ATTACHMENT 3

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Structure and Standing Stock of the Fish Assemblages of San Diego Bay, California from 1994 to 1999

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Abstract.—Twenty quarterly samples were taken of the fish assemblages of San Diego Bay from July 1994 to April 1999. Each quarter, four stations were occupied using a variety of sampling methods (large seine, small seines, square enclosure, purse seine, beam trawl, and otter trawl) designed to assess all components of the ichthyofauna. These samples yielded a total of 497,344 fishes belonging to 78 species and weighing 2,775 kg over the five-year period. Northern anchovy was the most abundant fish species comprising 43% of the total catch despite its virtual absence in 1997–98, followed by topsmelt, the slough anchovy and Pacific sardine. Round stingrays dominated in weight constituting almost 25% of the total biomass taken followed by spotted sand bass, and northern anchovy. Both numerical abundance and biomass were highest in the spring and summer months due largely to heavy recruitment of juvenile surfperches, topsmelt and northern anchovies. Large catches of northern anchovies, Pacific sardines, round stingrays, and spotted sand bass also contributed to the pronounced peaks in most July samples. Approximately 70% of all individual fish captured in San Diego Bay during this study were juveniles. The 40 most common species/recruits clustered into eleven, resident and seasonal groups. According to canonical correlation analysis, distance from the mouth of the bay, depth, temperature, and salinity accounted for nearly 88% (R^2 = 0.875) of the variance in species abundances.

In general, the fish assemblages of San Diego Bay were found to be diverse, abundant, highly seasonal, and highly productive. The bay serves as a significant nursery area for at least 28 species of fish while presenting a unique combination of harbor, nearshore soft bottom, and bay/estuarine habitats which each contribute unique sets of species to the overall assemblage. One of these sets includes 12 species which are indigenous to the bays and estuaries of southern California. South San Diego Bay represents a crtical habitat for these unique bay/estuarine species whose habitats have disappeared at an alarming rate during the last half century. The extensive shallow water habitat and eelgrass beds also support a very high standing stock of midwater, schooling (forage) fishes, such as northern anchovies, slough anchovies and topsmelt which, in turn, serve as an important forage resource for larger predatory fishes and marine birds. In addition, the general warm and hypersaline waters of south San Diego Bay offer a warm water refuge for a number of southern, "Panamic" province fish species making it unique among all other southern California embayments.

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Introduction

Bays and estuaries normally are considered to be important nursery areas for coastal marine fishes (Haedrich and Hall, 1976; Cronin and Mansueti, 1971). The warm spring-summer water temperatures coupled with high productivity enable these environments to support large numbers of juvenile fish. Southern California bays and estuaries are relatively small and scarce when compared to the large, river-dominated estuaries common in other parts of the world. They do, however, function as nursery areas in the classical sense for some species. At least one commercially important species (California halibut, *Paralichthys californicus*) has been shown to rely heavily on southern California bays and estuaries as nursery areas (Allen, 1988). Juveniles of non-commercial fishes can be extremely abundant and usually dominate the fish assemblages of bays and estuaries in the Southern California Bight (Allen, 1982). Many of these abundant, non-commercial species (e.g. gobies, anchovies, and silversides) are important forage fishes for commercial fish species (Horn, 1980) and sea birds. Another characteristic of the fish assemblages from southern California bays and estuaries which is often overlooked is that these habitats support a unique set of species found nowhere else in the bight (Horn, 1980; Allen, 1985).

The principal, resident species found in the smaller bays and estuaries of the Bight include topsmelt (*Atherinops affinis*), California killifish (*Fundulus parvipinnis*), striped mullet (*Mugil cephalus*), longjaw mudsucker (*Gillichthys mirabilis*), arrow goby (*Clevelandia ios*), shadow goby (*Quietula ycauda*), cheekspot goby (*Ilypnus gilberti*), yellowfin goby (*Acanthogobius flavimanus*—introduced), deepbody anchovy (*Anchoa compressa*), slough anchovy (*Anchoa delicatissima*), shiner surfperch (*Cymatogaster aggregata*), black surfperch (*Embiotoca jacksoni*), diamond turbot (*Hypsopsetta guttulata*), and juvenile California halibut (*Paralichthys californicus*), spotted sand bass (*Paralabrax maculatofasciatus*), round stingray (*Urolophus halleri*), and yellowfin croaker (*Umbrina roncador*) (Horn and Allen, 1981).

California killifish and longjaw mudsuckers are most abundant in the shallow tidal channels of the marsh islands. Topsmelt, striped mullet, deepbody anchovy, and slough anchovy inhabitat the water column of both the main channels and along the shoreline, although topsmelt and mullet feed on the bottom. The five species of gobies (family Gobiidae) as a group are the most abundant benthic fishes along the shoreline. The deeper channels are inhabited mainly by residents and seasonal migrants including shiner surfperch, black surfperch, diamond turbot, juvenile California halibut, spotted sand bass, juvenile barred sand bass, yellowfin croaker, and round stingray (Horn and Allen, 1981).

San Diego Bay is the largest naturally occurring marine embayment between San Francisco and Scammon's Lagoon in central Baja California containing approximately 12,000 acres (4,858 ha) of marine habitat (San Diego Unified Port, 1990). As a whole, the bay provides expansive and diverse habitats for fishes including deep channels, marinas, and extensive shallows largely covered with eelgrass. Only the lower portion, South San Diego Bay, appears comparable to other Southern California bays and estuaries in terms of physical and biotic characteristics. The overall goal of this study was to provide the first definitive assessment of the fish populations inhabiting this important coastal habitat.

Since 1968, the fish populations of San Diego Bay have been the subject of numerous monitoring studies with most being concentrated in the to the South San Diego Bay region (Ford 1968, 1985, & 1986, Ford et al. 1971, Lockheed 1979, San Diego Unified Port District 1980, San Diego Gas & Electric Co. 1980, Lockheed 1983). Most of these studies were limited in scope and duration. A comprehensive review of all work and the work in South San Diego Bay, in particular, is presented in San Diego Unified Port District (1990). No comprehensive studies of the fish populations of the entire bay existed prior to the present study.

San Diego Unified Port District (1990) also presented the most complete work on the South San Diego Bay fish populations yet completed. Sampling was conducted on a quarterly basis throughout the south bay in 1988–89. The sampling included multiple gear protocol (otter trawls, gill nets, beam trawls, and two sizes of beach seine) to effectively sample the major subhabitats utilized by fishes. This study concluded that the species composition, relative abundances, and biomass contributions of the south bay fishes have remained very similar since 1968. Topsmelt, slough anchovy, arrow goby, barred pipefish, and California killifish were the most numerically abundant species found in South San Diego Bay while round stingrays, California halibut, and spotted sand bass dominated in terms of biomass.

Hoffman (1986) compared abundance and biomass of fish utilizing eelgrass beds and adjacent non-vegetated areas in three sections of San Diego Bay. Beach seine hauls were made in the north, central, and south portions of the bay on a quarterly basis from July 1980 through April 1981. Topsmelt, shiner surfperch, and three species of gobies (arrow, cheekspot, and shadow) made up 93% of the individuals taken. Topsmelt, shiner surfperch, spotted sand bass, staghorn sculpin, round stingray, and California halibut comprised more than 87% of the fish biomass sampled. Hoffman (1986) concluded that nearly twice as many individual fish and fish species were taken at eelgrass sights than non-vegetated sites when all samples were considered. Furthermore, the total number of individuals and total biomass seemed to remain relatively constant from season to season in these shallow nearshore areas. Hoffman's (1986) results underscore the importance of the eelgrass habitat in San Diego in supporting juvenile and adult fish populations. This study served as a major impetus for the present study, which will eventually provide a statistically reliable comparison of fish numbers and biomass between vegetated (eelgrass) and non-vegetated areas.

The most recent work on the fishes of San Diego Bay was a long-term beach seine study also conducted by Hoffman (1995; and unpubl. data). A single station at the base of the Coronado Bridge has been sampled quarterly since January 1988. This sight corresponds directly with the station 2, vegetated site in the present investigation.

Finally, since 1985, nine, southern or "Panamic", fish species have been recorded from San Diego that add to the overall species list recorded from the bay (Table 1).

The overall objectives of this study were to: 1) identify, quantify and determine the seasonal utilization of the fish populations in San Diego Bay, 2) identify key habitats that support juvenile fish species, and 3) determine geographic and/or habitat areas of San Diego Bay that support significant populations of fish species

Table 1. Exotic, southern species recorded in San Diego Bay in the literature from 1985 to 1991.

Common name	Scientific name	Citation	Collection date
Anchoveta	*Ctengraulis mysticetus*	Duffy (1987)	1986?
Pacific cervalle jack	*Caranx caninus*	Duffy (1987)	1986?
Bonefish	*Albula vulpes*	Duffy (1987)	1986?
White mullet	*Mugil curema*	Lea et al. (1988)	May 1985
Milkfish	*Chanos chanos*	Duffy and Bernard (1985)	1985?
Pacific seahorse	*Hippocampus ingens*	Jones et al. (1988)	?
Cortez grunt	*Haemulon flaviguttatus*	Lea and Rosenblatt (1992)	May 1991
Bigeye trevally	*Caranx sexfasciatus*	Lea and Walker (1995)	Nov 1990
Mexican lookdown	*Selene brevoorti*	Lea and Walker (1995)	Nov 1990

utilized as forage by endangered avian species. To these ends, the following were determined and will be described for the five-year period, July 1994 to April 1999 in San Diego Bay: 1) physical and chemical (PC) factors, 2) species composition and abundance, 3) principal species, 4) species diversity, 5) abundance by bay ecoregion, 6) seasonal abundance, 7) ecological importance of species, 8) nursery area function, 9) fish assemblage structure, 10) abundance patterns in relationship to PC factors, 12) numerical and biomass density, 13) density and standing stock of forage species, and 14) density and standing stock of fisheries species.

Methods and Materials

Station Locations

In order to assess the status of all components of the ichthyofauna of San Diego Bay, we sampled intensively at four stations located in each of four geographic sections (north, north-central, south-central, and south) of bay (Figure 1).

At each station, five subhabitat types were sampled. These subhabitats are designated as follows (from deep to shallow water): 1) channel, 2) nearshore, non-vegetated, 3) nearshore, vegetated, 4) intertidal, non-vegetated, and 5) intertidal vegetated.

Sampling Procedures

The actual sampling locations for each type of gear within each station subhabitat were selected randomly for each sampling period. Sampling was conducted on a quarterly basis from July 1994 to April 1999. Each station was occupied on a separate day in order to sample each section thoroughly with a multiple gear approach. The use of multiple gears was necessary to adequately sample all of the habitat types available to the fishes of San Diego Bay. Collections were carried out using the R/V Yellowfin (California State University) as our base of operations with much of the work was conducted out of two, 5 m Boston Whalers. At each station, the following gear types were employed:

1) A 15.2 × 1.8 m **large seine** fitted with a 1.8 × 1.8 × 1.8 m bag (1.2 cm mesh in wings and 0.6 cm mesh in bag) was utilized to sample juvenile fishes in the nearshore portion of the station at a depth of 0–2 m. This net was set parallel to shore and hauled to shore by 15 m lines. This seine is an accurate sampler of nearshore schooling fishes and gives reliable density estimates. Two replicate hauls were made at each station, each of which covered about 220 m^2.

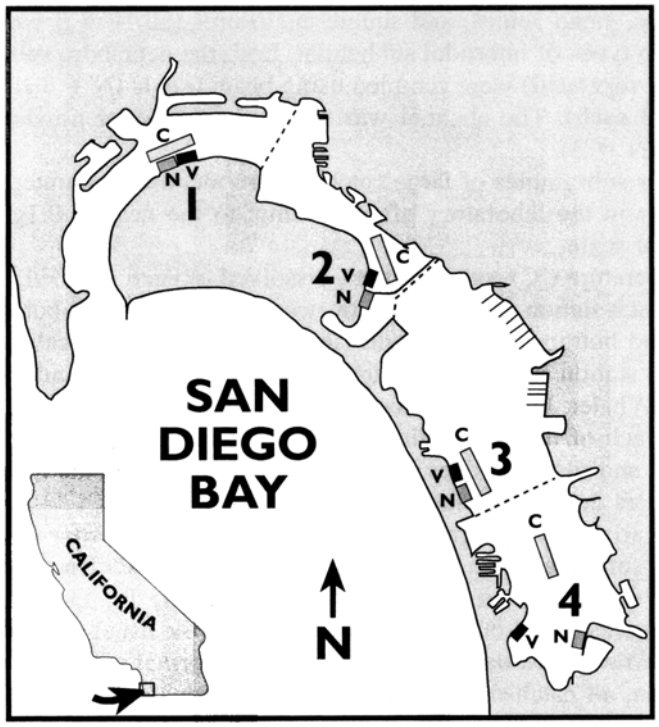

Fig. 1. Map of San Diego Bay illustrating the locations of the 4 sampling stations. (N = Non-vegetated site; V = Vegetated site; C = Channel site).

2) A 4.6 m × 1.2 m **small seine** (3 mm mesh) was employed to collect juvenile and adult fishes occupying the shallow, inshore areas (0–0.5 m depth). The small seine was hauled 10 m along shore and pivoted shoreward yielding a consistent areal coverage of about 62 m^2.

3) A **square enclosure** (1m × 1m × 1m) constructed of 2.5 cm PVC pipe and canvas was used to sample small, burrow inhabiting fish species such as gobies in the shallow waters of the bay. The enclosure was set randomly within each subhabitat in a depth range of 0.25 to 0.75 m and firmly settled into the substrate. One liter of 3:1 acetone-rotenone solution was then added to the enclosed water column and the substrate searched thoroughly for 10 min. with a 1 mm mesh, long-handled dipnet. This device samples an area of 1.0 m^2.

4) A 1.6 m **beam trawl** with 4 mm mesh in the wings and 2 mm knotless mesh in the codend. Standardized ten minute tows were be made behind the 5m Boston Whalers covering about 290 m^2.

5) A 66 × 6 m **purse seine** (1.2 cm mesh in wings and 0.6 cm mesh in bag) was utilized to sample juvenile and adult fishes in the water column of nearshore portion and channel of the station. Purse seine hauls were conducted using a specially out-fitted 5 m Boston Whaler and each sampled about 296 m^2.

6) An 8 m semi-balloon **otter trawl** (2 cm mesh in wings and 0.8 cm mesh in codend) towed behind the R/V Yellowfin was used to sample demersal juvenile and adult fishes from the deepest channel portions of each sampling area covering an average of 2417 m^2.

Large seines, small seines, and square enclosures (all N = 3 each) were used to sample both types of intertidal subhabitat. Both the nearshore subhabitats (non-vegetated and vegetated) were sampled using beam trawls (N = 3 each) and purse seines (N = 3 each). The channel was sampled using otter trawls (N = 3) and purse seines (N = 3).

All fishes or subsamples of large catches were identified, counted and weighed aboard ship or in the laboratory after freezing, to the nearest 0.1g on a Mettler PE2000 digital scale.

Water temperature (°C), salinity (ppt), dissolved oxygen (mgO^2/l), and pH were measured at each station at the shoreline, nearshore surface and bottom, and channel surface and bottom using a Hydrolab Digital 4041 field analyzer. Maximum depth of each station was recorded using Lowrance depth sounders mounted on each Boston Whaler. PC measurements were taken once at each of the four stations during each of the 4 sampling periods. Unfortunately, technical difficulties with the D.O. and pH electrodes in October 1996 prevented the measurements of these parameters during that sampling period.

Data summarization and graphing were accomplished using *Microsoft Excel* and *Statistica* software on an IBM compatible Pentium PC. Data analysis including ANOVA, canonical and regular correlations among PC factors and numbers and biomass were carried out using *Statistica.* As is the usual case with ecological data on fishes, raw catch data were generally non-normal with unequal variances. For this reason, all catch data for number of individuals of all species were log-transformed ($\log_{10}(x + 1)$) before statistical comparisons were made. This transformation generally solved problems of normality and unequal variances in this data set.

The Shannon-Weiner Diversity index (H′):

$$H' = -\sum p_i(\ln p_i) \quad \text{where} \quad p_i = \text{proportion of species i}$$

was calculated for total catches by station and total catch by sampling month. This index incorporates both components of species diversity, species richness and evenness.

In order to determine the relative importance of each species to the energy flow within the fish component of the bay ecosystem, an Index of Community Importance (I.C.I.) was calculated using the total catch for each species over the four years of the study. This index incorporates the three significant ecological variables (% Number, % Weight, and % Frequency of Occurrence by station over month) for each species as follows:

$$\text{I.C.I.} = (\%N + \%Wt) \times \%F$$

The structure of the fish assemblages was examined using cluster analysis (*Statistica*). Clustering was based on the log-transformed ($\log_{10}(x + 1)$), co-occurrences of the 35 most abundant species in samples summed over gear-type from each station over sampling month and utilized complete linkage and the correlation coefficient, *r,* as the index for distance.

For the current study, the *Best Estimate of Density* within each ecoregion was determined in the following manner: 1) Sample densities estimated by gear type for each species were averaged over all samples within the three depth strata (Intertidal, Nearshore, and Channel). 2) The *maximum* density for each species

Table 2. Estimates of areal coverage of depth strata within the four Ecoregions of San Diego Bay. Proportions and areas were used to weight density estimates and to estimate standing stocks of fishes.

	Intertidal	Nearshore	Channel	Total	% of bay
% AREA Ecoregion					
North	6	33	60		
North-central	5	38	57		
South-central	3	61	36		
South	4	84	13		
Hectares/Habitat Ecoregion					
North	61	327	593	982	20
North-central	41	307	460	808	17
South-central	51	1227	726	2005	41
South	41	890	133	1064	22
# Hectares	194	2751	1913	4858	
% Bay Area	4	57	39		

by gear type within the each depth stratum was determined to be the *Best Estimate of Density* for that species within that depth stratum. 3) The proportional areal coverage of the three depth strata within the ecoregion was determined using a grid on a scaled chart of San Diego Bay (Table 2). These areal proportions were then used to weight the *Best Estimates of Density* within the depth strata by species. A weighted average was then taken among these best estimates over the three depth strata for each species. 4) The sum of the weighted densities of all species then represented the *Best Estimate of Density* (numerical and biomass) for each depth stratum and the Ecoregion (station). 5) Standing stock estimates were then made by simply multiplying the best estimates by the total area of the individual ecoregions and San Diego Bay, as a whole.

Results

Physical and Chemical (PC) Factors

Over the five years of the study, temperature varied from a high of 27.3 °C at Station 4 in July 1997 to a low of 14.9 °C at Station 1 in January 1995 and 1997 (Figure 2). Predictably, the highest mean temperatures were also encountered in the summer of all five years (July 1994, 1995, 1996, 1997 and 1998) and the lowest in the winter (January 1995, 1996, 1997, 1998 and 1999). In January 1998, the mean temperature for the entire bay, while being low, was almost 1.5 degrees higher than the four other January sampling periods. Thermal stratification was evident during all sampling periods with temperatures becoming warmer (2–5 °C) north to south (Station 4 being the warmest) in the bay except in October 1994 when Station 1 had the highest mean temperature (Figure 2).

Surface salinity was relatively stable over the first two years of the study period varying about 6 ppt (39.8 to 33.4 ppt) over the entire year despite heavy rainfall in January of 1995 which had little impact on surface salinity. After July 1996 salinities increased to a peak in October 1996 followed by a dramatic drop-off in January 1997. During the fourth year (1997–98) salinities rose into the summer months then decreased to an overall low of less than 33 ppt in April 1998. Salinities were typically higher than 34 ppt, the average value for sea water. Mean salinities peaked in October of each year (1994, 1995, 1996 and 1997) when 35–

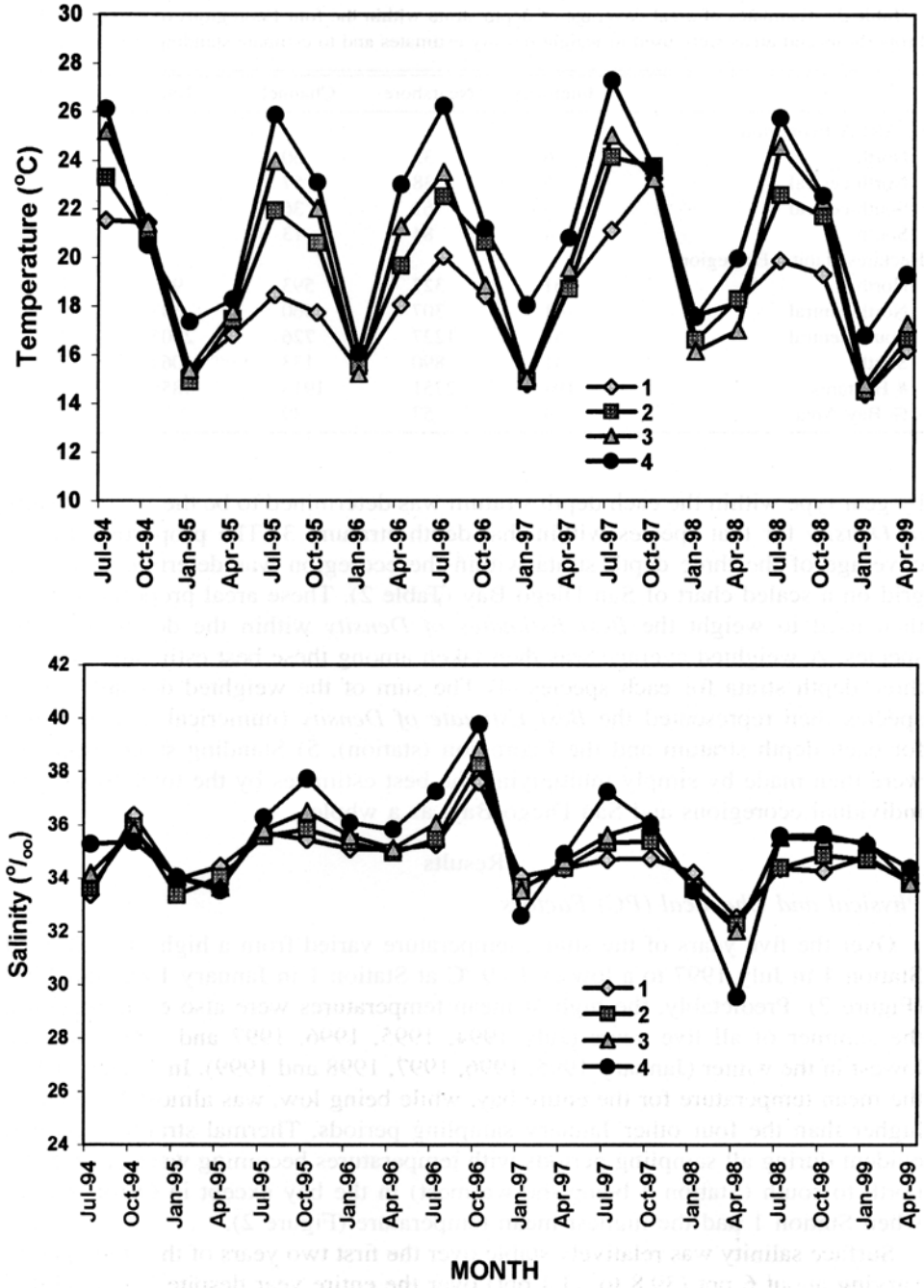

Fig. 2. Summary of Mean Surface Temperature (°C) and Salinity (‰) measurements by Station over the Sampling Months, July 1994 to April 1999.

37 ppt prevailed at all stations, but where particularly hypersaline in October 1996 at station 4 (39.8 ppt) (Figure 2). Salinities were generally lower than 34 ppt in January and April 1998. Overall, mean monthly salinities ranged from 31.6 ppt in April 1998 to 38.6 ppt in October 1996.

Mean surface pH readings were generally varying only from 7.5 in January 1995 to 8.2 in July 1994 while mean surface dissolved oxygen exhibited a range of 7.2 to 9.2 mgO_2/l in July 1995 and April, 1995, respectively. Unfortunately, problems with the calibration and the operation of the Hydrolab remote sensing unit have resulted in numerous unreliable readings for pH and dissolved oxygen. Therefore, it became necessary to exclude pH and D.O. from most analyses.

The eastern Pacific was subjected to a fairly intense El Niño-Southern Oscillation (ENSO) event in 1997–98. This event was clearly reflected in the temperature readings recorded during our sampling in San Diego Bay. Surface water temperature was significantly higher in July 1997 (two-way ANOVA, $F = 8.34$; $df = 3, 4$; $p < 0.01$) than in the four other July samples (1994, 1995, 1996, 1998). In addition, surface water temperature was significantly higher in January 1998 (two-way ANOVA, $F = 5.08$; $df = 3, 4$; $p < 0.05$) than in the other four January samples (1995, 1996, 1997, and 1999).

Surface water temperatures were also elevated at the beginning of the study in July 1994 which may have represented a lag effect of the 1992–93 El Nino event.

Abundance and Biomass

A total of 497,344 fishes belonging to 78 species and weighing 2,775 kg were captured in the 20 sampling dates from July 1994 to April 1998 in San Diego Bay (Table 3 and 4). Northern anchovy remained as the most abundant fish species comprising 43% of the total catch despite its virtual absence in 1997–98, followed by topsmelt at 23%, the slough anchovy at 19%, Pacific sardine at 3% and shiner surfperch at about 2% of the total catch (Table 3). Round stingrays dominated in weight constituting almost 25% of the total biomass taken followed by spotted sand bass at about 14%, northern anchovy at 9%, bat ray, 9%, topsmelt, 9%, and slough anchovy, 7% (Table 4).

The greatest number of individuals was taken at Station 1 (198,141) followed closely by Station 2 (188,147), then Station 3 (57,892), and Station 4 (53,164) (Figure 3). The high count at Station 1 and 2 compared to the other stations was primarily due to the large numbers of juvenile northern anchovy, Pacific sardine, and topsmelt taken at these stations in most years. This northern portion of the bay may represent a preferred nursery area for northern anchovy, Pacific sardine, and topsmelt within San Diego Bay.

The distributions of four of the numerically dominant, schooling species, northern anchovy, topsmelt, slough anchovy, and Pacific sardine showed an interesting pattern. The station abundances of the northern anchovy, topsmelt, and sardine appear to have a positive relationship with these three species dominating in north San Diego Bay. This pattern of abundance was the opposite of that found for the slough anchovy which was prominent in the southern portion of the bay (Figure 4).

The catch in terms of biomass also showed an interesting pattern across stations for all species (Figure 5). Large catches of round stingray and spotted sand bass were taken across all stations. Large catches of northern anchovies at Stations 1

Table 3. Total abundance of fish species taken from San Diego Bay over the five years of the study, July 1994 to April 1999 by station.

		STATIONS, 1994-1999					
SCIENTIFIC NAME	COMMON NAME	1	2	3	4	TOTAL	%
Engraulis mordax	northern anchovy	121,888	88,925	3,556	1,249	215,618	43.35
Atherinops affinis	topsmelt	44,055	51,041	12,791	7,693	115,580	23.24
Anchoa delicatissima	slough anchovy	4,315	25,526	31,874	35,106	96,821	19.47
Sardinops sagax	Pacific sardine	12,964	1,417	398	74	14,853	2.99
Cymatogaster aggregata	shiner surfperch	3,191	3,821	3,194	1,051	11,257	2.26
Atherinopsis californiensis	jacksmelt	399	7,290	664	395	8,748	1.76
Leuresthes tenuis	California grunion	4,225	767	600		5,592	1.12
Heterostichus rostratus	giant kelpfish	1,687	1,989	881	131	4,688	0.94
Urolophus halleri	round stingray	715	1,060	720	1,371	3,866	0.78
Syngnathus leptorhynchus	bay pipefish	701	1,394	1,040	292	3,427	0.69
Syngnathus auliscus	barred pipefish	390	777	598	917	2,682	0.54
Clevelandia ios	arrow goby	51	484	82	1,677	2,294	0.46
Paralabrax nebulifer	barred sand bass	311	954	342	240	1,847	0.37
Paralabrax maculatofasciatus	spotted sand bass	226	570	334	347	1,477	0.30
Ilypnus gilberti	cheekspot goby	580	582	70	190	1,422	0.29
Paralichthys californicus	California halibut	316	200	167	250	933	0.19
Quietula ycauda	shadow goby	40	193	84	325	642	0.13
Fundulus parvipinnis	California killifish		29	10	598	637	0.13
Mugil cephalus	striped mullet	8	1	1	510	520	0.10
Hyporhamphus rosae	California halfbeak	18	15	203	174	410	0.08
Anchoa compressa	deepbody anchovy	1	212	23	130	366	0.07
Paralabrax clathratus	kelp bass	268	24	4	2	298	0.06
Embiotoca jacksoni	black surfperch	272	8			280	0.06
Hypsoblennius gentilis	bay blenny	128	129	9	1	267	0.05
Hypsopsetta guttulata	diamond turbot	69	71	43	74	257	0.05
Micrometrus minimus	dwarf surfperch	244	3	2		249	0.05
Seriphus politus	queenfish	216	12			228	0.05
Xenistius californiensis	salema	76	116	24	2	218	0.04
Pleuronichthys ritteri	spotted turbot	120	84	5	8	217	0.04
Cheilotrema saturnum	black croaker	55	39	31	53	178	0.04
Albula vulpes	bonefish	10	115	4	46	175	0.04
Scomber japonicus	Pacific mackerel	11	97	20		128	0.03
Umbrina roncador	yellowfin croaker	42	4	37	27	110	0.02
Gibbonsia elegans	spotted kelpfish	56	35	3	4	98	0.02
Symphurus atricauda	California tonguefish	87	11			98	0.02
Porichthys myriaster	specklefin midshipman	27	5	10	37	79	0.02
Xystreurys liolepis	fantail sole	62	9		1	72	0.01
Synodus lucioceps	California lizardfish	56	4	2	7	69	0.01
Myliobatis californica	bat ray	27		2	28	57	0.01
Sphyraena argentea	California barracuda	14	43			57	0.01
Scorpaena guttata	California scorpionfish	37	8	1	1	47	0.01
Post-larval anchovy	Post-larval anchovy				45	45	0.01
Strongylura exilis	California needlefish	3	23	9	7	42	0.01
Syngnathus californiensis	kelp pipefish	18	8	14	2	42	0.01
Leptocottus armatus	staghorn sculpin	9	12	11	4	36	0.01
Acanthogobius flavimanus	yellowfin goby		2	7	25	34	0.01
Cynoscion parvipinnis	shortfin corvina	6	8	2	14	30	0.01
Syngnathus exilis	barcheek pipefish	2	7	8	8	25	0.01
Halichoeres semicinctus	rock wrasse	24				24	0.00
Oxyjulis californica	senorita	24				24	0.00
Gillichthys mirabilis	longjaw mudsucker				19	19	0.00
Trachurus symmetricus	jack mackerel	18				18	0.00
Cosmocampus arctus	snubnose pipefish	10	3		1	14	0.00
Genyonemus lineatus	white croaker	13				13	0.00
Hippocampus ingens	Pacific seahorse		7	4	2	13	0.00
Mustelus californicus	gray smoothhound	1	1	1	9	12	0.00
Post-larval goby	Post-larval goby	9				9	0.00
Anisotremus davidsoni	sargo	6		1		7	0.00
Atractoscion nobilis	white seabass	3	1		3	7	0.00
Rhinobatis productus	shovelnose guitarfish	4		2	1	7	0.00
Girella nigricans	opaleye	6				6	0.00
Mustelus henlei	brown smoothhound	5		1		6	0.00
Paraclinus integripinnis	reef finspot	1	3	2		6	0.00
Pleuronichthys coenosus	C0 turbot	6				6	0.00
Roncador stearnsii	spotfin croaker	1			5	6	0.00
Gymnura marmorata	California butterfly ray	2			2	4	0.00
Pleuronichthys verticalis	horneyhead turbot		4			4	0.00
Citharichthys stigmaeus	speckled sanddab	3				3	0.00
Dorosoma petenense	threadfin shad				3	3	0.00
Menticirrhus undulatus	California corbina		2		1	3	0.00
Porichthys notatus	plainfin midshipman	1			2	3	0.00
Phanerodon furcatus	white surfperch	2				2	0.00
Zapteryx exasperata	banded guitarfish	2				2	0.00
Gibbonsia metzi	striped kelpfish		1			1	0.00
Heterodontus francisi	California hornshark		1			1	0.00
Medialuna californica	halfmoon	1				1	0.00
Pseudupeneus grandisquamous	red goatfish	1				1	0.00
Pleuronectess vetulus	English sole	1				1	0.00
Rimicola muscarum	kelp clingfish	1				1	0.00
Tridentiger trigonocephalus	chameleon goby			1		1	0.00
TOTAL		198,141	188,147	57,892	53,164	497,344	
				Number of Species =		78	

Table 4. Total biomass (g) of fish species taken from San Diego Bay over the five years of the study, July 1994 to April 1999 by station.

SCIENTIFIC NAME	COMMON NAME	STATIONS, 1994-1999 1	2	3	4	TOTAL (g)	%
Urolophus halleri	round stingray	175,747	167,033	123,010	221,280	687,070	24.76
Paralabrax maculatofasciatus	spotted sand bass	65,634	152,308	87,005	77,259	382,206	13.77
Engraulis mordax	northern anchovy	138,927	115,387	2,486	1,498	258,297	9.31
Myliobatis californica	bat ray	175,731		17,500	61,336	254,568	9.17
Atherinops affinis	topsmelt	104,236	78,188	29,324	39,800	251,547	9.06
Anchoa delicatissima	slough anchovy	10,395	61,171	65,690	45,201	182,456	6.57
Paralabrax nebulifer	barred sand bass	27,180	35,350	13,494	46,907	122,931	4.43
Paralichthys californicus	California halibut	38,017	22,443	21,142	30,770	112,373	4.05
Cymatogaster aggregata	shiner surfperch	26,821	28,134	17,525	3,653	75,933	2.74
Sardinops sagax	Pacific sardine	46,650	5,547	7,560	4,711	64,467	2.32
Atherinopsis californiensis	jacksmelt	24,109	4,210	2,231	13,875	44,424	1.60
Heterostichus rostratus	giant kelpfish	14,273	13,589	8,407	1,034	37,303	1.34
Hypsopsetta guttulata	diamond turbot	13,600	12,198	4,681	6,228	36,707	1.32
Leuresthes tenuis	California grunion	15,245	10,801	10,007		36,053	1.30
Cheilotrema saturnum	black croaker	5,533	4,520	4,202	8,500	22,756	0.82
Rhinobatis productus	shovelnose guitarfish	10,150		6,595	3,757	20,502	0.74
Scomber japonicus	Pacific mackerel	4,128	11,405	3,647		19,180	0.69
Umbrina roncador	yellowfin croaker	5,684	499	5,793	4,492	16,469	0.59
Pleuronichthys ritteri	spotted turbot	7,829	7,843	154	121	15,948	0.57
Embiotoca jacksoni	black surfperch	13,858	344			14,202	0.51
Cynoscion parvipinnis	shortfin corvina	4,679	4,981	1,476	801	11,937	0.43
Gymnura marmorata	California butterfly ray	7,727			2,714	10,441	0.38
Xystreurys liolepis	fantail sole	4,674	4,175		188	9,036	0.33
Scorpaena guttata	California scorpionfish	6,400	1,161	151	182	7,893	0.28
Seriphus politus	queenfish	6,222	169			6,392	0.23
Mustelus californicus	gray smoothhound	336	968	950	3,793	6,047	0.22
Mustelus henlei	brown smoothhound	4,536		813		5,349	0.19
Porichthys myriaster	specklefin midshipman	2,040	384	1,394	926	4,744	0.17
Trachurus symmetricus	jack mackerel	4,095				4,095	0.15
Strongylura exilis	California needlefish	483	1,771	363	1,137	3,753	0.14
Micrometrus minimus	dwarf surfperch	2,971	38	28		3,037	0.11
Paralabrax clathratus	kelp bass	2,309	496	29	83	2,917	0.11
Xenistius californiensis	salema	44	2,508	260	27	2,840	0.10
Sphyraena argentea	California barracuda	2,009	821			2,830	0.10
Menticirrhus undulatus	California corbina		2,600		150	2,750	0.10
Anchoa compressa	deepbody anchovy	2	592	454	1,479	2,527	0.09
Heterodontus francisi	California hornshark		2,420			2,420	0.09
Symphurus atricauda	California tonguefish	1,976	379			2,354	0.08
Hypsoblennius gentilis	bay blenny	911	1,210	205	3	2,329	0.08
Syngnathus leptorhynchus	bay pipefish	512	650	1,042	101	2,304	0.08
Mugil cephalus	striped mullet	2	0	0	2,270	2,272	0.08
Albula vulpes	bonefish	133	744	42	880	1,799	0.06
Girella nigricans	opaleye	1,796				1,796	0.06
Atractoscion nobilis	white seabass	909	250		568	1,727	0.06
Synodus lucioceps	California lizardfish	1,473	54	45	73	1,645	0.06
Syngnathus auliscus	barred pipefish	313	406	378	519	1,615	0.06
Fundulus parvipinnis	California killifish		111	25	1,318	1,454	0.05
Roncador stearnsii	spotfin croaker	102			1,163	1,265	0.05
Zapteryx exasperata	banded guitarfish	1,067				1,067	0.04
Hyporhamphus rosae	California halfbeak	51	29	676	303	1,059	0.04
Pleuronichthys coenosus	CO turbot	867				867	0.03
Acanthogobius flavimanus	yellowfin goby		22	388	420	830	0.03
Halichoeres semicinctus	rock wrasse	743				743	0.03
Oxyjulis californica	senorita	667				667	0.02
Genyonemus lineatus	white croaker	610				610	0.02
Phanerodon furcatus	white surfperch	605				605	0.02
Anisotremus davidsoni	sargo	18		579		597	0.02
Pleuronichthys verticalis	hornyhead turbot		597			597	0.02
Hippocampus ingens	Pacific seahorse		267	129	91	487	0.02
Leptocottus armatus	staghorn sculpin	119	119	123	60	420	0.02
Gibbonsia elegans	spotted kelpfish	165	150	28	9	352	0.01
Quietula ycauda	shadow goby	18	30	117	103	268	0.01
Ilypnus gilberti	cheekspot goby	115	37	7	71	231	0.01
Clevelandia ios	arrow goby	8	26	6	187	227	0.01
Dorosoma petenense	threadfin shad				224	224	0.01
Syngnathus californiensis	kelp pipefish	86	38	15	3	142	0.01
Pseudupeneus grandisquamous	red goatfish	100				100	0.00
Porichthys notatus	plainfin midshipman	9			61	69	0.00
Gillichthys mirabilis	longjaw mudsucker				51	51	0.00
Citharichthys stigmaeus	speckled sanddab	37				37	0.00
Cosmocampus arctus	snubnose pipefish	2	29		0	31	0.00
Post-larval goby	Post-larval goby	30				30	0.00
Syngnathus exilis	barcheek pipefish	5	7	8	7	27	0.00
Pleuronectes vetulus	English sole	5				5	0.00
Paraclinus integripinnis	reef finspot	1	1	3		5	0.00
Tridentiger trigonocephalus	chameleon goby			4		4	0.00
Post-larval anchovy	Post-larval anchovy				1	1	0.00
Gibbonsia metzi	striped kelpfish		0			0	0.00
Medialuna californica	halfmoon	0				0	0.00
Rimicola muscarum	kelp clingfish	0				0	0.00
TOTAL		985,530	759,210	440,185	590,386	2,775,311	

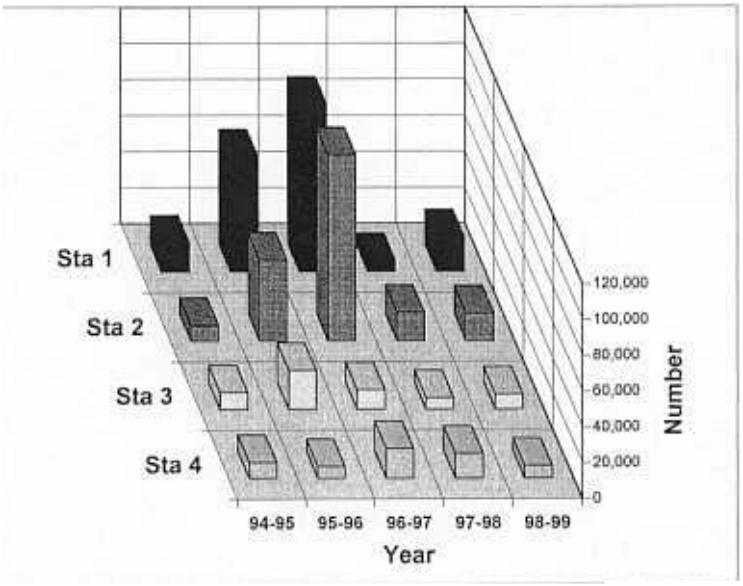

Fig. 3. Abundance of San Diego Bay Fishes by Station, 1994–1999.

and 2, in addition to those of stingrays and spotted sand bass yielded much higher biomass catches in the northern part of the bay.

Abundance by Bay Ecoregion

North (Station 1).—A total of 198,141 fishes belonging to 68 species and weighing 985.5 kg were captured in the North Ecoregion over the 20 sampling

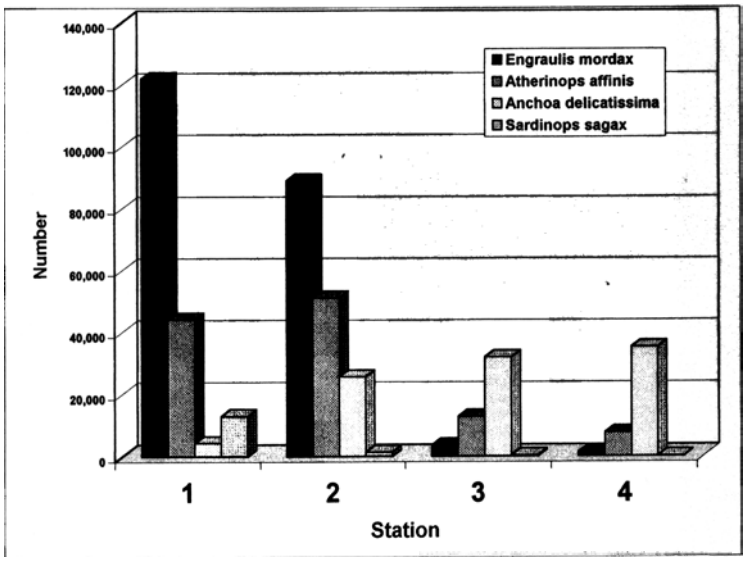

Fig. 4. Abundance of the four numerically dominate species by station in San Diego Bay, July 1994 to April 1999.

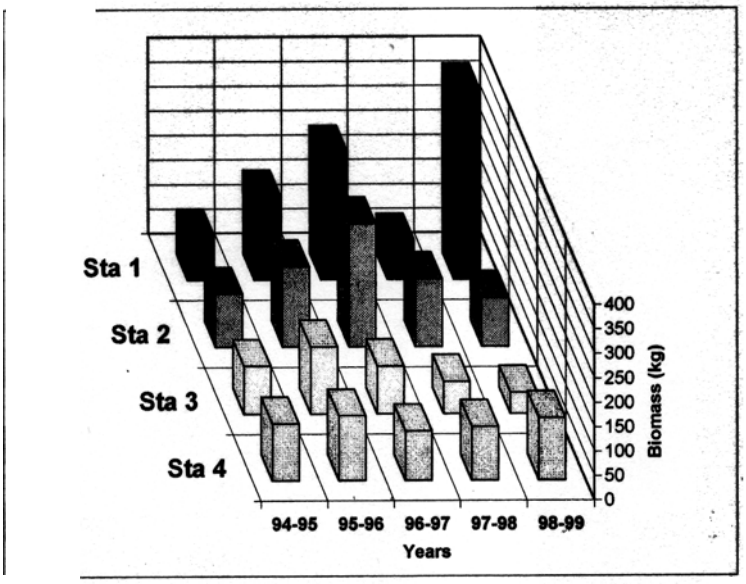

Fig. 5. Biomass (kg) of San Diego Bay Fishes by Station, 1994–1999.

dates from July 1994 to April 1999 (Table 3 and 4). Northern anchovy was the most abundant fish species comprising 62% of the total catch, followed by topsmelt at 22%, Pacific sardine at 5%, slough anchovy, 2%, California grunion (*Leuresthes tenuis*), 2% and shiner surfperch at about 2% of the total catch. Round stingrays led in total biomass at 18% followed closely by bat rays also at 18%, northern anchovy at 14%, topsmelt, 11%, spotted sand bass, 7%, and California halibut, 4%.

North-Central (Station 2).—A total of 188,147 fishes belonging to 55 species and weighing 759.2 kg were captured in the North-Central Ecoregion over the 20 sampling dates from July 1994 to April 1999 (Table 3 and 4). Northern anchovy remained the most abundant fish species comprising nearly 47% of the total catch, followed by topsmelt at 27%, slough anchovy at 14%, jacksmelt at 4%, shiner surfperch at about 2%, and giant kelpfish at approximately 1% of the total catch. Round stingrays constituted the largest portion of total biomass at 22%, followed closely by spotted sand bass, 20%, northern anchovy, 15%, topsmelt, 10%, and slough anchovy at almost 8% (Figure 6).

South-Central (Station 3).—A total of 57,892 fishes belonging to 49 species and weighing 440.2 kg were captured in the South-Central Ecoregion over the 20 sampling dates from July 1994 to April 1999 (Table 3 and 4). Slough anchovy was the most abundant fish species comprising 55% of the total catch, followed by topsmelt at 22%, northern anchovy at 6%, shiner surfperch at about 6%, and bay pipefish at approximately 2% of the total catch. Round stingrays ranked first in total biomass at 28% followed closely by spotted sand bass at 20%, slough anchovy, 15%, topsmelt, 7%, and California halibut, 5%.

South (Station 4).—A total of 53,164 fishes belonging to 51 species and weighing 590.4 kg were captured in the South Ecoregion over the 20 sampling dates from July 1994 to April 1999 (Table 3 and 4). As with station 3, slough anchovy

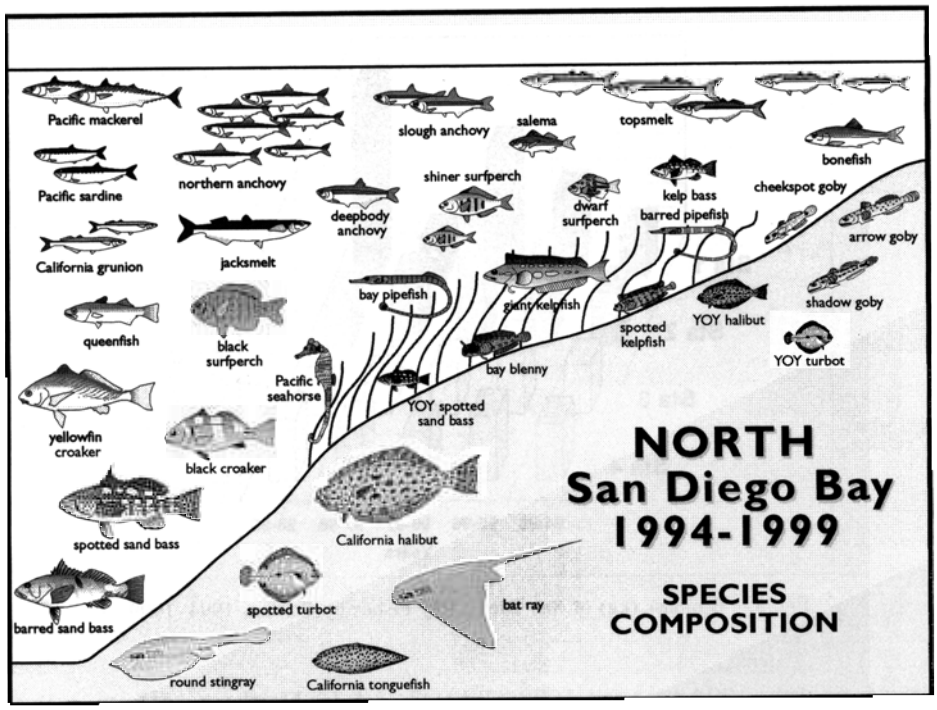

Fig. 6. Diagrammatic representation of the common and distinctive species of fish which occurred in the northern portion (North and North Central Ecoregions) of San Diego Bay during the study period of July 1994 to April 1999.

was, again, the most abundant fish species comprising over 66% of the total catch, followed by topsmelt at 14%, arrow goby at 3%, round stingray at also at 3%, and shiner surfperch at 2% of the total catch. Once again, round stingrays led in total biomass at nearly 37% of the total biomass followed by spotted sand bass at 13%, bat ray at 10%, and barred sand bass at 8% (Figure 7).

South San Diego Bay provides critical habitat for at least 12 fish species (Table 5) which are indigenous to bay and estuarine environments in the Southern California Bight (Allen, 1985).

Seasonal Abundance

Marked changes in the number individuals and total biomass occurred seasonally over the course of the study. When all four stations are considered together, numerical abundance was generally highest in the spring (April 1995, 1996, 1997, 1998, and 1999) and summer (July 1995, 1996, and 1998) months (Figure 8). Heavy recruitment of juvenile surfperches and topsmelt in April of 1995 and 1996 was largely responsible for those abundance peaks (Table 6). Large numbers of topsmelt, slough anchovy, shiner surfperch and California grunion were responsible for relatively high catches in April 1997, while the April 1998 catches were dominated by slough anchovies. Very large catches of juvenile northern anchovy and Pacific sardine caused the pronounced peaks in July 1995 and 1996. Interestingly, July 1997 catches were low due to the virtual absence of northern anchovies. The catch in July 1998 was dominated by slough anchovy, northern

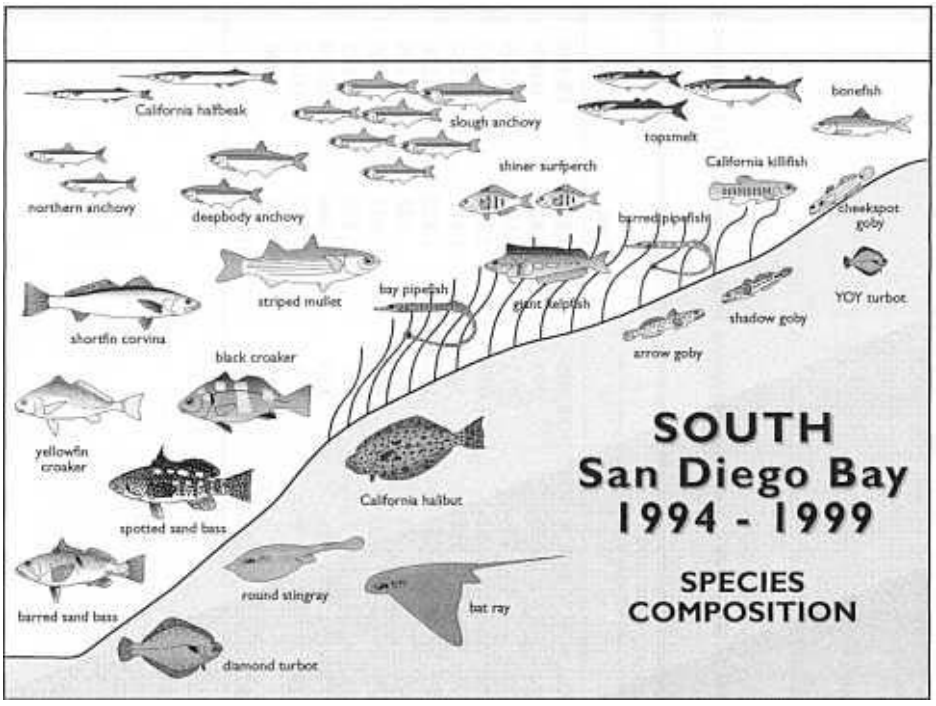

Fig. 7. Diagrammatic representation of the common and distinctive species of fish which occurred in the southern portion (South Central and South Ecoregions) of San Diego Bay during the study period of July 1994 to April 1999.

anchovy, and topsmelt. Lowest abundances were generally encountered in the coldest months of the study (January 1995, 1996, 1997, and 1999) with the January 1998 sample containing about 3X the number of fishes as the previous January samples due to a large recruitment of jacksmelt. This abundance pattern was consistent among Stations 1, 2, and 3. However, the southern-most station, 4, exhibited peak abundance in October 1994, October 1996, and April 1998 (Figure 8).

Biomass varied greatly from quarter to quarter and was largely related to the abundance of northern anchovy, round stingrays, bat rays, and spotted sand bass in the catch (Table 7). In the first four years of the study, weights of the catches consistently peaked in the spring (April 1995, 1996, 1997 and 1998) and the summer (July 1995 and 1996) except for July 1997(Figure 9). Significant catches of bat rays in October 1998 (Station 1) and January 1999 (Station 4) greatly disrupted this earlier pattern (Figure 9).

The general seasonal patterns of abundance and distribution of fishes in the northern and southern portions of San Diego Bay are depicted in Figures 10 and 11.

Nursery Area Function

Approximately 70% of all individual fish captured in San Diego Bay during this study were juveniles. In fact, 28 of the 35 most abundant species were represented by over 50% juveniles (Table 8). Of these, ten species were represented by more than 90% juveniles including the most abundant species, northern an-

Table 5. Indigenous Bay/Estuarine species captured in San Diego Bay from July 1994 to April 1999. Note the increasing total abundance of 11 of these 12 species from north to south in the bay.

Scientific name	Common name	Stations, 1994–1999				Total	%
		1	2	3	4		
Anchoa delicatissima	slough anchovy	4,315	25,526	31,874	35,106	96,821	19.468
Syngnathus leptorhynchus	bay pipefish	701	1,394	1,040	292	3,427	0.689
Syngnathus auliscus	barred pipefish	390	777	598	917	2,682	0.539
Clevelandia ios	arrow goby	51	484	82	1,677	2,294	0.461
Paralabrax maculatofasciatus	spotted sand bass	226	570	334	347	1,477	0.297
Ilypnus gilberti	cheekspot goby	580	582	70	190	1,422	0.286
Quietula ycauda	shadow goby	40	193	84	325	642	0.129
Fundulus parvipinnis	California killifish		29	10	598	637	0.128
Mugil cephalus	striped mullet	8	1	1	510	520	0.105
Anchoa compressa	deepbody anchovy	1	212	23	130	366	0.074
Hypsoblennius gentilis	bay blenny	128	129	9	1	267	0.054
Gillichthys mirabilis	longjaw mudsucker				19	19	0.004
	TOTAL	6,440	29,897	34,125	40,112	110,574	

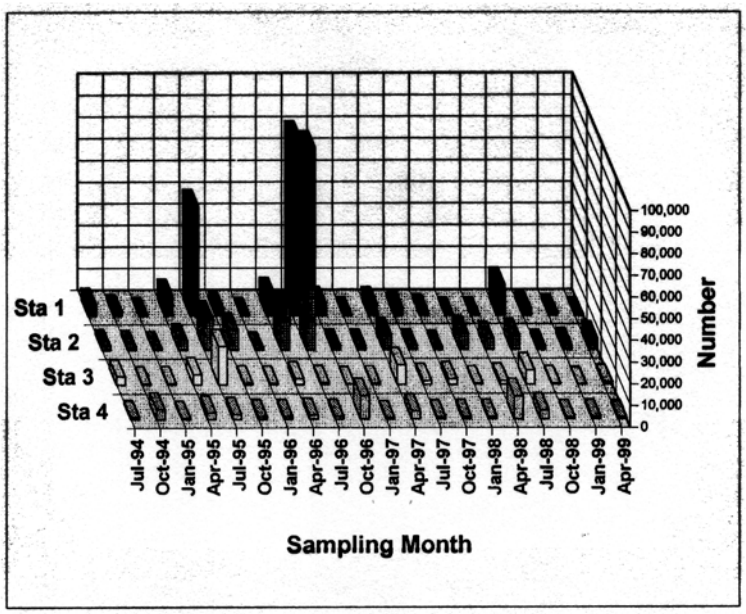

Fig. 8. Abundance of San Diego Bay Fishes by Station over Sampling Months, 1994–1999.

chovy (100% juveniles). This high proportion of juveniles overall in the catch underscores the importance of the San Diego Bay system as an important nursery area for a large number of fish species.

Species Importance

The Index of Community Importance (Table 9) incorporates three significant ecological variables (% Number, %Weight, and %Frequency) for each species and yields a value that is indicative of the importance of each species to the energy flow within the fish component of the bay ecosystem. When all three factors are taken into account, topsmelt rank first among all San Diego Bay fish species with an I.C.I. of 3230. Round stingrays ranked second with an I.C.I. of 2553 followed by northern anchovy with 2271(only 45% frequency within stations by sampling month), slough anchovy with 1790, and spotted sand bass with 1354.

Species Diversity

Species richness (number of species) was generally highest in the northern section of the bay nearest the bay mouth (Station 1–2) being highest at station 1 (Figure 12). H′ diversity which incorporates evenness of relative species abundances was found to be highest in the southern portion of the bay (Station 3–4) peaking at about H′ = 1.5. The higher H′ values in the south bay reflect the lower numerical dominance by one or two species at these stations. Northern anchovy was the numerically dominant species overall at Station 1 in the North Bay while slough anchovy dominated Station 4 in the South Bay.

In the first three years of this study (July 1994 to April 1997), species richness consistently peaked between 40 and 50 species in the spring-summer months (April and July) (Figure 12). This pattern was disrupted in April and July 1997

Table 6. Total abundance of fish species taken from San Diego Bay over the five years of the study, July 1994 to April 1999 by quarterly sampling period.

	MONTHS, 1994-1999																					
COMMON NAME	Jul-94	Oct-94	Jan-95	Apr-95	Jul-95	Oct-95	Jan-96	Apr-96	Jul-96	Oct-96	Jan-97	Apr-97	Jul-97	Oct-97	Jan-98	Apr-98	Jul-98	Oct-98	Jan-99	Apr-99	TOTAL	%
northern anchovy	1,697	1		9	52,380	5,461	2	12	147,161		61	3				7	8,366	27	2	429	215,618	43.4
topsmelt	5,043	2,369	1,006	13,045	12,227	4,883	2,300	27,918	5,997	2,177	2,780	10,064	2,853	1,333	547	1,996	7,236	2,129	3,775	5,902	115,580	23.2
slough anchovy	1,813	4,245	159	1,652	15,169	2,530		1,408	15,208	10,250	62	8,879	2,150	4,340	58	14,944	12,846	817	203	88	96,821	19.5
Pacific sardine	1	84	9		2,300	359	2		5,391	3,641		19	566	64	130	11	773	1,357	145	1	14,853	3.0
shiner surfperch	31	44	13	3,305	693	180	5	2,672	550	287	7	2,540	254	23	1	213	123	115	8	193	11,257	2.3
jacksmelt		2	532	2		4	9	1	2	18	160	3	9	4	7,903	15		4	80		8,748	1.8
California grunion									739	404		1,969	1,167			6	1,117	190			5,592	1.1
giant kelpfish	322	395	23	697	605	332	94	868	536	186	41	227	150	33	2	2	69	15	2	89	4,688	0.9
round stingray	89	155	123	481	82	77	121	164	151	414	117	237	241	162	88	72	50	480	379	183	3,866	0.8
bay pipefish	225	255	189	219	131	287	495	248	135	295	183	224	131	18	33	8	69	23	97	162	3,427	0.7
barred pipefish	550	112	100	506	482	134	22	79	117	197	45	83	29	8	10	2	54	2	64	86	2,682	0.5
arrow goby	306	115	23	161	240	145	16	100	239	18	28	2	93	33	280	12	61	19	16	387	2,294	0.5
barred sand bass	81	187	55	386	317	124	25	56	42	19	11	132	97	101	17	26	33	28	44	66	1,847	0.4
spotted sand bass	23	50	57	100	73	43	74	59	77	94	77	77	89	147	68	131	69	88	56	25	1,477	0.3
cheekspot goby	950	62	43	47	5		33		27	2	2	65	40	5	59	12	15	25	20	10	1,422	0.3
California halibut	159	25	29	45	52	24	44	29	46	52	60	45	29	22	44	29	25	33	72	69	933	0.2
shadow goby	1	31	62	9	1	17	13	30	4	58	13	97	6	2	116	27	42	9	60	44	642	0.1
California killifish	5	11	94	21	5	8	13	1	86	17	65		60	24			123	43	58	3	637	0.1
striped mullet		1	9	1		2		1							273	231	1	1			520	0.1
California halfbeak	13	39	1	1		5	61	8	9	49	3	15	24	25			3	149	5		410	0.1
deepbody anchovy	7		22	12	57	10		219	2			29				1	4			3	366	0.1
kelp bass	1	192	4	8	4	3	1	1	8	10	7	5	20	15			1	13	5		298	0.1
black surfperch	4	19		34	97	22		16	30	47		8	1	1			1				280	0.1
bay blenny	26	21	2	15	19	8	4	9	13	41	5	34	10	41	2	1	11	4		1	267	0.1
diamond turbot	33	4	17	26	18	9	3	7	16	16	11	8	20	15	6	15	4	5	12	12	257	0.1
dwarf surfperch	52	14	2	53	49		2	2	12	42				21							249	0.1
queenfish				6	10	42			157							4	5	4			228	0.0
salema		79		8	7	1				25		6	82	10							218	0.0
spotted turbot	13	6	3	9	11	6	13	11	7	4	23	24	13	9	13	1	6	5	21	19	217	0.0
black croaker	3	9	3	21	10	16		6	16	2	1	11	42	5	6	20	1	4		2	178	0.0
bonefish					1										2	115	15	36	5	1	175	0.0
Pacific mackerel				19	5				64	1			37	1	1						128	0.0
yellowfin croaker	9	4	1	2	6	3		16				2	2	11		5	6	38	4	1	110	0.0
spotted kelpfish	52			8	17	2			16				2						1		98	0.0
California tonguefish	12	3		5	2		3	1	18	2	4	10	1	13	5	8	1	3	2	5	98	0.0
specklefin midshipman	9			1	3	1			27		1	9	9	7	1	1	3	4	2	1	79	0.0
fantail sole	9	1	1	5	2	1	2	2	3	1		1		33	1	1	1		6	2	72	0.0
California lizardfish	8		2	17	10			1	15		1	7			1	2	2	2	1		69	0.0
bat ray	1			3	4			5	1								1	27	15		57	0.0
California barracuda	2	1											1	51		1		1			57	0.0
40 additional spp/taxa	97	41	21	39	95	12	8	14	30	7	7	20	7	30	3	9	29	27	16	17	529	0.1
TOTAL	**11,647**	**8,577**	**2,605**	**20,978**	**85,189**	**14,751**	**3,365**	**33,964**	**176,952**	**18,376**	**3,775**	**24,855**	**8,235**	**6,607**	**9,670**	**17,928**	**31,166**	**5,727**	**5,176**	**7,801**	**497,344**	

Table 7. Total biomass (g) of fish species taken from San Diego Bay over the five years of the study, July 1994 to April 1999 by quarterly sampling period.

	MONTHS, 1994-1999																					
COMMON NAME	Jul-94	Oct-94	Jan-95	Apr-95	Jul-95	Oct-95	Jan-96	Apr-96	Jul-96	Oct-96	Jan-97	Apr-97	Jul-97	Oct-97	Jan-98	Apr-98	Jul-98	Oct-98	Jan-99	Apr-99	TOTAL	%
round stingray	12,381	30,696	31,286	61,684	17,442	15,403	31,497	31,268	32,279	33,250	34,497	40,221	36,964	28,559	18,874	11,895	13,962	107,036	67,849	29,985	687,070	24.8
spotted sand bass	7,775	16,747	20,801	34,148	25,781	11,273	25,851	14,555	15,194	25,807	20,252	16,163	17,347	21,454	21,073	27,270	14,930	20,556	17,894	7,335	382,206	13.8
northern anchovy	882	5		7	49,694	18,688	1	20	178,879		2	8				1	9,471	32	13	597	258,297	9.3
bat ray	4,333			13,000	3,902			36,750	484								450	173,398	22,250		254,568	9.2
topsmelt	7,977	16,520	5,897	4,293	18,574	27,166	13,467	8,012	12,486	9,567	13,532	36,868	7,509	9,025	6,225	9,686	10,787	8,142	20,455	5,359	251,547	9.1
slough anchovy	1,552	2,531	139	6,314	39,389	4,750		3,215	26,894	8,146	90	16,476	2,833	2,681	69	40,052	25,989	973	214	153	182,456	6.6
barred sand bass	2,851	4,650	535	15,774	22,494	7,748	1,928	35,562	4,600	2,453	754	2,409	8,157	4,629	267	2,773	1,914	1,779	372	1,282	122,931	4.4
California halibut	23,469	7,463	4,408	3,832	9,932	2,396	10,467	4,645	4,584	4,959	5,347	3,792	1,938	962	8,508	4,928	1,184	1,357	4,339	3,843	112,373	4.0
shiner surfperch	188	544	371	15,863	5,247	2,335	42	22,838	3,958	1,640	221	16,371	1,566	153	40	1,179	687	1,964	187	541	75,933	2.7
Pacific sardine	1	362	75		5,467	2,919	19		18,644	11,783		198	1,837	6,523	9,021	883	1,549	4,248	922	17	64,467	2.3
jacksmelt		365	3,500	1		328	830	113	635	2,850	5,666	312	279	647	20,595	1,096		777	6,429		44,424	1.6
giant kelpfish	2,315	7,168	208	1,898	5,357	5,685	2,564	1,649	5,238	2,940	143	517	793	319	1	0	272	186	0	51	37,303	1.3
diamond turbot	3,009	612	1,622	2,400	2,458	1,781	666	2,483	2,739	1,784	1,246	1,482	2,715	3,002	1,096	1,607	114	1,047	2,675	2,170	36,707	1.3
California grunion									885	1,162		29,380	1,925			101	2,123	480			36,053	1.3
black croaker	133	1,266	20	1,948	2,164	3,094		1,510	1,289	18	242	1,543	1,892	692	1,300	4,264	13	894		475	22,756	0.8
shovelnose guitarfish					4,598							1,997			3,757			10,150			20,502	0.7
Pacific mackerel				3,147	726				8,848	51			5,740	168	500						19,180	0.7
yellowfin croaker	486	258	514	64	877	239		1,500				242	91	2,202		2,358	635	4,952	1,650	400	16,469	0.6
spotted turbot	733	408	36	546	1,482	969	1,064	1,626	938	393	1,331	1,613	847	494	657	20	465	397	1,023	907	15,948	0.6
black surfperch	79	1,091		963	5,155	2,024		460	676	2,891		731	28	91			14				14,202	0.5
shortfin corvina								750	1,089			726	2	440		4,540	3,500	91	800		11,937	0.4
California butterfly ray																1,114	7,500	227	1,600		10,441	0.4
fantail sole	1,622	198	336	729	30	500	393	514	1,331	363		363		320	180	480	160		1,048	470	9,036	0.3
spotted scorpionfish	3,102	352	334	416	908	500		484	30	242	182	363				500		22	459		7,893	0.3
queenfish				137	354	71			5,392							342	25	71			6,392	0.2
grey smoothhound	272	227						968			242			336		1,500	115		737	1,650	6,047	0.2
brown smoothhound								813										4,536			5,349	0.2
specklefin midshipman	78			9	485	63			637		15	1,341	1,185	114	15	40	484	53	1	225	4,744	0.2
jack mackerel									4,095												4,095	0.1
California needlefish	1	1	109	26		133	393	605	182			516	325	474		33	163	501	250	42	3,753	0.1
dwarf surfperch	201	133	22	265	1,716		34	37	84	379				166							3,037	0.1
kelp bass	15	881	65	70	650	79	3	17	228	64	69	80	317	125			100	19	136		2,917	0.1
salema		52		56	111	8				9		182	2,419	4							2,840	0.1
California barracuda	1	1											20	958		150		1,700			2,830	0.1
California corbina																1,100	1,500			150	2,750	0.1
deepbody anchovy	89		349	210	1,044	62		643	4			29				14	67			15	2,527	0.1
California hornshark									2,420												2,420	0.1
California tonguefish	308	47		172	121		91	30	695	30	212	182	20	196	98	9	5	10	43	85	2,354	0.1
bay blenny	304	215	3	87	355	46	3	22	225	195	35	158	235	259	0	1	170	14		2	2,329	0.1
bay pipefish	254	138	683	60	82	151	153	98	131	147	47	83	84	11	9	4	33	39	37	59	2,304	0.1
40 additional spp/taxa	1,613	1,474	455	2,787	3,161	1,660	1,092	1,050	2,077	908	397	474	204	750	848	153	2,069	1,473	1,044	236	23,926	0.9
TOTAL	**76,023**	**94,405**	**71,769**	**170,905**	**229,755**	**110,071**	**90,557**	**172,237**	**337,869**	**112,032**	**84,522**	**174,817**	**97,290**	**85,773**	**93,134**	**118,092**	**100,467**	**347,120**	**152,425**	**56,048**	**2,775,311**	

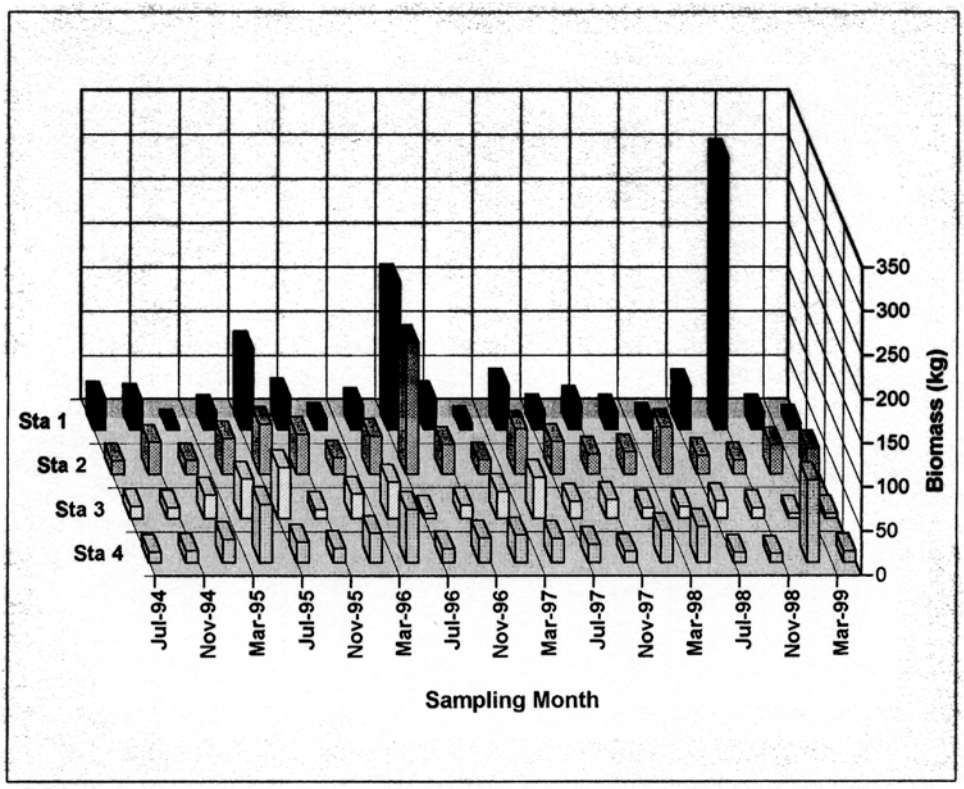

Fig. 9. Biomass (kg) of San Diego Bay Fishes by Station over Sampling Months, 1994–1999.

when only 37 and 35 total species were captured. Within the last two sampling years the April and July catches included only 24 to 37 species. In 1997–1999, the highest number of species was actually taken in October 1997. H′ diversity followed a pattern which was typically the inverse of species richness in the first three years. H′ was typically highest in October and January reflecting the higher evenness of species abundances during these months. The generally lower H′ values in April and July were due to the numerical dominance a few species in these months. Again, this pattern changed starting in 1997 when April and, especially July had relatively high H′ values. The relatively low recruitment of shiner surfperch in April 1997 and the lack of the usual occurrence of large numbers of northern anchovies in July 1997 were primarily responsible for this change. H′ values rose again in July and October 1998 indicating a partial return to the pattern observed in the first three years of the study.

Fish Assemblage Structure

Fish assemblage structure was examined using cluster analysis. The clustering strategy was based on co-occurrences of the species ranking in the top 35 in numerical abundance or in the top 20 in biomass and yielded 11 distinct species and eight site groupings (Figure 13). The species groups reflected the varying abundances and distributions of these species in space and time (Figure 14). Spe-

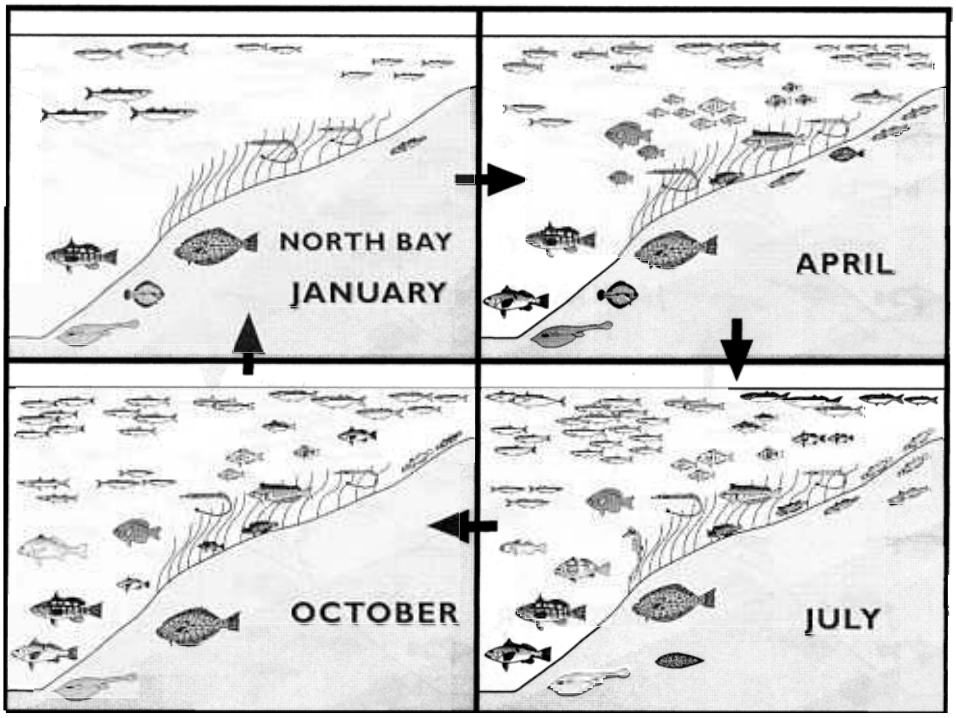

Fig. 10. Diagrammatic representation of the general, seasonal occurrence of the common species of fish occuring in the northern portion (North and North Central) of San Diego Bay during the study period of July 1994 to April 1999.

cies groups which occurred in both the intertidal and nearshore depth strata are characterized as "inshore" below.

Species Group I.—This group contained three species of inshore, wide-spread, resident and summer-seasonal, schooling (midwater) fishes. Topsmelt, California grunion, Pacific sardine, were numerically dominant species, particularly, in the north-central bay during the spring-summer months when large numbers of their young-of-the-year (YOY) occurred. Topsmelt represented the truly resident member of this group which was abundant at all stations in the bay with YOY occurring in highest abundance in spring samples (April). All members of this group also occurred in lower abundance in the midwater regions of the channels.

Species Group II.—This group of three, inshore, summer-seasonal, eelgrass-associated fishes occurred only in the north and north-central portion of the bay. These included the surfperch species, the black surfperch (*Embiotoca jacksoni*), dwarf surfperch (*Micrometrus minimus*), and spotted kelpfish (*Gibbonsia elegans*). Most of the individuals of these species were YOY.

Species Group III.—This small group included two, inshore, north bay, resident, spring-recruiting fishes. YOY of the flatfish, California halibut (*Paralichthys californicus*) inhabited the intertidal areas along with all age groups of the cheekspot goby (*Ilypnus gilberti*).

Species Group IV.—This group of inshore, resident & summer-seasonal, eelgrass-associated fishes included the YOY of kelp bass (*Paralabrax clathratus*),

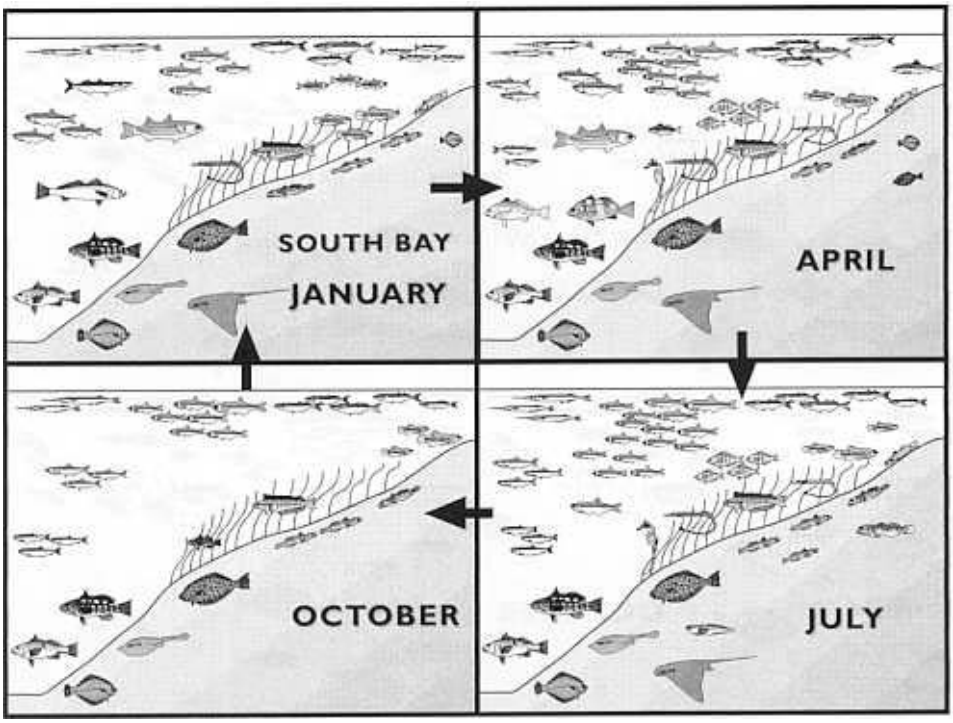

Fig. 11. Diagrammatic representation of the general, seasonal occurrence of the common species of fish occuring in the southern portion (South Central and South Ecoregions) of San Diego Bay during the study period of July 1994 to April 1999.

salema (*Xenistius californiensis*), spotted sand bass (*Paralabrax maculatofasciatus*), and bay blenny (*Hypsoblennius gentilis*). All of these species used the eelgrass beds of the north bay as nursery areas.

Species Group V.—This group included four, inshore, resident, eelgrass-associated fishes which occurred throughout the bay with the greatest abundance in the north, north-central, and south-central portions. Species included the shiner surfperch (*Cymatogaster aggregata*) and the cryptically-colored fishes, the giant kelpfish (*Heterostichus rostratus*), barred pipefish (*Syngnathus auliscus*), and bay pipefish (*Syngnathus leptorhynchus*).

Species Group VI.—This is a group of five, inshore, primarily south bay, resident schooling and benthic species. The numerically dominant, resident fish in the south-central and south bay, the slough anchovy (*Anchoa delicatissima*), clustered in this group along and California halfbeak (*Hyporhamphus rosae*), the deepbody anchovy (*Anchoa compressa*), the California killifish (*Fundulus parvipinnis*) and arrow goby (*Clevelandia ios*).

Species Group VII.—This group included five taxa of inshore, south bay, resident, species which recruited in the winter months and remained abundant into the spring of some years. Included in this group were bonefish (*Albula vulpes*) along with striped mullet (*Mugil cephalus*), jacksmelt (*Atherinopsis californiensis*), shadow goby (*Quietula ycauda*), and YOY of diamond turbot (*Hypsopsetta guttulata*).

Species Group VIII.—A group of three, nearshore and channel, summer-sea-

Table 8. Estimated percent of juveniles in the catch of the top 35 species of fish from San Diego Bay, July 1994–April 1999.

Scientific name	Common name	% juv
Engraulis mordax	northern anchovy	100
Gibbonsia elegans	spotted kelpfish	100
Heterostichus rostratus	giant kelpfish	100
Paralabrax clathratus	kelp bass	100
Paralichthys californicus	California halibut	99
Albula vulpes	bonefish	99
Paralabrax nebulifer	barred sand bass	97
Sardinops sagax	Pacific sardine	96
Mugil cephalus	striped mullet	95
Xenistius californiensis	salema	94
Clevelandia ios	arrow goby	79
Syngnathus auliscus	barred pipefish	78
Syngnathus leptorhynchus	bay pipefish	76
Atherinops affinis	topsmelt	73
Seriphus politus	queenfish	73
Fundulus parvipinnis	California killifish	72
Quietula ycauda	shadow goby	71
Atherinopsis californiensis	jacksmelt	69
Porichthys myriaster	specklefin midshipman	67
Ilypnus gilberti	cheekspot goby	67
Embiotoca jacksoni	black surfperch	66
Leuresthes tenuis	California grunion	66
Umbrina roncador	yellowfin croaker	66
Micrometrus minimus	dwarf surfperch	63
Xystreurys liolepis	fantail sole	61
Urolophus halleri	round stingray	53
Cymatogaster aggregata	shiner surfperch	51
Anchoa delicatissima	slough anchovy	43
Hypsoblennius gentilis	bay blenny	37
Cheilotrema saturnum	black croaker	36
Pleuronichthys ritteri	spotted turbot	35
Anchoa compressa	deepbody anchovy	23
Paralabrax maculatofasciatus	spotted sand bass	22
Hypsopsetta guttulata	diamond turbot	18
	Average % juveniles	69

sonal, schooling fishes, which primarily occurred in the north bay. The most abundant, seasonal species in the study, the northern anchovy (*Engraulis mordax*), clustered in this group along with the highly summer-seasonal species, Pacific mackerel (*Scomber japonicus*) and queenfish (*Seriphus politus*).

Species Group IX.—Clustering designated this group of large, predatory, benthic species which were resident in the nearshore areas and channels of all sections of the bay. This group was represented by the larger size classes of the the spotted sand bass (*Paralabrax maculatofasciatus*) and barred sand bass (*Paralabrax nebulifer*), and all size classes of round stingray (*Urolophus halleri*) and black croaker (*Cheilotrema saturnum*).

Species Group X.—This group was made up of three large carnivores which occupied the nearshore and channel areas in low to moderate numbers throughout the bay, but were most often captured in the south bay. The group included

Table 9. Percent number (%N), percent biomass (%WT), percent frequency of occurrence (%FREQ), and Index of Community Importance (I.C.I.) for the top 50 species (ranked by I.C.I.) of fishes from San Diego Bay, July 1994–April 1999.

RANK	Common Name	%N	%WT	%FREQ	I.C.I.
1	topsmelt	23.24	9.06	100.00	3230.3
2	round stingray	0.78	24.76	100.00	2553.4
3	northern anchovy	43.35	9.31	45.00	2369.7
4	slough anchovy	19.47	6.57	68.75	1790.4
5	spotted sand bass	0.30	13.77	96.25	1354.1
6	barred sand bass	0.37	4.43	96.25	462.1
7	California halibut	0.19	4.05	100.00	423.7
8	shiner surfperch	2.26	2.74	72.50	362.5
9	Pacific sardine	2.99	2.32	40.00	212.4
10	giant kelpfish	0.94	1.34	75.00	171.5
11	bat ray	0.01	9.17	13.75	126.3
12	jacksmelt	1.76	1.60	36.25	121.8
13	diamond turbot	0.05	1.32	86.25	118.5
14	bay pipefish	0.69	0.08	91.25	70.5
15	barred pipefish	0.54	0.06	85.00	50.8
16	California grunion	1.12	1.30	20.00	48.5
17	black croaker	0.04	0.82	52.50	44.9
18	spotted turbot	0.04	0.57	55.00	34.0
19	arrow goby	0.46	0.01	67.50	31.7
20	yellowfin croaker	0.02	0.59	31.25	19.2
21	cheekspot goby	0.29	0.01	61.25	18.0
22	black surfperch	0.06	0.51	21.25	12.1
23	fantail sole	0.01	0.33	27.50	9.4
24	Pacific mackerel	0.03	0.69	11.25	8.1
25	shadow goby	0.13	0.01	53.75	7.5
26	California scorpionfish	0.01	0.28	22.50	6.6
27	specklefin midshipman	0.02	0.17	35.00	6.5
28	California halfbeak	0.08	0.04	53.75	6.5
29	California killifish	0.13	0.05	33.75	6.1
30	bay blenny	0.05	0.08	43.75	6.0
31	shortfin corvina	0.01	0.43	13.75	6.0
32	kelp bass	0.06	0.11	36.25	6.0
33	California needlefish	0.01	0.14	28.75	4.1
34	deepbody anchovy	0.07	0.09	23.75	3.9
35	shovelnose guitarfish	0.00	0.74	5.00	3.7
36	California tonguefish	0.02	0.08	28.75	3.0
37	queenfish	0.05	0.23	10.00	2.8
38	gray smoothhound	0.00	0.22	12.50	2.8
39	striped mullet	0.10	0.08	13.75	2.6
40	salema	0.04	0.10	17.50	2.6
41	dwarf surfperch	0.05	0.11	15.00	2.4
42	California butterfly ray	0.00	0.38	5.00	1.9
43	California lizardfish	0.01	0.06	21.25	1.6
44	bonefish	0.04	0.06	15.00	1.5
45	California barracuda	0.01	0.10	8.75	1.0
46	yellowfin goby	0.01	0.03	20.00	0.7
47	spotted kelpfish	0.02	0.01	17.50	0.6
48	Pacific seahorse	0.00	0.02	27.50	0.6
49	brown smoothhound	0.00	0.19	2.50	0.5
50	staghorn sculpin	0.01	0.02	20.00	0.4

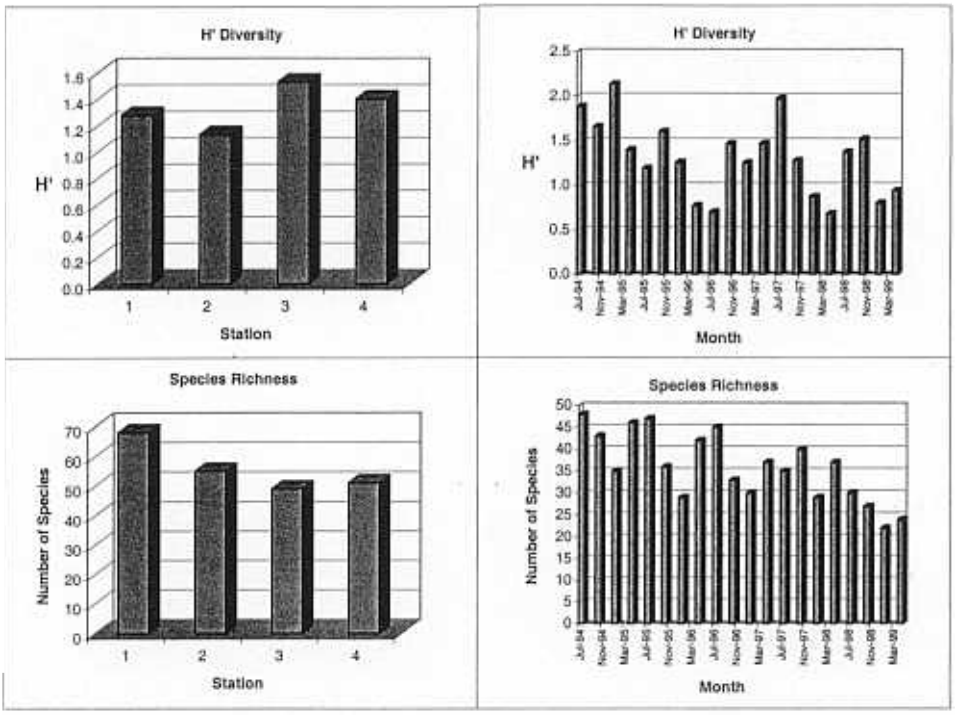

Fig. 12. Number of species (species richness) and Shannon-Weiner Diversity (H') of fishes in San Diego Bay by station and sampling month, July 1994–April 1999.

resident (Shortfin corvina, *Cynoscion parvipinnis* and bat rays, *Myliobatis californicus*) and summer seasonal (yellowfin croaker, *Umbrina roncador*) species.

Species Group XI.—This group included four species of resident, benthic, flatfish species which occurred throughout the bay primarily in the channels. Included in this group were the larger juveniles and adults of California halibut (*Paralichthys californicus*) and diamond turbot (*Hypsopsetta guttulata*) which were distributed in all depth strata. The remaining two species (spotted turbot (*Pleuronichthys ritteri*) and California tonguefish (*Symphurus atricauda*)) mainly occupied the channels of the north bay.

Relationship of PC factors to Fish Distribution and Abundance

Canonical correlation was utilized to estimate the relationship of the four prominent PC factors of station (as a surrogate for distance from the mouth of the bay), depth, temperature, and salinity to the individual station abundances ($\log_{10}(x + 1)$) of the 35 most abundant species. These four PC factors accounted for nearly 88% ($R^2 = 0.875$) of the variance in individual species abundance among stations over sampling month (Table 10). This extremely high R^2 value served to underscore the great influence which relatively few environmental factors can have on the distribution and abundance of fishes over time.

As a result of this highly significant relationship, the eleven species groups determined through cluster analysis discriminated very well among the first three, significant discriminate roots (Figure 15).

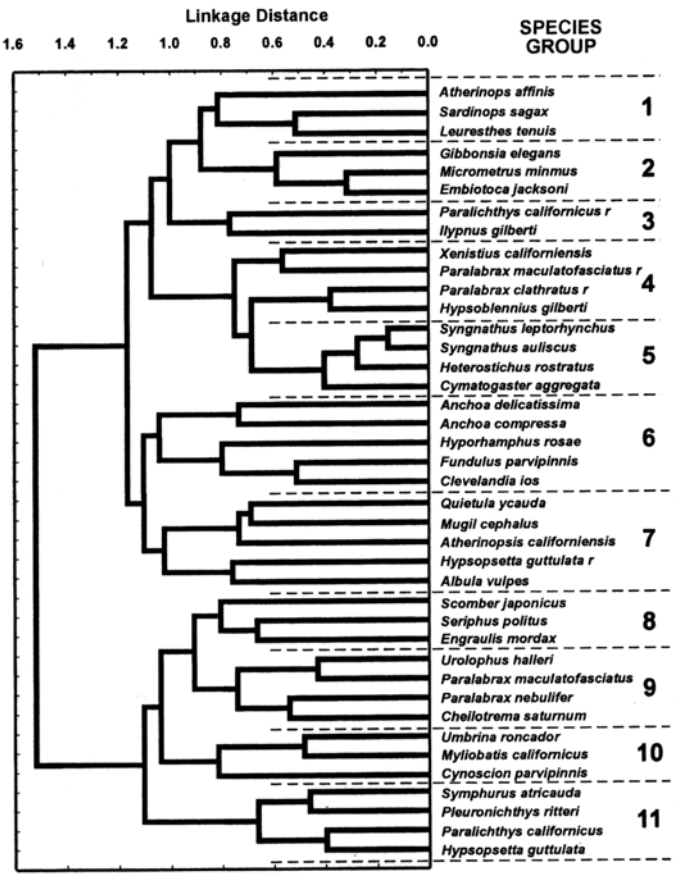

Fig. 13. Results of the cluster analysis of the top 40 fish species or recruits based on co-occurrences in station/ depth strata samplescollected from July 1994 to April 1999 in San Diego Bay (r = new recruits of the species).

Standing Stock Estimates

All Fish Species.—Over the entire bay for all five years, the total best estimate of numerical density was 1.75 indiv./m^2 (Table 11). Based on a surface area of approximately 4858 ha, San Diego Bay, on average, contained almost 85 million fish during this time. Most of the individuals are made up of northern anchovies (42 million), but there were also, again on average, almost 18 million slough anchovies, 10 million topsmelt, 3 million sardines, 3 million arrow gobies, and nearly 2 million shiner surfperch. Among the most common, higher-level carnivores, there are about 280,000 round stingrays, 169,000 spotted sand bass, 133,000, barred sand bass, and almost 80,000 California halibut.

The total best estimate of biomass density was 7.05 g/m^2 (Table 12). Again, based on area, during 1994–1999, San Diego Bay, on average, contained about 340 metric tons (mt) of fish. On a yearly basis most of the biomass was made up of northern anchovies (52 mt), spotted sand bass (50 mt), round stingrays (49 mt), topsmelt (37 mt), and slough anchovy (36 mt).

The best estimate process yielded an overall biomass density (7.05 g/m^2) which

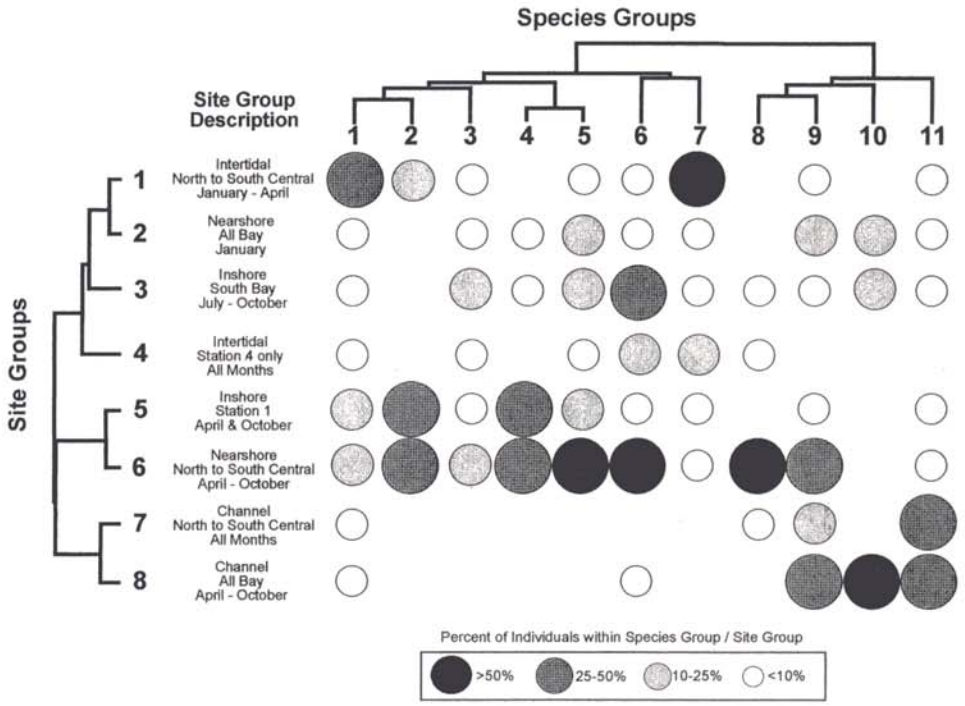

Fig. 14. Two-way table depicting the relative abundances of species within site groups derived by cluster analysis. Circles represent abundances of the individuals within the species of a species group at each of the eight site groups. Site groups are described according to there distribution in space over time.

Table 10. Results of canonical correlation analysis for four PC factors (Station, Depth, Temperature, Salinity) versus log-abundance of the 35 most abundant individual species taken in each quarterly sampling from San Diego Bay, July 1994–April 1999.

Chi-square tests with successive roots removed					
Root removed	Canonical R	Canonical R-sqr.	Chi-sqr.	df	p
0	0.935	0.875	923.474	160	<0.0001
1	0.835	0.698	473.408	117	<0.0001
2	0.642	0.412	214.440	76	<0.0001
3	0.607	0.368	99.480	37	<0.0001

Canonical weights, physical-chemical factors			
	Root 1	Root 2	Root 3
STA	0.106	0.952	−0.037
DEPTH	−0.992	0.184	0.071
TEMP	−0.032	0.097	0.664
SAL	0.053	0.040	−1.053

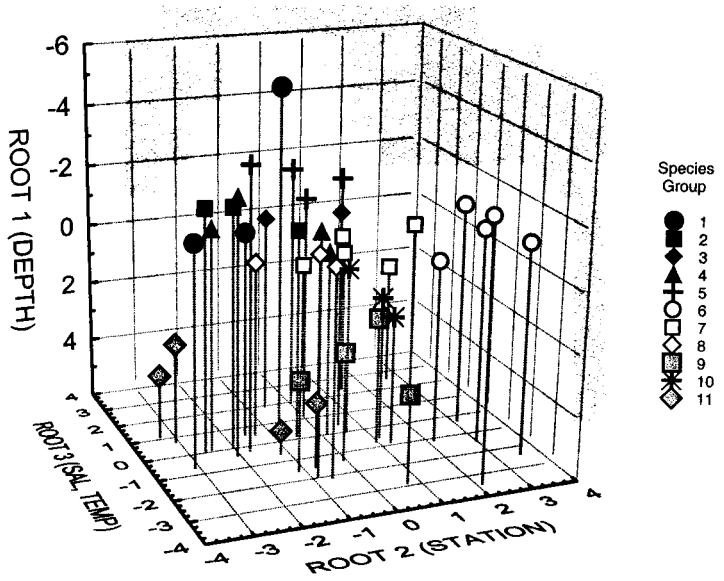

Fig. 15. Three-dimensional plot of species within species groups by three significant discriminant roots.

was over three times higher than that (2.03 g/m^2) derived from taking the simple mean of individual gear densities. This discrepancy is due to the artificial bias introduced when catches from gears with dramatically different efficiencies are simply averaged quantitatively with no regard to quality of the estimate.

Forage Species.—Forage species are defined herein as those which are accessible to diving avian predators, particularly terns. Forage species are typically silvery-sided, schooling fishes which spend a lot of their time near the surface of the water overall depth strata. Of all the species captured during this study, eleven qualified as significant forage. These species were northern anchovy, topsmelt, slough anchovy, jack smelt, Pacific sardine, shiner surfperch, Pacific mackerel, California grunion, deepbody anchovy, California halfbeaks, and striped mullet (juveniles).

Over all Ecoregions for all five years, these eleven forage species averaged 3.15 (±1.28) g/m^2. Based on surface area, San Diego Bay contained, on average about 139 metric tons (mt) of these important forage species. The standing stock ranged from a low of about 22 mt in the South Ecoregion to a high of 43 mt in the North Ecoregion (Table 13).

In the North Ecoregion, northern anchovy ranked first among the forage species in contributing an average of nearly 14 mt over the study period followed by topsmelt (10.1 mt), Pacific sardine (7.9 mt), and jacksmelt (4.9 mt). The standing stock of the North-Central region was dominated, again, by northern anchovy (13.0 mt), followed by slough anchovy (8.5 mt) and topsmelt (6.3 mt). Slough anchovy (22.6 mt), topsmelt (5.5 mt), and shiner surfperch (5.2 mt) made up the bulk of the forage in the South-Central Ecoregion while slough anchovy (10.2 mt), topsmelt (5.4 mt) and jack smelt (3.3 mt) dominated the South Ecoregion.

Based on a conservative, hypothetical, ecological efficiency of 1%, overall, San Diego Bay has the potential to support about 1.4 mt of terns.

Table 11. Best estimate of numerical densities (No./m^2) and estimated stock size for the most abundant fish species taken from San Diego Bay, as a whole, from July 1994 to April 1999.

COMMON NAME	BEST ESTIMATE OF DENSITY (No/m^2) STRATA I	N	C	WTD MEAN	STOCK Est. No.
northern anchovy	0.014	1.434	0.148	0.876	42,533,776
slough anchovy	0.067	0.566	0.109	0.368	17,868,784
topsmelt	1.750	0.212	0.049	0.210	10,201,738
Pacific sardine	0.002	0.074	0.058	0.065	3,148,496
arrow goby	1.414	0.005	0.000	0.059	2,876,938
shiner surfperch	0.003	0.067	0.000	0.039	1,873,634
California grunion	0.005	0.035	0.002	0.021	1,006,501
shadow goby	0.485	0.002	0.000	0.020	992,253
bay pipefish	0.033	0.021	0.000	0.013	651,421
giant kelpfish	0.004	0.023	0.000	0.013	648,728
jacksmelt	0.266	0.003	0.002	0.013	624,777
cheekspot goby	0.254	0.004	0.000	0.013	609,349
barred pipefish	0.034	0.016	0.000	0.011	513,060
round stingray	0.001	0.007	0.004	0.006	277,119
spotted sand bass	0.000	0.006	0.001	0.003	169,452
barred sand bass	0.000	0.004	0.002	0.003	133,803
California halibut	0.015	0.001	0.001	0.002	78,725
deepbody anchovy	0.000	0.002	0.000	0.001	63,451
bay blenny	0.006	0.002	0.000	0.001	58,865
kelp bass	0.000	0.002	0.000	0.001	47,300
queenfish	0.000	0.001	0.001	0.001	45,933
California killifish	0.017	0.000	0.000	0.001	32,785
salema	0.000	0.001	0.000	0.001	32,514
black surfperch	0.000	0.001	0.000	0.001	26,967
Pacific mackerel	0.000	0.001	0.000	0.001	26,116
diamond turbot	0.006	0.000	0.000	0.000	24,004
California halfbeak	0.003	0.000	0.000	0.000	21,394
dwarf surfperch	0.001	0.001	0.000	0.000	20,286
bonefish	0.002	0.000	0.000	0.000	11,196
California barracuda	0.000	0.000	0.000	0.000	10,828
black croaker	0.000	0.000	0.000	0.000	10,220
striped mullet	0.004	0.000	0.000	0.000	9,221
47 additional species	0.009	0.003	0.001	0.003	127,138
TOTAL	**4.396**	**2.494**	**0.378**	**1.745**	**84,776,769**

Fisheries Species.—Eight species of fish were captured that can be characterized as fisheries species important to the recreational and/or commercial (RC) catch in southern California waters. Ranked according to mean biomass density, these species were northern anchovy, spotted sand bass, Pacific sardine, California halibut, barred sand bass, Pacific mackerel, shortfin corvina, and yellowfin croaker.

Over all Ecoregions for all five years, these eight, RC species averaged 2.40 ($\pm$1.14) g/m^2. Based on a surface area of approximately 4858 ha, San Diego Bay contains, on average about 104 metric tons (mt) of these important RC species. The standing stock of RC species ranged from a low of about 15 mt in the South Ecoregion to a high of 31 mt in the North Ecoregion (Table 13).

In the North Ecoregion, northern anchovy ranked first among the RC species in contributing an average of nearly 14 mt over the study period followed by

Table 12. Best estimates of biomass densities (g/m^2) and estimated stock size for the most abundant fish species taken from San Diego Bay, as a whole, from July 1994 to April 1999.

COMMON NAME	BEST ESTIMATE OF DENSITY (g/m^2) STRATA I	N	C	WTD MEAN	STOCK Est. No.	STOCK metric tons
northern anchovy	0.010	1.628	0.356	1.067	51,836,937	51.8
spotted sand bass	0.007	1.638	0.253	1.033	50,180,537	50.2
round stingray	0.051	1.284	0.714	1.012	49,181,019	49.2
topsmelt	0.675	1.054	0.330	0.756	36,745,334	36.7
slough anchovy	0.073	0.984	0.475	0.749	36,385,765	36.4
bat ray	0.000	0.540	0.303	0.426	20,680,619	20.7
Pacific sardine	0.009	0.294	0.301	0.286	13,878,325	13.9
shiner surfperch	0.043	0.481	0.001	0.276	13,424,822	13.4
shovelnose guitarfish	0.000	0.423	0.029	0.252	12,262,405	12.3
jacksmelt	0.006	0.200	0.216	0.198	9,623,670	9.6
California grunion	0.059	0.208	0.003	0.122	5,944,893	5.9
California halibut	0.031	0.093	0.159	0.117	5,660,609	5.7
barred sand bass	0.006	0.075	0.181	0.113	5,511,344	5.5
giant kelpfish	0.034	0.180	0.004	0.106	5,132,391	5.1
Pacific mackerel	0.000	0.112	0.044	0.081	3,931,394	3.9
shortfin corvina	0.000	0.058	0.051	0.053	2,569,953	2.6
black surfperch	0.003	0.074	0.001	0.043	2,082,049	2.1
yellowfin croaker	0.001	0.055	0.014	0.037	1,779,889	1.8
diamond turbot	0.083	0.014	0.057	0.033	1,610,660	1.6
queenfish	0.000	0.041	0.002	0.024	1,186,484	1.2
black croaker	0.000	0.019	0.034	0.024	1,167,441	1.2
grey smoothhound	0.003	0.023	0.013	0.018	898,173	0.9
jack mackerel	0.000	0.029	0.000	0.016	798,093	0.8
California butterfly ray	0.000	0.019	0.013	0.016	781,311	0.8
California needlefish	0.003	0.020	0.008	0.015	708,700	0.7
California barracuda	0.000	0.008	0.024	0.014	673,435	0.7
spotted turbot	0.000	0.005	0.026	0.013	628,138	0.6
salema	0.000	0.020	0.000	0.011	548,458	0.5
Calfornia corbina	0.000	0.019	0.000	0.011	535,960	0.5
deepbody anchovy	0.001	0.017	0.000	0.010	464,102	0.5
bay blenny	0.013	0.014	0.000	0.008	409,919	0.4
striped mullet	0.004	0.011	0.004	0.008	384,765	0.4
46 additional species	0.265	0.110	0.067	0.099	4,819,018	4.8
TOTAL	**1.380**	**9.749**	**3.684**	**7.049**	**342,426,611**	**342.4**

Pacific sardine (7.9 mt), and spotted sand bass (4.3 mt). The standing stock of the North-Central region was dominated, again, by northern anchovy (13.0 mt), followed by spotted sand bass (11.4 mt) and barred sand bass (1.3 mt). Spotted sand bass (19.4 mt), Pacific sardine (2.8 mt), and California halibut (2 mt) made up the bulk of the fisheries standing stock in the South-Central Ecoregion while spotted sand bass (19.4 mt), Pacific sardine (2.8 mt) and yellowfin croaker (0.8 mt) dominated the South Ecoregion.

Southern Species Unique to San Diego Bay

During the study period eight fish species were taken that can be described as southern or "Panamic Province" species including California halfbeaks (*Hyporhamphus rosae*), bonefish (*Albula vulpes*), California needlefish (*Strongylura exilis*), shortfin corvina (*Cynoscion parvipinnis*), Pacific seahorse (*Hippocampus in-*

Table 13. Best estimates of biomass densities and standing stocks for forage species only and fisheries species only. Estimates are for each depth strata within each Ecoregion of the San Diego Bay.

FORAGE FISH SPECIES

	BEST ESTIMATE OF DENSITY (g/m^2) STRATA					
ECOREGION	I	N	C	WTD MEAN	STAND. STOCK (kg)	mt
NORTH	0.8976	8.5278	2.4428	4.3337	42,557	43
NORTH-CENTRAL	1.0586	6.4966	2.9132	4.1821	33,792	34
SOUTH-CENTRAL	0.8767	2.5911	1.2028	2.0399	40,899	41
SOUTH	0.7618	2.3416	0.3697	2.0454	21,763	22
			TOTAL		139,011	139

RECREATIONAL/COMMERCIAL FISH SPECIES

	BEST ESTIMATE OF DENSITY (g/m^2) STRATA					
ECOREGION	I	N	C	WTD MEAN	STAND. STOCK (kg)	mt
NORTH	0.08256	5.98068	2.01888	3.18991	31,325	31
NORTH-CENTRAL	0.08203	6.47010	1.98423	3.59375	29,038	29
SOUTH-CENTRAL	0.08484	1.85872	0.90180	1.46101	29,293	29
SOUTH	0.01123	1.52618	0.68564	1.37157	14,594	15
			TOTAL		104,249	104

gens), California butterfly ray (*Gymnura marmorata*), banded guitarfish (*Zapteryx exasperata*), and red goatfish (*Pseudupeneus grandisquamous*). In addition, four more southern species (green jack, *Caranx caballus;* middling thread herring, *Opisthonema medirastre;* Pacific sierra, *Scomberomorus sierra;* scalloped hammerhead, *Sphyrna lewini*) were collected by gill nets in the Ocean Resource Enhancement and Hatchery Program (OREHP) sampling program conducted by Mike Shane of Hubbs-Sea World Research Institute in the same general time period. All of these species are commonly encountered further south in the Eastern Subtropical and Tropical Pacific. Southern California is listed as the extreme northern end point of the geographical ranges of each of these species. In fact, the occurrence of the single specimen of the red goatfish represented the first record of this species recorded in California waters. The southern portion of San Diego Bay undoubtedly acts as a refuge for these warm water species. Three of these, the California halfbeak, California needlefish and Pacific seahorse were encountered throughout the study period (Figure 16) while the remaining five occurred in greatest abundance during and just after the El Niño evident of 1997–98. Bonefish recruited heavily into the southern sections of the bay beginning in January 1998 and peaked April 1998. Bonefish leptocephalus larvae were captured in the intertidal zones in January and April 1998. These leptocephali metamorphosed into juveniles which were abundant in July and October of the same year.

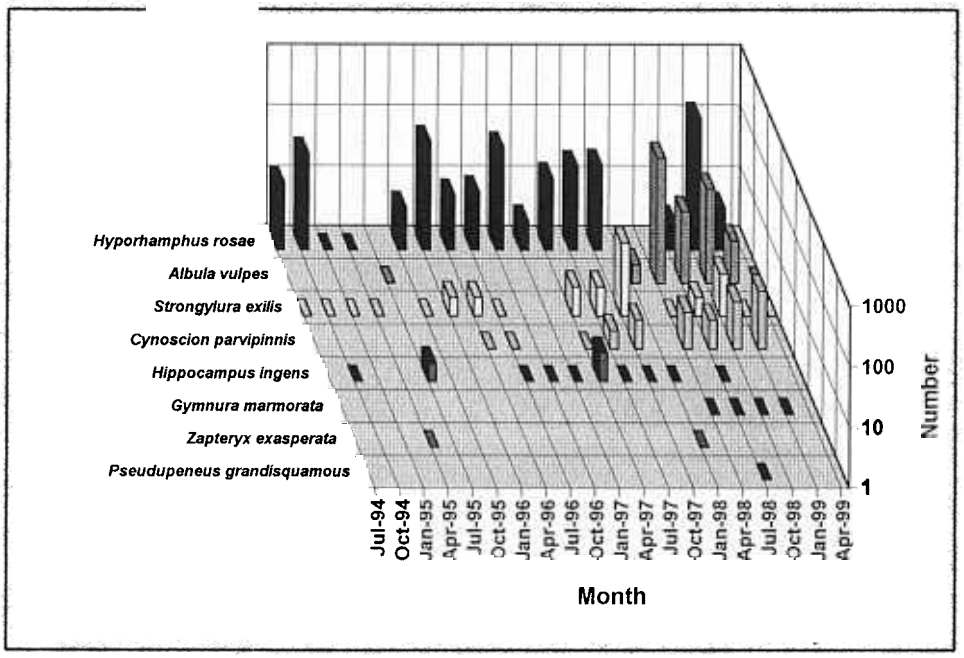

Fig. 16. Abundance of "Panamic Province" or southern species captures in San Diego Bay from July 1994 to April 1999.

Effects of 1997–98 El Nino

The greatest, detectable impact of the 1997–98 El Niño event on the fish assemblages of San Diego Bay was the generally low abundance of schooling, planktivorous species, including northern anchovy, topsmelt, slough anchovy, sardine, and shiner surfperch (the five most abundant species). In fact, the northern anchovy was virtually absent during 1997. Of the most abundant schooling fishes, topsmelt and slough anchovy seemed to be least affected by the El Niño event. Overall, the abundance of these planktivorous species was significantly and negatively correlated ($\log(n + 1)$, $r = -0.86$, $df = 4$, $p < 0.05$) with summer-fall (July–October) surface water temperature over the entire 1994–1999 sampling period.

The quantitative impact of the El Niño on the total number of fishes in San Diego Bay can be approximated using the regression model:

$$N = 7232.12T - 113072;$$

where N = predicted number and T = mean surface temperature. This equation was based on the relationship between abundance of planktivorous species and surface water temperature for the non- El Niño years of the study. Based on this equation, the total catch of all species in San Diego Bay was 50,000 to 55,000 individuals lower in July and October 1997 than would be predicted for a "normal" temperature year.

Another important effect that can probably be attributed to the ENSO event was the recruitment and/or occurrence of the southern species mentioned previouslv.

Discussion

A total of 78 species of fish were captured in the five years of sampling in San Diego Bay. This total approaches the 89 species predicted from the species-area relationship developed by Horn and Allen (1976). A number of relatively rare, large, and mobile species were undoubtedly missed by this quantitative sampling protocol. The aforementioned OREHP gill net survey (June 1996 through August 1999) yielded eight additional species which were not taken in the current sampling program. The addition of these species (green jack, *Caranx caballus;* pile surfperch, *Damalichthys vacca;* middling thread herring, *Opisthonema medirastre;* white surfperch, *Phanerodon furcatus;* Pacific sierra, *Scomberomorus sierra;* scalloped hammerhead, *Sphyrna lewini;* angel shark, *Squatina californica;* leopard shark, *Triakis semifasciata*) brings the total up to 86 species, even closer to the predicted number of 89 species.

Two, introduced species of Japanese gobies were also captured during the study. The yellowfin goby (*Acanthogobius flavimanus*) was well represented in the samples (n = 34) while a single specimen of the chameleon goby (*Tridentiger trigonocephalus*) was captured in the eelgrass bed in the South-Central Ecoregion (Station 3).

Species richness by station in San Diego Bay was comparable, if not higher than values obtained from other southern California bays, estuaries, and harbors. The northern San Diego Bay stations 1 and 2 (No. spp = 69 and 55) had similar species richness to multiple-gear sampling studies in Los Angeles Harbor and Lower Newport Bay. Allen et al. (1983) captured 65 fish species in the Cabrillo Beach area of western Los Angeles Harbor in 1979. Marine Ecological Consultants (1988) reported 69 fish species in the area covering most of outer Los Angeles Harbor in 1986–87. Allen (1976) sampled a total of 65 species from Newport Bay in 1974–75 in a sampling strategy that included stations from throughout the upper and lower bay.

The southern San Diego Bay stations yielded slightly higher species richness (Station 3, 49 species; Station 4, 52 species) than comparable studies in two other bay/ estuaries in southern California, Mugu Lagoon and upper Newport Bay. Onuf and Quammen (1983) caught a total of only 28 fish species from the small, shallow embayment of Mugu Lagoon. Horn and Allen (1981) reported 46 species captured in a comparable, multiple-gear sampling design in Upper Newport Bay in 1978. Furthermore, Allen (1988) reported 41 species from upper Newport Bay in 1986–87.

Total Shannon-Weiner diversity (H′) for the San Diego Bay stations in 1994–99 ranged from values of 2.05 to 2.32. These H′ values were intermediate to the somewhat lower values reported from upper Newport Bay (1.71 from 1978; 1.94 from 1986–87) and the slightly higher values in Los Angeles Harbor and lower Newport Bay (Cabrillo, H′ = 2.39; outer LA Harbor, H′ = 2.69; lower Newport Bay, H′ = 3.09). The lower H′ values in upper Newport Bay reflect the numerical dominance of a single species, the topsmelt in the catches. The intermediate values of the San Diego Bay stations were the result of numerical dominance of three species, northern anchovy, slough anchovy and topsmelt.

The fish assemblages of San Diego Bay represent a blend of those normally associated with harbors and bay/estuaries within the Southern California Bight

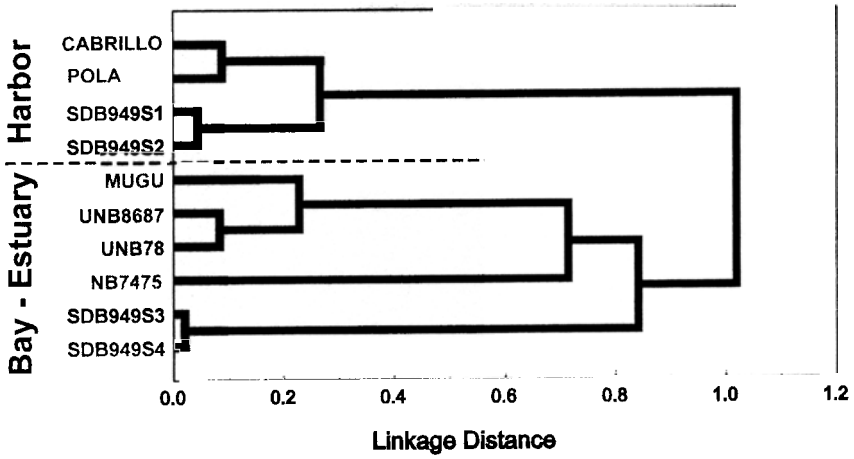

Fig. 17. Cluster of Southern Californian harbor (H), bay and estuarine (BE) habitats based on fish faunal relationships.(Cabrillo = Cabrillo Beach, Los Angeles Harbor; POLA = Port of Los Angeles; Mugu = Mugu Lagoon; NB7475 = Newport Bay study 1974–75; UNB = upper Newport Bay study 1978; UNB8687 = upper Newport Bay study 1986–87; SDB9499S = Present study for stations 1–4).

(Allen, 1985). San Diego Bay stations 1 and 2 cluster with the fish assemblages from previous, comparable studies in southern California harbors (Figure 17), while stations 3 and 4 are more closely associated with the assemblages in the bay/estuaries of southern California. Therefore, San Diego Bay represents a large, unique environment within the Southern California Bight combining elements of two major types of habitats, namely harbor-nearshore soft bottom (HNSB) and bay/estuary (BE) (cf. Allen, 1985).

Allen (1980) conducted the only comparable study utilizing the best estimate process in upper Newport Bay in 1978. Using a similar sampling design, Allen (1980) calculated an overall biomass density of 4.1 g/m^2 for the littoral (intertidal) fish assemblages in upper Newport Bay. This value was about two-thirds of the value of 6.3 g/m^2 derived from the best estimate process in the same study. It is important to note that the overall biomass density estimated herein for San Diego Bay (7.05 g/m^2) exceeded even that from the widely acknowledged, highly productive environment of upper Newport Bay.

Within individual Ecoregions of San Diego Bay, the intertidal areas contained, in general, the highest numerical densities with the North-Central and South regions with best estimates of over 6 indiv./m^2 overall. This was undoubtedly due to the large number of juvenile fishes which recruit to and occupy these warm, productive areas, particularly in the spring. The nearshore habitat supported, by far, the highest biomass densities of fish over the study period. The highest densities were recorded in the North and North-Central ecoregions due primarily to large catches of northern anchovy and spotted sand bass in the summer. The relatively high biomass density found in the South Ecoregion was due mainly to large catches of round stingrays, spotted sand bass, and slough anchovies.

In summary, the fish assemblages of San Diego Bay were found to be diverse, abundant, seasonal, and highly productive particularly for young-of-the-year fishes. The bay itself presents a unique combination of harbor, nearshore soft bottom,

and bay/estuarine habitats which each contribute unique sets of species to the overall assemblage. One of these is a group of 12 species which are indigenous to the bays and estuaries of southern California. South San Diego Bay represents a crtical habitat for these unique bay/estuarine species whose habitats have disappeared at an alarming rate during the last half century. The extensive shallow water habitat and eelgrass beds also support a very high standing stock of midwater, schooling fishes, such as northern anchovies, slough anchovies and topsmelt which, in turn, serve as an important forage resource for both marine birds and larger predatory fishes. In addition, the generally warm and hypersaline waters of south San Diego Bay offer a warm water refuge for a number of southern, "Panamic" province fish species making it unique among all other southern California embayments.

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