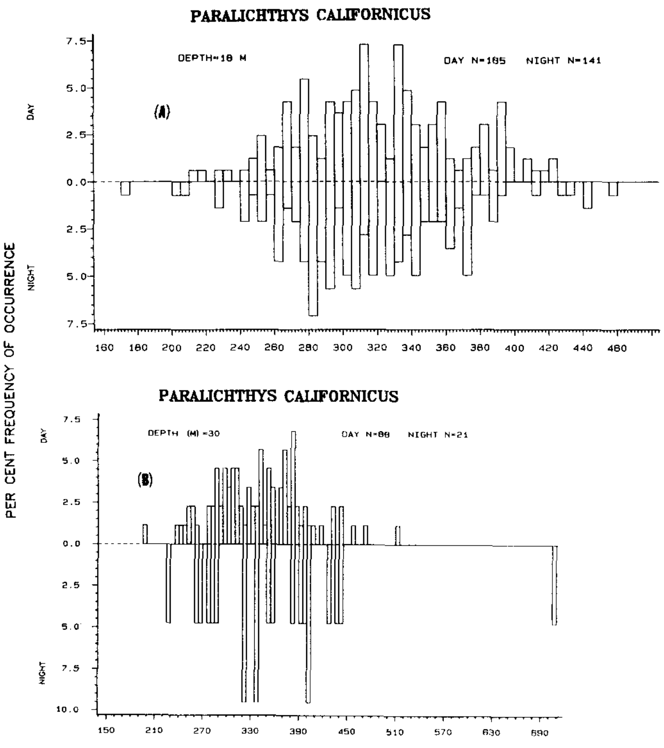

Figure 4. Length-frequency distributions of a third species of medium-sized (15-30 cm SL) flatfish, *Paralichthys californicus*, present in day and night trawls at each of the two sampling depths.

very turbid water or greatly reduced light (Greenfield 1968). *Ophidion scrippsae* apparently leave their burrows at night to feed on epibenthic invertebrates (Allen 1982). Juvenile (Arora 1948) and adult *Porichthys notatus* cover themselves with sediment on the surface of the seabed during the day, and rise into the water column at night to feed on planktonic organisms (Ibara 1970, Allen 1982). Studies of the feeding habits of *Symphurus atricauda* confirm its nocturnal activity pattern (Telders 1981; Manzanilla and Cross 1982). At least *O. scrippsae* and *S. atricauda* are primarily nonvisual feeders (Allen 1982), so visual avoidance of trawls may be relatively low (hence catchability high) at night.

Species richness (number of species per tow), the simplest measure of diversity, was generally greater at

TABLE 10
Results of Kolmogorov-Smirnov Two-Sample Comparisons of the Length-Frequency Distributions of Selected Species Present in Trawls

Species	Depth (m)	Day	Night	D_{max}	D_{crit}	P
Genyonemus lineatus	18	1,267	4,025	.05	.04	.02>P>.01*
	30	2,144	5,958	.13	.03	<0.001*
Paralichthys californicus	18	165	141	.10	.16	>0.1(NS)
Citharichthys xanthostigma	18	253	503	.13	.10	0.01*
	30	1,225	1,841	.02	.05	>0.1(NS)
Citharichthys sordidus	30	1,979	1,742	.07	.04	<0.001*
Citharichthys stigmaeus	18	242	300	.05	.12	>0.1(NS)
Xystreurys liolepis	30	133	66	.13	.20	>0.1(NS)
Pleuronichthys verticalis	18	108	198	.09	.16	>0.1(NS)
	30	137	166	.13	.16	>0.1(NS)

No *Citharichthys stigmaeus* were measured from 30-m trawls. Too few *Citharichthys sordidus* and *Xystreurys liolepis* were caught at 18 m, and too few *Paralichthys californicus* at 30 m, to warrant two-sample K-S tests. D_{max} refers to the maximum observed deviation between day and night length-frequency distributions. D_{crit} is the critical value at $\alpha_2 = 0.05$.
*Significant at $P \leq 0.05$.

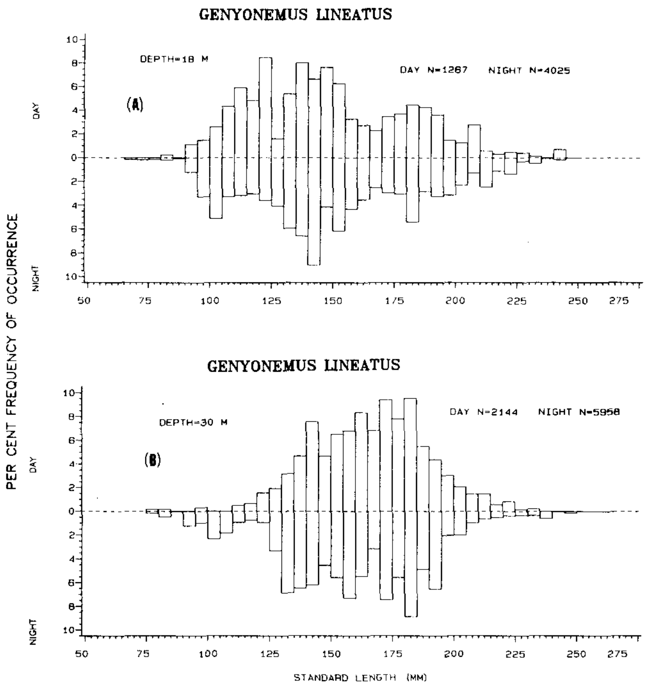

Figure 5. Length-frequency distributions of a small roundfish (*Genyonemus lineatus*) present in day and night trawls at each of the two sampling depths.

night than during the day (Table 5), largely because of night-active species such as *Ophidion* and *Porichthys.*

There was an average 37%-64% increase in the number of species per tow at night (Table 5). Other researchers have also noted the generally greater species richness of nighttime trawl catches, both within the bight and elsewhere. Night sampling averaged over twice the number of species in a limited day-night comparison based on an unpaired series of 4 nighttime versus 15 daytime trawls made along the 61-m contour off Palos Verdes from 1970-72 (LACSD 1981). Allen (1976), in his study of the fishes of Newport Bay within the central bight, trawled an average of 58% more species per tow at night. Nighttime trawls also provided an average maximum of 2.5 times as many species per trawl in a study of the fishes of Biscayne Bay, Florida (Roessler 1965). A similar average maximum of 2.4 times as many species of fishes per trawl was noted by Hoese et al. (1968) at Aransas Pass Inlet, Texas. Livingston (1976) found a mean increase of 19% in the number of species per trawl at night in a study of the benthic fishes of Apalachicola Bay, Florida.

Increased species richness at night undoubtedly reflects the availability of night-active species (Hoese et al. 1968; Allen 1976). Greater richness probably is also due to general increases in catchability at night (Blaxter et al. 1964; Blaxter and Parrish 1965). If

TABLE 11

Coefficients of Variation (CVs) of Grand Means of the Total Number, Biomass, Average Body Weight (All Species), and Species Richness per Single Trawl Tow

Category	Depth	Location(s)	CV (%) Day	CV (%) Night
Total numbers	18	Pooled	100	36
	30	Pooled	65	26
	18	Pooled	63	43
Total biomass (kg)	30	San Onofre	99	44
	30	Stuart Mesa	55	39
Average body weight (g)	18	Pooled	38	30
	30	San Onofre	67	41
	30	Stuart Mesa	50	21
	18	San Onofre	43	20
Species richness, S	18	Stuart Mesa	33	12
	30	Pooled	26	8

See Table 2 for rationale behind whether longshore locations were pooled or not.

fishes are generally more susceptible to capture at night (see reference below), it is more probable that greater numbers of relatively rare species will be encountered then. These influences of diel variations in trawl catches are likely to be general, since they appear to transcend habitat as well as geographic region (Wenner 1983).

Diel Variations in Weighted Diversity and Evenness

Gleason's d, a measure of species richness standardized for the influence of variable sample size (number of individuals caught) on richness (Peet 1974), was significantly greater at night for only one of four sample cases (Table 5). We feel that this is due to the inappropriate and simplistic assumption that the richness of samples is accurately standardized by the logarithm of the numbers of individuals caught. We concur with Green (1975) that the Gleason index is a poor measure of species diversity for benthic assemblages sampled by otter trawls in the Southern California Bight.

The general equivalence of weighted diversity and evenness values for day and night trawls (Table 5) was unexpected. In fact, the greater diversity and evenness (J') of daytime 18-m trawls were opposite our predictions, since there was prior reason (LACSD 1981) to have expected greater nighttime diversity. Lower values of Simpson's dominance (one minus lambda) for daytime 18-m trawls were supported by analogous results using Hill's (1973) N_2, a more accurate characterization of Simpson's index (Routledge 1979). Hill's N_1, thought to be a more accurate analogue of Shannon's diversity index (Routledge 1979), in fact was sensitive enough to detect a diel difference at 18 m, whereas Shannon's index was not (Table 5). The greater evenness of daytime 18-m samples is substantiated by Alatalo's modification of Hill's N_2/N_1 ratio, a less-biased measure of evenness than Pielou's J' (Alatalo 1981).

Hill's (1973) numbers and ratios have heretofore not been used to describe sample assemblages of benthic fishes in the bight. We encourage their use because recent developments in diversity theory have demonstrated their greater accuracy. However, we acknowledge that most patterns of interest are likely to be gross enough to trivialize the biases resolved by these new indices. We have provided these new measures for the sake of completeness and to facilitate future comparisons.

Greater diversity and evenness at 18 m during the day, although unexpected, is not enigmatic in retrospect. The relatively few moderately abundant species (like *Genyonemus lineatus* and *Seriphus politus*) present in daytime 18-m trawls produced an apparently "even" distribution of numbers among species compared to night samples at 18 m. At 30 m there were disproportionately more species that were numerically dominant during both diel periods (Table 3).

Diel Variations in Relative Abundances

Most of the abundant and frequently encountered species were caught in similar proportions during both diel periods (Table 6). The aforementioned differences in species composition of day-versus-night trawls, although striking for a few species, were insufficient to override general similarities in rank CPUE. This suggests that fish "communities" (*sensu* Allen 1982) based on assemblages sampled by otter trawls are equivalently (and oversimplistically) described by rank-order statistics such as Kendall's tau using either day or night trawl data. We feel that these types of characterizations may disregard important differences in functionally dominant species by overemphasizing the similarities of other abundant species. This is probably the reason that the similarity between diel periods was marginally insignificant for the biomass of assemblages sampled at 18-m and 30-m depths (Table 6). Specifically, the presence of many species of relatively rare, but large-bodied fishes in night trawls introduced more diel dissimilarity to the abundance rankings based on biomass versus numbers (Tables 3 and 4).

Diel Variations in Abundance of Major Species

Our total fish catches averaged 2.1-3.5 times larger at night for numbers, and 2.0-2.6 times larger for biomass (Table 2). Obviously, most species are more catchable at night. We can only speculate as to why catches of white seaperch (*Phanerodon furcatus*), fantail sole (*Xystreurys liolepis*), and *Paralichthys californicus* were generally larger during the day. Perhaps the distribution of *P. furcatus* is centered at 18 m and shallower during daylight, since the species is commonly observed in shallow areas by day (Ebeling et al. 1980). There are only meager data to suggest how *P. californicus* and *X. liolepis* might be more catchable during the day, perhaps because of more effective herding by trawls. *P. californicus* is an "ambusher" that lies buried in wait for free-swimming prey. Its habits are primarily diurnal (Allen 1982), so it might be herded more effectively during the day. *X. liolepis* is a "stalker-ambusher" of motile, epibenthic decapods; however, its diel habits are uncertain, so its response to the trawl is unknown.

Numerically larger catches also have been reported at night for research trawls made elsewhere in the bight and in other regions. For example, an average sixfold increase in total numerical catch was reported for nighttime trawls in the aforementioned survey at 61-m depth off Palos Verdes (LACSD 1981). Nighttime trawls averaged 162% and 24% larger for numbers and biomass, respectively, in Allen's (1976) Newport Bay study. Night otter trawl catches exceeded day catches by 33% for numbers and 101% for biomass in a study of the fishes from the Cabrillo Beach section of Los Angeles Harbor (Allen et al. 1983). At night, Roessler (1965) caught an average of twice as many individual fishes per trawl. Nighttime trawls also averaged 1.3- to 9.2-fold larger for total numbers of fishes in the Aransas Pass study (Hoese et al. 1968). Total fish catches averaged 73% larger at night in Livingston's (1976) diel trawl study.

In summary, various diel research studies indicate generally greater catches by otter trawls at night. Numerous evaluations of fisheries trawl data (e.g., Parrish et al. 1964; Woodhead 1964; Beamish 1966) have reached the same conclusion.

Diel Variations in Size-Composition

Diel differences in the size-composition of fishes were evident only for one roundfish (*Genyonemus lineatus*) and one medium-sized flatfish (*Paralichthys californicus*, see below) out of the seven species for which length measurements were taken (Table 10 and Figures 2-5). The average weight of *G. lineatus* captured was equivalent in day and night trawls (Table 9). However, this average value is misleading because at least several size-modes of fish are involved; Figure 5 illustrates that proportionally greater numbers of small (< 14 cm) *G. lineatus* were captured in night trawls at 30 m. Adult white croaker migrate offshore from 5- to 10-m depths at dusk (Allen and DeMartini 1983). Perhaps, like *Seriphus politus* (DeMartini et al., in press), the proportion of smaller *G. lineatus* present at a given bottom depth is greater at night than during the day.

For all species of small and two of the three species of medium-sized flatfishes measured, diel differences in length composition were trivial (Table 10; Figures 2 and 3). The average body weight per individual fish differed little between day and night for these and other flatfishes, as well as most other species abundant in our trawls (Table 9).

Little comparative data on average fish size exists for other research trawl studies; biomass data have usually not been provided in addition to numerical CPUE (Roessler 1965; Hoese et al. 1968; Livingston 1976). Commercial trawl data, however, generally indicate that nighttime trawls catch larger individual fish of a given species (Parrish et al. 1964; Woodhead 1964; Beamish 1966). This might reflect, as Jones (1956) implies, the fact that research trawls, with their typically fine-mesh (0.75 or 1.25 cm) cod-end liners generally vary less in their catch efficiencies between day and night than do their larger-mesh, commercial counterparts.

We feel that the average body sizes of the fishes caught in our day and night trawls were generally indistinguishable (Table 2) because most individuals in the populations sampled were juveniles (see Sherwood 1980) and other fishes too small to outswim a 7.6-m otter trawl towed at > 2 knots. One notable exception to this general rule illustrates this. The average body size of juvenile-small adult California halibut, *Paralichthys californicus*, increases with bottom depth over the range of 6-30 m (Plummer et al. 1983). Halibut of equivalent 25-40 cm SL were captured both day and night at 18 m (Figure 4A). At 30 m, however, where *P. californicus* > 30 cm SL are more abundant, relatively more fish > 40 cm long were caught at night (Figure 4B). It is likely that halibut > 40 cm SL are better able to avoid our trawls during the day. Most species of large, mobile fishes, though, probably avoid the trawl effectively any time.

Diel Contrasts of Precision

Precision based on CVs was consistently greater and, in many cases, increased > 50% when abundance (CPUE) and other variables were estimated using nighttime rather than daytime trawl data (Table 11). This undoubtedly reflects the fact that many nearshore fishes are more contagiously distributed during daylight (also see Allen and DeMartini 1983). No day-night comparisons of precision are available for otter trawl data elsewhere in the Southern California Bight, but several analogous studies made in widely separated geographic areas have had similar findings. Roessler's (1965) trawl study produced CVs that averaged 23% and 7% smaller at night for estimates of species richness and total fishes (numbers), respectively. Roessler used a relatively small 10-ft (3.1-m) otter trawl, towed for 2 minutes, with two replicates per station-cruise. Median CVs of nighttime trawls were 44% and 86% as large as the CVs of day catches for number of species and total fishes caught per trawl in Livingston's (1976) diel study. Livingston also used a relatively small 16-ft (4.9-m) trawl and 2-min tows, but estimates were based on three replicates.

We are unaware of any direct, diel comparisons of sampling precision for commercial fisheries trawl data. We feel that we can state, based on our and other research trawl data, that nighttime trawl samples are generally less variable than daytime samples.

Moreover, research trawl data (Roessler 1965; Livingston 1976; this study) provide good empirical proof that Taylor (1953) was correct when he concluded, based on evaluation of fisheries trawls, that multiple, short tows are better than single (or even the same number of) long tows. These data specifically confirm the general case discussed by Green (1979): relatively small samples typically yield more precise estimates than larger samples when sampling contagiously distributed organisms. Shorter tows are probably more precise than the same number of longer tows because longer tows, particularly when made during the day, more closely approximate patch size of benthic fishes (hence inflate CPUE variance, Elliott 1971) on some relevant spatial scale (Barnes and Bagenal 1951; Taylor 1953).

The benefit of shorter tows is especially pertinent considering the design of trawl monitoring studies in the Southern California Bight. The present standard in deepwater pollution monitoring is a daytime survey using unreplicated 10-min tows. Drag speeds have averaged about 2.7 knots since 1973 (LACSD 1981). The particularly large diel differences reported for trawls at 61 m, together with the relatively small average daytime catches at outer shelf and slope depths (175 fishes of 11 species weighing 7.1 kg: Allen and Voglin 1976) suggest that, despite sufficient drag speeds, there are serious problems with both catchability (accuracy) and precision for these daytime trawl series. Precision would be increased if shorter tows were made and mean CPUE reduced (Taylor 1953). Many studies at shallow shelf (< 30 m) depths (e.g., Stephens et al. 1974; LACSD 1981) have used 10- or even 20-min tows. Our trawl data suggest that the precision of trawls made at shallow shelf depths in the bight can be increased appreciably by taking shorter tows at night, thereby reducing mean CPUE (even if no additional replicate tows are made).

CONCLUSIONS

Our results generally confirmed other less extensive evaluations of diel trawl data collected elsewhere in the Southern California Bight. The basic pattern was one of greater total numbers, total biomass, and species richness per tow for night samples. Larger catches were made at night for 12 (numbers) and 9 (biomass) of the 20 most abundant species (total trawls). In addition, night catches averaged from 3.0 to 3.7 more species per tow than day catches at 18 and 30 m, respectively. Diel differences in species composition in part reflected diel changes in behavior and availability for several abundant species, notably basketweave cusk eel (*Ophidion scrippsae*); plainfin midshipman (*Porichthys notatus*); and California tonguefish (*Symphurus atricauda*). However, diel differences in composition were generally insufficient to distinguish day and night catches of the top 20 species based on their rank abundances.

Average weight per fish (all species) and the length-frequency distributions of five out of seven species measured differed little between day and night samples. The length frequencies of each of three small and two out of three medium-sized species of flatfishes were equivalent in day and night samples. Disproportionately more large individuals were caught at night only for California halibut (*Paralichthys californicus*) at 30 m, and this most likely reflected diel differences in catchability. Relatively more small white croaker (*Genyonemus lineatus*) were caught during night at 30 m. For *G. lineatus*, a diel shift in onshore-offshore distribution probably was involved.

Growing concern (MacCall et al. 1976) over the status of fish stocks within the Southern California Bight makes it increasingly important that we understand the significance of factors such as diel variability when designing monitoring studies. Is the nature and magnitude of diel differences in trawl catches sufficient to warrant the extra costs (overtime wages, etc.) of nighttime cruises? We think so. Questions such as this become ever more relevant as shoreline development, coastal power generating plants, and the number of monitoring studies using otter trawls continue to increase in southern California.

ACKNOWLEDGMENTS

We thank the many individuals who assisted in the field operations. We especially thank Jan Callahan for statistical advice, Bob Fountain and Dale Roberts for their beneficial criticisms of an early draft, and Jan Fox for typing the manuscript. This paper is the result of research funded by the Marine Review Committee (MRC), Encinitas, California. The MRC does not necessarily accept the results, findings, or conclusions stated herein.

LITERATURE CITED

Alatalo, R.V. 1981. Problems in the measurement of evenness in ecology. Oikos 37:199-204.

Allen, L.G. 1976. Abundance, diversity, seasonality and community structure of fish populations of Newport Bay, California. M.A. thesis, California State University, Fullerton, 108 p.

Allen, L.G., and E.E. DeMartini. 1983. Temporal and spatial patterns of nearshore distribution and abundance of the pelagic fishes off San Onofre-Oceanside, California. Fish. Bull., U.S. 81:569-586.

Allen, L.G., M.H. Horn, F.A. Edmands II, and C.A. Usui. 1983. Structure and seasonal dynamics of the fish assemblage in the Cabrillo Beach area of Los Angeles Harbor, California. Bull. So. Calif. Acad. Sci. 82:47-70.

Allen, M.J. 1982. Functional structure of soft-bottom fish communities of the southern California shelf. Ph.D. dissertation, University of California, San Diego, 577 p.

Allen, M.J., and R. Voglin. 1976. Regional and local variation of bottom fish and invertebrate populations. *In* W.S. Bascom (ed.), Coastal Water Research Project annual report 1975. Southern California Coastal Water Research Project, El Segundo, p. 217-221.

Arora, H.L. 1948. Observations on the habits and early life history of the batrachoid fish *Porichthys notatus* Girard. Copeia 1948:89-93.

Barnes, H., and T.B. Bagenal. 1951. A statistical study of variability in catch obtained by short repeated trawls taken over an inshore ground. J. Mar. Biol. Assoc. U.K. 19:649-660.

Beamish, F.W.H. 1966. Vertical migration by demersal fish in the northwest Atlantic. J. Fish. Res. Board Can. 23:109-139.

Blaxter, J.H.S. 1970. Light. *In* O. Kinne (ed.), Marine ecology, vol. I, environmental factors, part 1. Wiley-Interscience, London, p. 213-320.

Blaxter, J.H.S., and B.B. Parrish. 1965. The importance of light in schooling, avoidance of nets and vertical migration by herring. J. Cons. 30:40-57.

Blaxter, J.H.S., B.B. Parrish, and W. Dickson. 1964. The importance of vision in the reaction of fish to driftnets and trawls. *In* H. Kristjonsson (ed.), Modern fishing gear of the world, vol. 2. Fishing News (Books) Ltd., London, p. 529-536.

Bowman, R.E., and E.W. Bowman. 1980. Diurnal variations in the feeding intensity and catchability of silver hake (*Merluccius bilinearis*). Can. J. Fish. Aquat. Sci. 37:1565-1572.

Clifford, H.T., and W. Stevenson. 1975. An introduction to numerical classification. Academic Press, New York, 229 p.

DeMartini, E.E., L.G. Allen, R.K. Fountain, and D. Roberts. In press. Diel and depth variations in the sex-specific abundance, size-composition, and food habits of queenfish (*Seriphus politus:* Sciaenidae). Fish. Bull., U.S. 82.

Ebeling, A.W., R.J. Larson, and W.S. Alevizon. 1980. Habitat groups and island-mainland distribution of kelp-bed fishes off Santa Barbara, California. *In* D.M. Power (ed.), Multidisciplinary symposium on the California islands. Santa Barbara Mus. Nat. Hist., p. 403-431.

Elliott, J.M. 1971. Some methods for the statistical analysis of samples of benthic invertebrates, 2d ed. Freshw. Biol. Assoc., Sci. Publ. 25, 160 p.

Green, C.S. 1975. Comparison of diversity indices. *In* W.S. Bascom (ed.), Coastal Water Research Project annual report 1975. Southern California Coastal Water Research Project, El Segundo, California, p. 79-83.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York, 257 p.

Greenfield, D.W. 1968. Observations on the behavior of the basketweave cusk-eel *Otophidium scrippsi* Hubbs. Calif. Fish Game 54:108-114.

Helwig, J.T., and K.A. Council, eds. 1979. SAS user's guide, 1979 edition. SAS Inst. Inc., Cary, North Carolina, 494 p.

Hill, M.O. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology 54:427-432.

Hoese, H.D., B.J. Copeland, F.N. Moseley, and E.D. Lane. 1968. Fauna of the Aransas Pass Inlet, Texas. III. Diel and seasonal variations in trawlable organisms of the adjacent area. Texas J. Sci. 20:33-60.

Horn, M.H., and L.G. Allen. 1981. A review and synthesis of ichthyofaunal studies in the vicinity of Los Angeles and Long Beach Harbors, Los Angeles County, California. 23 Feb 1981. Final report submitted to the U.S. Fish and Wildlife Service, Ecological Services, Laguna Niguel, CA 92677.

Ibara, R.M. 1970. The buoyancy change in the diel vertically migrating fish, *Porichthys notatus*. Ph.D. dissertation, University of California, Santa Barbara, 76 p.

Jones, R. 1956. A discussion of some limitations of the trawl as a sampling instrument. Rapp. P.-v. Réun. Cons. Perm. Int. Explor. Mer 140:44-47.

LACSD (Los Angeles County Sanitation Districts). 1981. Ocean monitoring and research, annual report 1980-1981. Los Angeles County Sanitation Districts. November 1981. 384 p.

Livingston, R.J. 1976. Diurnal and seasonal fluctuations of organisms in a north Florida estuary. Estuar. Coast. Mar. Sci. 4:373-400.

MacCall, A.D., G.D. Stauffer, and J.P. Troadec. 1976. Southern California recreational and commercial marine fisheries. Mar. Fish. Rev. 38:1-32.

Manzanilla, E., and J.N. Cross. 1982. Food habits of demersal fish in Santa Monica Bay. *In* W.S. Bascom (ed.), Coastal Water Research Project, biennial report for the years 1981-1982. Southern California Coastal Water Research Project, Long Beach, CA 90806, p. 119-124.

Mearns, A.J. 1974. Southern California's inshore demersal fishes: diversity, distribution, and disease as responses to environmental quality. Calif. Coop. Oceanic Fish. Invest. Rep. 17:141-148.

Mearns, A.J., and M.J. Allen. 1978. Use of small otter trawls in coastal biological surveys. Southern California Coastal Water Research Project, Contrib. no. 66. EPA-600/3-78-083. August 1978, 34 p.

Morrison, D.F. 1976. Multivariate statistical methods. McGraw-Hill, New York, 415 p.

Parrish, B.B., J.H.S. Blaxter, and W.B. Hall. 1964. Diurnal variations in size and composition of trawl catches. Rapp. P. -v. Réun. Cons. Int. Explor. Mer 155:27-34.

Peet, R.K. 1974. The measurement of species diversity. Ann. Rev. Ecol. System. 5:285-307.

Plummer, K.M., E.E. DeMartini, and D.A. Roberts. 1983. The feeding habits and distribution of juvenile-small adult California halibut (*Paralichthys californicus*) in coastal waters off northern San Diego County. Calif. Coop. Oceanic Fish. Invest. Rep. 24:194-201.

Roessler, M.A. 1965. An analysis of the variability of fish populations taken by otter trawl in Biscayne Bay, Florida. Trans. Am. Fish. Soc. 94:311-318.

Routledge, R.D. 1979. Diversity indices: which ones are admissible? J. Theor. Biol. 76:503-515.

SCCWRP (Southern California Coastal Water Research Project). 1973. The ecology of the Southern California Bight: implications for water quality management. SCCWRP TR 104, 531 p.

Sherwood, M. 1980. Recruitment of nearshore demersal fishes. *In* W. Bascom (ed.), Coastal Water Research Project, biennial report for the years 1979-1980. Southern California Coastal Water Research Project, Long Beach, CA 90806, p. 319-333.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York, 312 p.

Sissenwine, M.P., and E.W. Bowman. 1978. An analysis of some factors affecting the catchability of fish by bottom trawls. Internat. Comm. Northwest Atl. Fish. Res. Bull. 13:81-87.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco, 776 p.

Stephens, J.S., Jr., C. Terry, S. Subber, and M.J. Allen. 1974. Abundance, distribution, seasonality and productivity of the fish populations in Los Angeles Harbor, 1972-73. *In* D.F. Soule and M. Oguri (eds.), Marine studies of San Pedro Bay, part 4. Allan Hancock Foundation, Univ. So. Calif., Los Angeles, p. 1-42.

Taylor, C.C. 1953. Nature of variability in trawl catches. Fish. Bull., U.S. 54:145-166.

Telders, E.L. 1981. Feeding periodicity and diet of the California tonguefish, *Symphurus atricauda* (Pisces: Cynoglossidae). M.Sc. thesis, California State University, Long Beach, 49 p.

Wenner, C.A. 1983. Species associations and day-night variability of trawl-caught fishes from the inshore sponge-coral habitat, South Atlantic Bight. Fish. Bull., U.S. 81:537-552.

Woodhead, P.M.J. 1964. Diurnal changes in trawl catches of fishes. Rapp. P.-v. Réun. Cons. Int. Explor. Mer 155:35-44.