Supplemental Expert Opinion
Mr. Chris Nordby- Nordby Biological Consulting

My name is Chris Nordby of Nordby Biological Consulting and I am an expert in the field of tidal wetlands restoration. Poseidon Resources Corporation asked me to prepare this supplemental statement to explain that the Marine Life Mitigation Plan will more than adequately account for CDP's *de minimis* impingement impacts.

CDP's Impingement-Related Impacts Will Be No More Than 1.56 kg/day—a *De Minimis* Amount

The Encina Power Station hired Tenera Environmental to conduct an Impingement Mortality and Entrainment (IM&E) Study to comply with new 316(b) rules that the EPA promulgated in 2004. In 2004-2005, Tenera collected impingement and entrainment data pursuant to the Board-approved IM&E Study.

Since CDP will use EPS's existing intake structure, Tenera used the data it collected for the IM&E Study to estimate CDP's impingement-related impacts. In order to isolate and account for impacts related to CDP's stand-alone efforts, Tenera had to make several adjustments. This process of adjusting EPS's impingement data to project CDP's impingement-related impacts has caused some confusion and may warrant additional explanation.

In Section 5 of its Revised Flow, Entrainment, Impingement Minimization Plan ("Minimization Plan"), Poseidon mistakenly identified Table 5-1. The Table's caption indicates that the impingement data set forth therein represents the number and weight of fishes, sharks and rays that will be impinged when CDP operates with a flow rate of 304 MGD—a total count of 19,408 organisms weighing 351,672 grams. The Regional Board staff correctly pointed out that this Table actually represents 52-day totals for EPS's operations; it does not adjust for CDP's stand-alone operations. Therefore, Tenera erred by dividing these totals by 365 days to project CDP's daily impingement impacts.

In response to this comment, Tenera adjusted its methodology for isolating CDP's impingement-related impacts. Tenera conducted a regression analysis that factored in EPS's impinged biomass (kg) observed during weekly 24-hour surveys against the flow rates (MGD) measured during the 50 impingement surveys conducted from June 2004 to June 2005. The resulting regression equation was solved in order to project a daily impingement rate at desalination plant flow rates of 304 MGD.

The results of Tenera's regression analysis indicate that CDP's operations will result in the impingement of 1.56 kg/day. This level of impingement represents a *de minimis* impingement impact. Moreover, this figure overstates CDP's impact because it does not account for technology measures that CDP will take to further reduce impingement and entrainment, including reducing the intake's through-flow velocity to 0.5 fps or below—a threshold level that minimizes impingement mortality to acceptable levels (*see* Poseidon's Comment, § V), and the installation of micro-screens, law impact pretreatment technology, and variable frequency drives, which will even further reduce impingement losses.

Poseidon's Mitigation Project Will Account for CDP's De Minimis Impingement-Related Impacts

As is set forth in the MLMP, Poseidon's mitigation project will restore up to 55.4 acres of estuarine wetlands. The primary/express objective of this project is to mitigate for unavoidable entrainment-related impacts. Because impingement-related impacts are *de minimis*, mitigation is not necessary to offset impingement. Nevertheless, in addition to accomplishing the stated objective (mitigating for entrainment-related impacts), the mitigation project will provide the incidental benefit of mitigating for whatever *de minimis* impingement-related impacts are associated with CDP's operations. In effect, the MLMP accomplishes two objectives: it mitigates for both entrainment and impingement-related impacts.

Fish productivity in shallow tidal wetlands is extremely high due to high primary productivity, efficient transfer of energy, and nursery functions that promote rapid growth and provide refugia from predators. The biomass of fishes in estuaries is often among the greatest biomass of higher trophic levels in natural ecosystems in the world (Day et al., 1989).

Allen (1982) conducted a study of fish productivity of the littoral zone of Upper Newport Bay where he calculated fish productivity at 9.35 $gDW/m^2/yr$. The mudflats and tidal channels that Allen sampled in Upper Newport Bay are analogous to the habitat that would be created by Poseidon as mitigation for impacts associated with the CDP. Allen's measurements were conservative in that he did not include mullet, an abundant but difficult to sample species whose large size would have increased biomass estimates; and he reported very low densities of arrow goby, a small but extremely abundant species in many southern California wetlands.

There are few studies of fish productivity in southern California wetlands that are similar to Allen's; however, there are fish density data available from the other southern California systems from the same time period that can be compared to Upper Newport Bay. Nordby and Zedler (1991) sampled fishes at Tijuana Estuary and Los Penasquitos Lagoon form 1986 to 1989 and from 1987 to 1989, respectively. Allen sampled monthly while Nordby and Zedler sampled quarterly. Fish densities are compared for summer months when densities are highest (Table 1). While there is considerable variability to from month to month and year to year, the densities of the dominant estuarine fishes in Allen's Newport Bay studies are typical of southern California estuaries. Tijuana Estuary consistently had the highest fish densities. Typified by continuous tidal flushing and shallow, dendritic channels, Tijuana Estuary serves as the model estuarine system to be created by Poseidon compared to Upper Newport Bay. Although density is an indirect indicator of productivity, it is reasonable that systems with similar densities of these species would have similar productivities.

Poseidon's Mitigation Project Will Yield 2.4-3.5 Times the Amount of Fish Impinged

Because the density of fishes sampled in Allen's study was typical of the density of fishes in other southern California coastal wetlands, it is reasonable to assume that his conservative productivity measurement for Upper Newport Bay would be applicable to Poseidon's mitigation. Based on Allen's estimate of approximately 9 $g/m^2/yr$, 37 acres of restored coastal wetland habitat would yield 1,348 kg/yr fish biomass; 55 acres would yield 2,003 kg/yr fish biomass.

As described above, CDP's operations will result in the impingement of no more than 1.56 kg of organisms per day. On an annual basis, this is equal to 569 kg. By restoring 37 acres, Poseidon will yield 1348 kg fish biomass—a mitigation ratio of 2.4. By restoring 55 acres, Poseidon will yield 2003 kg fish biomass—a mitigation ratio of 3.5 Given that Poseidon's mitigation project yield between 2.4 and 3.5 times the amount of fish that are impinged by CDP's operations, Poseidon will more than adequately account for CDP's *de minimis* impingement impacts.

Literature Cited:

1. Larry Glen Allen, *Seasonal Abundance, Composition and Productivity of the Littoral Fish Assemblage in Upper Newport Bay, California*, 80 Fishery Bulletin 4, 769-90 (1982).
2. John W. Day et al., Estuarine Ecology (John Wiley and Sons, Inc.) (1989).
3. C.S. Nordby & J.B. Zedler, *Responses of Fish and Macrobenthic Assemblages to Hydrologic Disturbances in Tijuana Estuary and Los Penasquitos Lagoon, California*, 14 Estuaries 1, 80-93 (1991).

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Responses of Fish and Macrobenthic Assemblages to Hydrologic Disturbances in Tijuana Estuary and Los Peñasquitos Lagoon, California

CHRISTOPHER S. NORDBY
JOY B. ZEDLER
Biology Department
San Diego State University
San Diego, California 92182-0057

ABSTRACT: Changes in the assemblages of fishes and benthic macro-invertebrates were evaluated in relation to wastewater inflows at Tijuana Estuary and impounded streamflows and mouth closure at Los Peñasquitos Lagoon. Freshwater from sewage spills or winter rains lowered water salinities and had major impacts on the channel organisms of both southern California coastal wetlands. Benthic infaunal assemblages responded more rapidly to reduced salinity than did fishes, with continued salinity reduction leading to the extirpation of most species. Both the fish and benthic invertebrate assemblages became dominated by species with early ages of maturity and protracted spawning seasons. Between-system comparisons showed that good tidal flushing reduced negative impacts on both the fish and benthic assemblages.

Introduction

Southern California estuaries and lagoons are subject to interannual variability in rainfall, streamflow, and disturbances such as sedimentation, dredging, and wastewater inflows. Two San Diego County wetlands, Tijuana Estuary (TJE; 32°34′N, 117°7′W) and Los Peñasquitos Lagoon (LPL; 32°56′N, 117°15′W) differ in many respects, including size and watershed, but especially in disturbance and tidal histories.

TJE has been open to tidal flushing except for periodic closures in the early 1960s and prolonged closure in 1984 (Zedler and Nordby 1986). LPL has been primarily closed to tidal flushing for most of this century (Bradshaw, unpublished report). A comparison of primary productivity of the two systems (Zedler et al. 1980) demonstrated higher accumulation of biomass of vascular plants at LPL, possibly due to impoundment of freshwater during the growing season. TJE and LPL represent extremes in southern California coastal wetlands (e.g., mouth usually open vs. usually closed) and the differences between the two systems could be explained in terms of the reliability of communication with the Pacific Ocean. In the last decade, human disturbance of these systems has intensified. A comparison of the channel communities of these two wetlands was undertaken to understand the responses to the wider range and increased severity of stresses resulting from these multiple disturbances.

Study Sites

TIJUANA ESTUARY

Tijuana Estuary is located in the southwestern corner of the continental U.S. (Fig. 1) and is included in the Tijuana River National Estuarine Research Reserve, administered by the National Oceanic and Atmospheric Administration (NOAA). The reserve includes approximately 1,012 ha (2,500 acres), 60 ha of which are tidal channels. The Tijuana River, with a watershed of 1,731 km², bisects the estuary into a northern and southern portion and rarely provides much freshwater input except in years with sewage-augmented flows.

In recent years, several disturbances at Tijuana Estuary have changed the salt marsh and channel communities dramatically (Zedler and Beare 1986; Zedler and Nordby 1986; Nordby 1987, 1988). Coastal dune sands were destabilized by trampling, and high tides coupled with sea storms washed large volumes of sand into the main channels of the estuary in 1983 (Zedler and Nordby 1986). The sedimentation events immediately affected channel biota through burial and increased turbidity (Nordby 1987). Later, the reduced tidal prism allowed sand to accumulate, and the tidal inlet closed in April 1984. Dredging to reopen the inlet (in December 1984) removed large numbers of channel organisms, and affected others by suspending sediments. During the eight-month closure of the estuary, hy-

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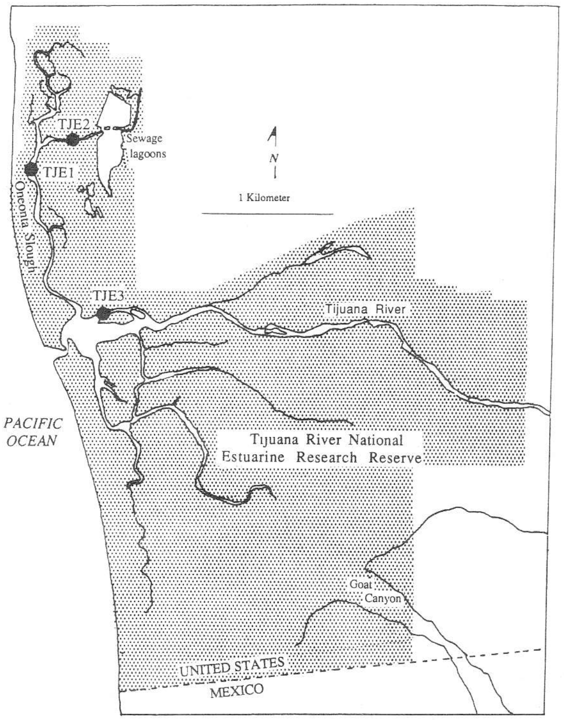

Fig. 1. Fish and invertebrate sampling stations at Tijuana Estuary (TJE). Stippled area represents the boundaries of the Tijuana River National Estuarine Research Reserve.

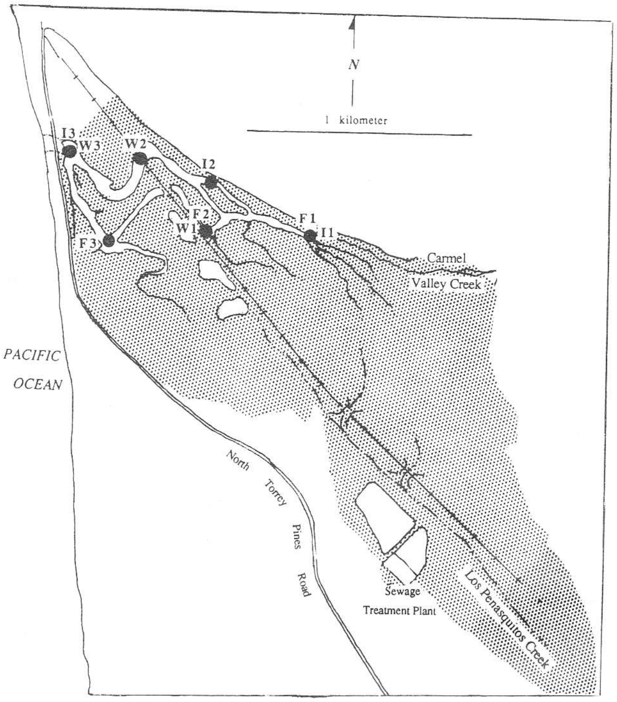

Fig. 2. Fish, invertebrate, and water quality sampling stations at Los Peñasquitos Lagoon (LPL). F = Fish site. I = Invertebrate site. W = Water quality site. Stippled area represents the approximate extent of coastal wetland habitat.

persaline conditions (60‰ in channels) developed through the long dry season, roughly May through November. Three fish species *Gillichthys mirabilis* (longjaw mudsucker), *Paralichthys californicus* (California halibut), and *Hypsopsetta guttulata* (diamond turbot) declined in abundance, and the dominant bivalve species *Nutallia nuttallii* (purple clam) became extinct at Tijuana Estuary (Nordby 1987).

The Tijuana River usually has very little or no flow in summer months when rainfall is low and evaporation rates are high (Zedler et al. 1984). For over 50 years, the river has received raw sewage flows from the City of Tijuana, Mexico (City of San Diego 1988), increasing in volume to an estimated average of 10–12 million gallons per day (MGD) in recent years (Seamans 1988). It has been estimated that a prolonged input of 12.5 MGD of raw or treated sewage would negatively impact the channel biota of the system (Zedler et al. 1984). Renegade flows were estimated at 22 MGD in 1987–1988 (Seamans 1988). Intermittent sewage flows also enter the estuary from Goat Canyon and Smuggler's Gulch. The latter conveyed 4–5 MGD of sewage to the estuary in recent years (City of San Diego 1988). In 1988 the International Boundary and Water Commission built an interceptor to collect and return those flows to the Tijuana treatment system. No interceptor was built at Goat Canyon, which carries intermittent sewage spills to the southern arm of Tijuana Estuary (Fig. 1).

Los Peñasquitos Lagoon

Los Peñasquitos Lagoon is a small coastal wetland of approximately 142 ha, 12 ha of which are channel habitat. The lagoon is the terminus of a small watershed (246 km^2) and is fed by two creeks: Carmel Valley Creek to the east and Los Peñasquitos Creek to the southeast (Fig. 2). Historically, both streams were seasonal, with little or no flow during summer and autumn. Recently, agricultural and residential run-off have increased flows of Carmel Valley Creek to year-round so that brackish marsh has encroached into the salt marsh.

In recent decades, LPL has evolved from a tidal estuary to a lagoon that is usually closed to tidal flushing. Construction of a railroad embankment across the center of the lagoon in 1925 isolated channels and thereby greatly reduced tidal volume and circulation. In 1932–1933, construction of a highway along the barrier beach resulted in more fill and constriction at the mouth. The tidal prism of the lagoon is no longer large enough to maintain an opening to the ocean. Consequently, mechanical removal of the sand and cobble sill at the mouth is necessary to provide occasional tidal circulation. The lagoon is nearly always nontidal in summer, and impounded seawater increases in salinity through the summer and autumn due to evaporation. In the cool wet season, storm run-off flows into the lagoon and decreases water salinity. Only major rainfalls raise the lagoon water level high enough to break through the sand berm at the mouth. The extremes in salinity cause conditions that are stressful to channel organisms (Bradshaw, unpublished report).

Wastewater flows also affect this lagoon. From 1962 to 1972 a sewage treatment facility discharged 0.5–1.0 MGD of treated effluent into the lagoon, increasing nitrate and phosphate loads and reducing water salinity. While the wastewater line was connected to the metropolitan sewer system in 1972, the pumps transporting the sewage to the treatment facility on Pt. Loma have failed repeatedly. A raw sewage spill of about 20 MGD occurred in March 1987. There were flood events during the wet seasons of 1986, 1987, and 1988. Organic matter from sewage spills, tidal closure, and floods probably interact to cause both salinity and oxygen stress to organisms. Persistence of these conditions for 2 to 3 d can eliminate most of the channel fauna. Only species that survive rapid reduction in salinity and dissolved oxygen or reinvade from the nearshore habitat via extreme high tides, storm waves, or brief tidal openings, persist from year to year.

Sampling Stations and Methods

TIJUANA ESTUARY STATIONS

This study was conducted primarily in the northern arm of the estuary known as Oneonta Slough (Fig. 1). Sampling stations were chosen to reflect differences in channel morphometry (width, depth, and substrate type) and distance from the mouth. During the study, chronic wastewater inflows entered the system via the Tijuana River, while sewage spills from broken pipelines intermittently flowed across the southern portion of the marsh to the mouth. Areas near the mouth received more sewage than did areas further from the mouth.

Station TJE1 was 15 m wide, usually less than 1 m deep during sampling and had a sand substrate. This site was located about 900 m from the mouth. At station TJE1, extremely high tides (2.38 m MLLW) and coincident storm-induced waves washed dune sand into the channel on two occasions during the study period: December 31, 1986, and December 31, 1987. Several centimeters of dune sand were deposited at this sampling site on those dates. In April 1987, the north arm of the estuary was dredged to restore the tidal prism lost from sediment deposited that winter. Dredging was performed by drag line from the western bank of the channel beginning approximately 0.25 km north of TJE1 and ending roughly adjacent to TJE3 (Fig. 1). Following the dune wash-over of 1987, a shorter length of the southern main channel was bulldozed to remove sediment.

Station TJE2 was located in a man-made channel that was excavated in the early 1900s to link the former sewage lagoons with the main channels (Fig. 1). This was the deepest site (usually about 1 m), with eroding banks. The channel was 10 to 11 m wide at this site with a substrate that was composed of a clay/mud mixture with broken shell fragments in the upper 10 to 15 cm over a bed of coarse sand/gravel. TJE2 was located approximately 1,800 m from the mouth.

Site TJE3 was situated in the mouth region on a side channel paralleling the Tijuana River. This was the shallowest site (<0.5 m) and had sloping banks. The channel was 6 to 7 m wide with a sand substrate. TJE3 received sewage flows directly from the Tijuana River.

LOS PEÑASQUITOS LAGOON STATIONS

Sampling stations at LPL were chosen to represent a spatial continuum from the mouth to the terminal tidal creeks in the eastern end of the lagoon (Fig. 2). Station LPL1 was located in the extreme eastern end of the lagoon. The channel at this site was 5 to 7 m wide, 40 to 90 cm in depth depending upon season, with a clay substrate. Station LPL2 was located in a blind diverticulum which resulted from the construction of the railroad berm. This site was approximately half-way between the mouth and LPL1. The channel was 8 m wide and 30 to 90 cm deep with a clay/mud substrate. Station LPL3 was the widest site (>40 m), 30 to 100 cm deep with a mud substrate and was located in the mouth region.

SAMPLING PROTOCOL

Fishes and benthic invertebrates were collected quarterly from each wetland. All samples were collected during daylight hours on moderate to low tides. Each system was sampled within the same 1-wk period. TJE has been sampled for 3 yr, from June 1986 to March 1989, while LPL has been sampled for 2 yr, from June 1987 to March 1989. However, due to different start-up times for various stages of invertebrate sampling, and due to a lag in the analysis of some benthic invertebrate samples, the numbers of samples are not identical (Table 1).

At each site, two "blocking nets" (13.7 m long, 1.8 m deep, 3-mm mesh) were used to confine all fishes within a section of the channel. A beach seine (3.7 m long, 1.8 m deep, with a 2 × 2 m bag, 3-mm mesh) was then drawn in a circular manner

TABLE 1. Sampling schedule for the collection of fishes and benthic invertebrates at Tijuana Estuary (TJE) and Los Peñasquitos Lagoon (LPL).

	TJE	LPL
Fishes	12 quarterly samples June 1986–March 1989	8 quarterly samples June 1987–March 1989
Bivalves	10 quarterly samples September 1986–December 1989	7 quarterly samples June 1987–December 1988
Polychaetes and other benthic forms	7 quarterly samples June 1987–December 1988	7 quarterly samples June 1987–December 1988

within the two blocking nets and pulled to shore. Hauls were repeated until the number of fish captured declined to near zero, usually 4–5 hauls. The blocking nets were then drawn together in a semicircle to catch any fishes that were hiding in the blocking nets.

The areas sampled differed both within each wetland and between the two systems. The earliest samples at TJE were taken from relatively large areas. For example, June 1986 samples at TJE1, TJE2, and TJE3 were taken from areas of 520 m^2, 300 m^2, and 150 m^2, respectively. These areas were reduced to a standard area of 110 m^2, 110 m^2, and 70 m^2 for TJE1, TJE2, and TJE3, respectively, after preliminary analysis demonstrated that the number of species collected was not affected and densities were not significantly reduced.

The areas sampled at LPL were modeled after those at TJE. Thus, stations LPL1–LPL3 included areas of 70 m^2, 70 m^2, and 110 m^2, respectively. The numbers of fishes collected are expressed as densities (number m^{-2}) for comparative purposes.

To test the effectiveness of the fish sampling method and to demonstrate the catchability of individual species, the numbers of fish captured per haul were compared. A test of the number of hauls required to provide an adequate sample was also performed by plotting the number of fish caught against the prior cumulative catch. These tests were performed in March 1987.

Benthic invertebrates were collected using a 15-cm diameter (177 cm^2) coring device pressed into the sediment to a depth of 20 cm. The core was then sieved through a 1-mm mesh screen, with large organisms tallied in the field and the remaining specimens fixed in 3% formalin and transported to the laboratory for identification. Three replicate samples consisting of three pooled cores each were taken per site for a total of nine cores (0.16 m^2) per station. Sampling sites corresponded to fish sampling stations at TJE. At LPL, three stations within the main channel were sampled (Fig. 2).

Water quality was monitored approximately biweekly at LPL and quarterly at TJE. Sampling sites at TJE were the same as benthic invertebrate and fish sampling sites. Sampling stations at LPL were chosen to reflect extremes in water quality. These extremes represent a spatial continuum from the mouth of the lagoon to the terminal creeks (Fig. 2). Station LPL1 was nearest the freshwater inflows from Carmel Valley Creek, while station LPL3 was nearest the mouth and was the most affected by seawater when the mouth was open.

Water temperature and dissolved oxygen were measured using a Yellow Springs Instrument Model 51B DO/temperature meter. Salinity was measured to the nearest part per thousand using an American Optical salinity refractometer.

Sediments were analyzed for grain size using the Emery Settling Tube (Emery 1938), a 164-cm long water-filled glass tube that allows differential settling and separation of particles into size classes. This analysis was employed at TJE1 and TJE2 only.

Statistical tests of patterns of fish and benthic invertebrate distributions and abundances were conducted for each wetland. To test for differences in the number of fish species collected at each sampling station, a two-way ANOVA without replication was performed with stations and surveys as treatments. Because the assumption of no interaction may not have been met, these results are presented as an index of species distributions rather than a strict test of the null hypothesis. A one-way ANOVA was employed to test for differences in the sizes of *Atherinops affinis* (topsmelt) present each June at TJE1. A two-way ANOVA was performed on the square roots of bivalve densities using stations and surveys as treatments. Density data for bivalve assemblages were transformed to make the variances equal and distributions normal ($n = 3$ pooled cores).

Results

ENVIRONMENTAL CONDITIONS

The streamflow of the Tijuana River is characterized by high variability in both mean annual and monthly flows. Streamflow records from 1937 to 1977 document a mean annual discharge of 5,500 MGD with a coefficient of variability of 325% (Zedler and Beare 1986). Due to high variability in both

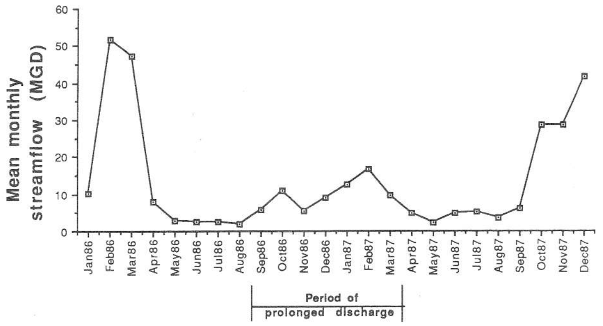

Fig. 3. Mean monthly streamflow for the Tijuana River 1986–1987. Data from the International Water and Boundary Commission (IBWC).

streamflow and rainfall, there is no means of separating "normal" streamflow from wastewater flows. For this study, we will refer to all flows as wastewater flows, realizing that considerable amounts of freshwater may enter the system following winter rainfall events.

The volume of wastewater entering the United States via the Tijuana River varied widely from 1986 through 1987 (Fig. 3). A peak discharge in winter 1986 was followed by about 6 months of low flow. Flow volumes were on the order of 5 to 20 MGD in late 1986 and early 1987 but increased again in late 1987.

At LPL, water salinity and dissolved oxygen levels fluctuated widely when the mouth was closed (Fig. 4). During this study period rapid reductions in salinity and dissolved oxygen occurred during October 1987 and December 1988.

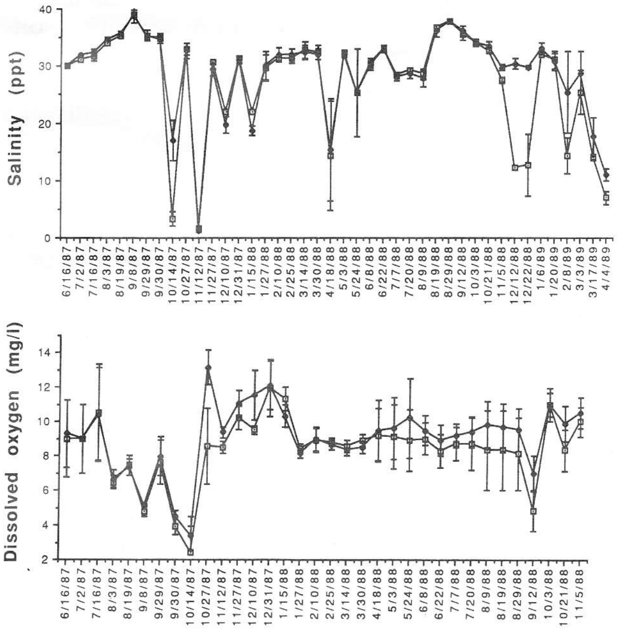

Fig. 4. Mean water salinity and dissolved oxygen at three sampling sites at Los Peñasquitos Lagoon (LPL). Error bars = ± one standard error.

TABLE 2. Fish species collected at Tijuana Estuary (TJE) and Los Peñasquitos Lagoon (LPL).

Taxon	Common Name	TJE 1986–1988	LPL 1987–1988
Atherinidae			
Atherinops affinis	topsmelt	15,437	1,875
Blennidae			
Hypsoblennius gentilis	bay blenny	4	0
Hypsoblennius gilberti	rockpool blenny	1	0
Hypsoblennius jenkinsi	mussel blenny	1	0
Bothidae			
Paralichthys californicus	California halibut	283	12
Cottidae			
Leptocottus armatus	staghorn sculpin	1,431	346
Artedius sp.	sculpin	2	0
Cyprinodontidae			
Fundulus parvipinnis	California killifish	2,367	107
Engraulidae			
Anchoa compressa	deepbody anchovy	11	67
Girellidae			
Girella nigricans	opaleye	82	0
Gobiidae			
Clevelandia ios	arrow goby	60,097	816
Gillichthys mirabilis	longjaw mudsucker	275	877
Ilypnus gilberti	cheekspot goby	50	22
Lepidogobius lepidus	bay goby	0	9
Quietula y-cauda	shadow goby	3	0
Mugilidae			
Mugil cephalus	striped mullet	5	3
Pleuronectidae			
Hypsopsetta guttulata	diamond turbot	83	14
Pleuronichthys ritteri	spotted turbot	4	0
Poeciliidae			
Gambusia affinis	mosquitofish	0	937
Rhinobatidae			
Rhinobatos productus	shovelnose guitarfish	2	0
Serranidae			
Paralabrax clathratus	kelp bass	12	0
Sciaenidae			
Seriphus politus	queenfish	1	0
Syngnathidae			
Syngnathus leptorhynchus	bay pipefish	14	2
Total fishes collected		80,165	5,087
Total species encountered		21	13
Total sampling effort (cumulative area in m²)		4,795	1,985
Number of quarterly samples		12	8

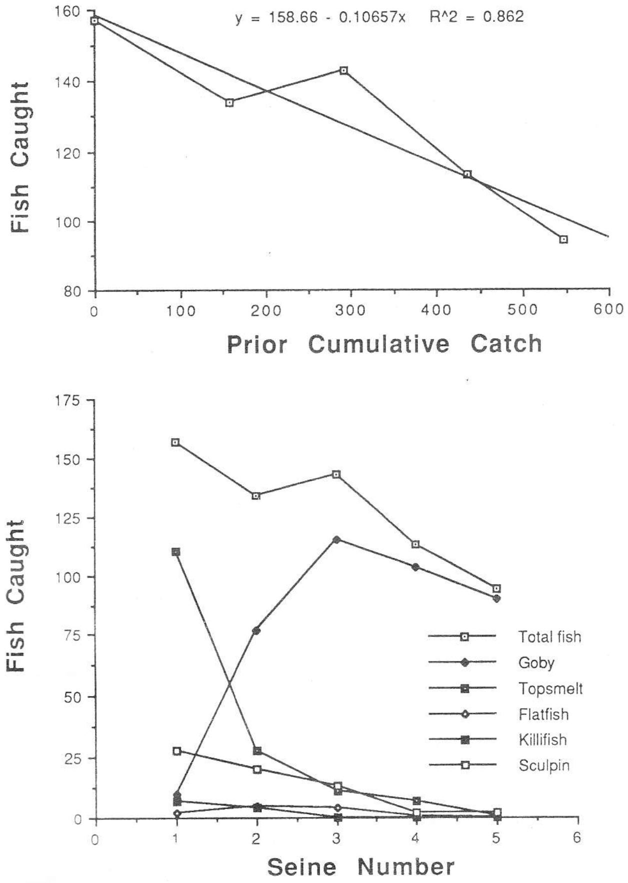

Fig. 5. Tests of the sampling efficiency of the method of collecting fish used in this study. Top: repeated seining of a blocked channel plotted against prior cumulative catch. Bottom: species composition of repeated seinings.

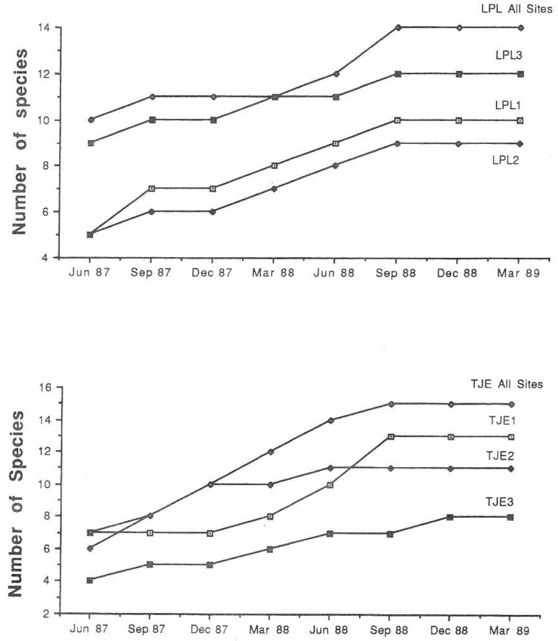

Fig. 6. Cumulative species curves for fishes collected at Tijuana Estuary (TJE) and Los Peñasquitos Lagoon (LPL) from June 1987 to March 1989.

FISHES

The two wetlands exhibited obvious differences in fish assemblages (Table 2) in terms of dominants (total individuals collected) and species richness (number of species). At TJE, 21 species of fish representing 14 families were collected over the 3-yr period. Three species dominated the samples: 75% were *Clevelandia ios* (arrow goby), 19% *Atherinops affinis,* and 3% *Fundulus parvipinnis* (California killifish). The remaining 18 species comprised only 3% of the total combined. In contrast, 13 species from 10 families were collected at LPL. Dominants included four species: 36% were *Atherinops affinis,* 18% *Gambusia affinis* (mosquitofish), 17% *Gillichthys mirabilis,* and 16% *Clevelandia ios.*

A test of the sampling procedure used in this study illustrates its effectiveness in capturing the majority of the fishes contained within the two blocking nets (Fig. 5). Repeated seining was especially needed to sample the small, numerically dominant *Clevelandia ios.* The number of *C. ios* captured per seine increased on the second and third sweeps and remained high throughout the fourth and fifth efforts. Conversely, *Atherinops affinis* densities declined dramatically after the first seine, illustrating the relative ease with which this pelagic species was captured.

The differences in the number of species encountered in each wetland are partially due to a greater sampling effort at TJE. Many of the species taken at TJE were collected in 1986, a year before sampling began at LPL. There was also some disparity in areas sampled, with the total area at LPL somewhat smaller than at TJE. When the 1986 data from TJE are omitted from comparisons, the cumulative species curves for each wetland are similar with curves leveling after the sixth quarterly sample (Fig. 6), suggesting that both wetlands were adequately assessed for species richness.

A comparison of absolute and relative abundances demonstrated system-wide changes at TJE during the study (Table 3). The fish assemblage shifted from one codominated by *Atherinops affinis* and *Clevelandia ios* in 1986 to one in which *Clevelandia ios* was by far the numerical dominant. The relative abundance of *Atherinops affinis* remained fairly constant in LPL (Table 3). While *Clevelandia ios* dominated TJE, it was a relatively minor species at LPL. Conversely, *Gillichthys mirabilis* was important at LPL but rare at TJE. *Atherinops affinis* was common in both wetlands but declined throughout

TABLE 3. Annual relative abundance (% of total) of the dominant channel organisms collected at Tijuana Estuary (TJE) and Los Peñasquitos Lagoon (LPL). X = no data.

Species	TJE			LPL	
	1986–1987	1987–1988	1988–1989	1987–1988	1988–1989
Fishes					
Atherinops affinis	52%	14%	7%	38%	36%
Clevelandia ios	41%	58%	90%	22%	14%
Fundulus parvipinnis	4%	19%	1%	4%	2%
Gillichthys mirabilis	0%	<1%	<1%	28%	14%
Gambusia affinis	0%	0%	0%	<1%	24%
Total fishes collected	20,888	4,976	54,301	1,253	3,834
Bivalves					
Tagelus californianus	73%	33%	27%	35%	50%
Protothaca staminea	19%	34%	42%	2%	8%
Macoma nasuta	2%	17%	19%	7%	5%
Cryptomya californica	0%	6%	4%	0%	8%
Total bivalves collected	658	490	651	55	40
Polychaetes					
Capitellidae	X	33%	50%	22%	36%
Spionidae					
Boccardia spp.	X	<1%	5%	19%	7%
Polydora spp.	X	18%	20%	28%	21%
Nephtys spp.	X	16%	1%	0%	0%
Pseudopolydora spp.	X	0%	0%	5%	3%
Spiophanes missionensis	X	0%	8%	0%	0%
Opheliidae					
Armandia brevis	X	<1%	5%	<1%	<1%
Euzonus mucronata	X	0%	0%	<1%	25%
Unidentified taxa	X	3%	0%	4%	0%
Total polychaetes collected		276	1,422	709	659

the study period at TJE. *Gambusia affinis* was common at LPL but absent from TJE.

The total numbers of fish species have also changed. At TJE, species richness fell from a high of 14 in September 1986 to a low of 6 in December 1988 and March 1989 (Fig. 7). The most dramatic change in species richness occurred between September 1986 and June 1987, a time of prolonged sewage discharge. Each quarterly sampling period in 1986–1987 yielded more species than the corresponding sampling period in 1987–1988. The number of fish species differed significantly with sampling station ($p < 0.05$; Fig. 8).

At LPL, species richness was highest in June and September and lowest in December (Fig. 7). There were no significant differences among stations ($p > 0.05$). A maximum of 10 species was collected from LPL during any single sampling period.

Fishes also declined in density and size. At TJE,

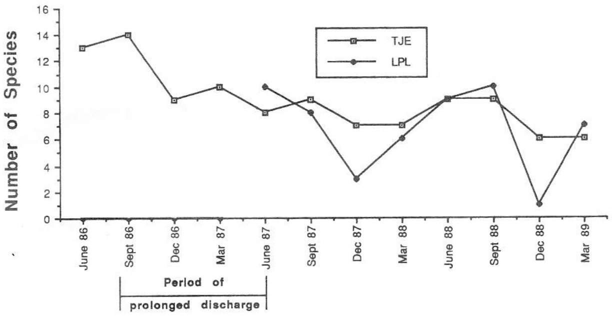

Fig. 7. Total number of fish species collected from each of three sampling sites at Tijuana Estuary (TJE) and Los Peñasquitos Lagoon (LPL).

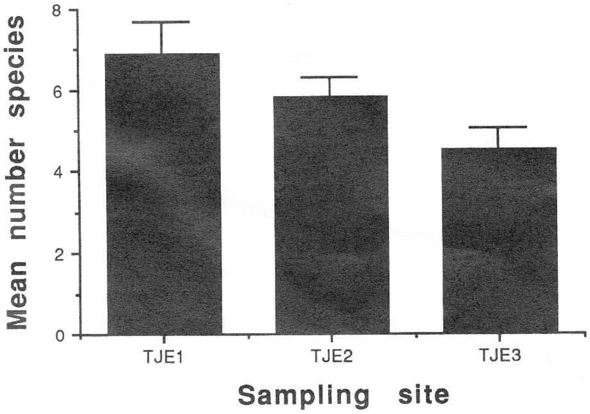

Fig. 8. Mean number fish species (n = 12) collected at three sampling sites at Tijuana Estuary (TJE). Error bars = ± one standard error.

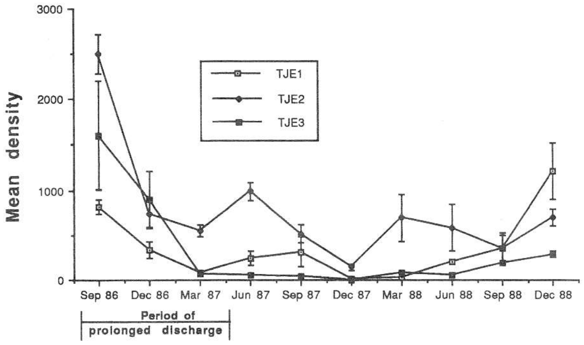

Fig. 10. Mean densities (no. m^{-2}) of all bivalves collected from each of three sampling sites at Tijuana Estuary (TJE). Error bars = ± one standard error.

(two-way ANOVA, $p < 0.01$); the interaction was also significant ($p < 0.01$), primarily because there were zero bivalves collected on some dates at some stations.

Two of the three dominant bivalve species were found in highest densities at station TJE2 compared to TJE1 and TJE3 (Fig. 11). Both *Protothaca staminea* and *Macoma nasuta* showed a strong site preference for TJE2. *Tagelus californianus* did not demonstrate a clear site preference but occurred at all sampling stations. TJE2 also supported higher mean relative abundances of bivalves than did stations TJE1 and TJE3 (Fig. 12).

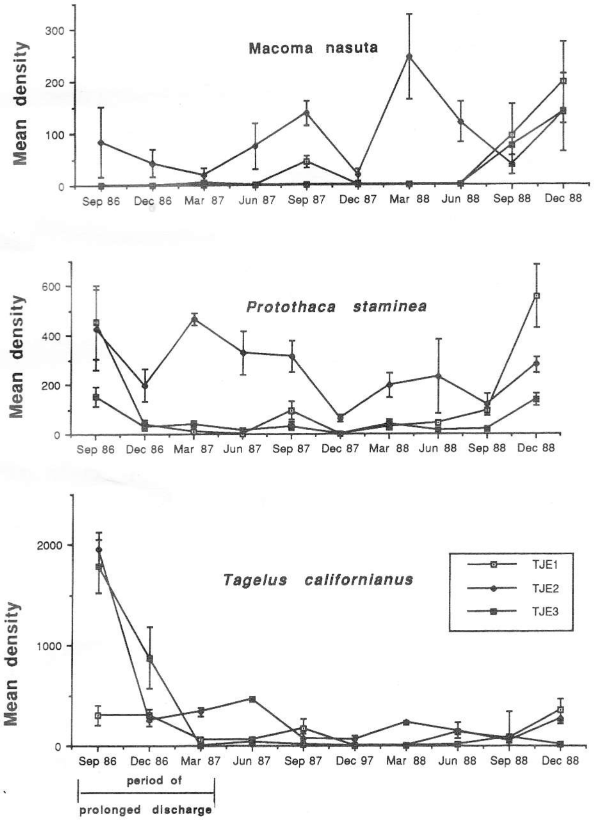

Fig. 11. Mean densities (no. m^{-2}) of the dominant bivalve species collected at each of three sampling sites at Tijuana Estuary (TJE). Error bars = ± one standard error. Note different vertical scales.

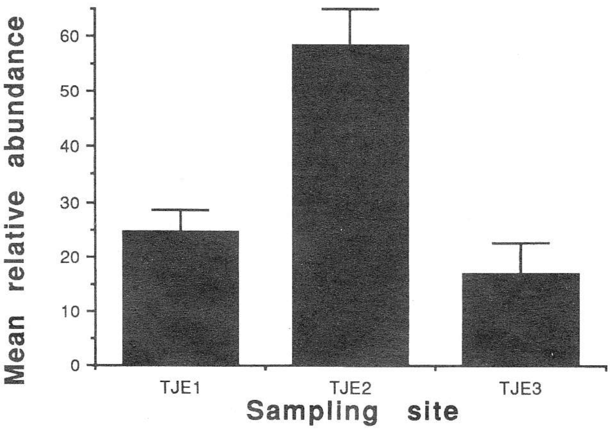

Fig. 12. Mean number of bivalve species collected from each of three sampling sites at Tijuana Estuary (TJE). Data are means for 10 sampling dates. Error bars = ± one standard error.

Sediments analyzed at TJE2 had ϕ values (Table 6) that indicated a very coarse grain size and a high degree of variation about the mean grain size (sorting and skewness). Sediments from station TJE1 were coarse and well sorted. This site was buried with several centimeters of dune sand on two occasions during the study and was dredged once to remove sediments.

As with the fish assemblage, benthic invertebrates at TJE showed a shift in dominance and an overall decline in total number of individuals collected (Table 3). In 1986, *Tagelus californianus* dominated the collections while *Cryptomya californica* was absent. *Callianassa californiensis*, a commensal of *Cryptomya*, was collected in low densities in 1986. By 1987, *T. californianus* had declined

TABLE 6. Phi values determined from sediment analysis for Tijuana Estuary site TJE1 (from Duggan 1989).

Station	Date	Mean Grain Size[a] (mm)	Sorting[b]	Skewness[c]
TJE1	Sept. 1986	2.22	0.65	−0.11
TJE1	Jan. 1987	1.90	0.81	0.05
TJE2	May 1987	1.04	1.65	0.09
TJE2	Sept. 1987	0.75	1.81	−0.41

[a] 2 mm to 1 mm indicates very coarse grain size, 0.5 to 1.00 indicates coarse sand (from Krumbein and Pettijohn 1938).

[b] 0.5 to 1.0 indicates moderately well to moderately sorted; 1.0 to 2.0 indicates poorly sorted, with sorting a measure of dispersion of grain size around the mean grain size of that sample (from Folk and Ward 1957).

[c] −0.10 to +0.10 indicates nearly symmetrical distribution of grain size around the mean; −1.0 to −0.3 indicates negatively skewed (from Folk and Ward 1957).

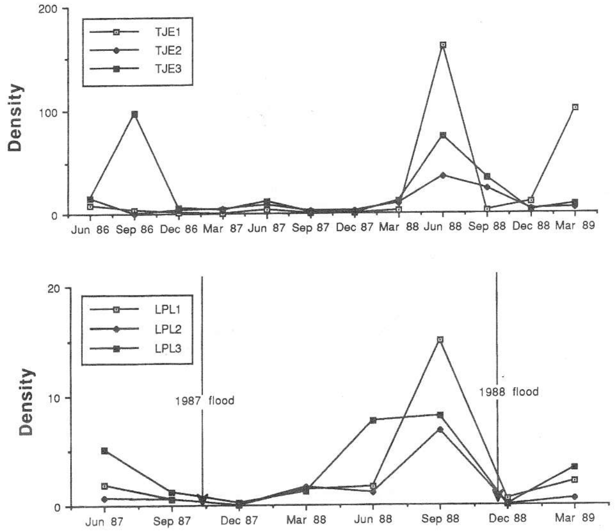

Fig. 9. Mean densities (no. m^{-2}) of all fishes collected at each of three sampling sites at Tijuana Estuary (TJE) and three sites at Los Peñasquitos Lagoon (LPL). Note different vertical scales.

the density of fishes collected decreased from a peak in September 1986 to relatively low values throughout 1987 before rising dramatically in March and June 1988 (Fig. 9). Mean density of fishes at LPL declined after a June peak to levels near zero in December, following the 1987 flood, and peaked again in September 1988, before crashing as a result of the 1988 flood (Fig. 9).

The maximum and mean sizes of *Atherinops affinis* captured at station TJE1 in June of each year declined dramatically (Table 4). There were significant differences in sizes present each June ($p < 0.001$). Station TJE1 was chosen for this example because it typically yielded the highest numbers of this species.

BENTHIC INVERTEBRATES

Fifty-eight taxa of benthic invertebrates were collected from TJE from September 1986 to June 1988 (Table 5). The collections were nearly equally represented by polychaetes and bivalves. The dominant bivalve species included *Tagelus californianus*, *Protothaca staminea*, and *Macoma nasuta*, while capitellids and spionids dominated the polychaete fraction. The decapod crustacean *Callianassa californiensis* was also abundant.

TABLE 4. Sizes of *Atherinops affinis* (fork length in mm) collected at station TJE1 during June of three consecutive years. SE = ± one standard error.

Year	Maximum Size	Mean Size	SE	n
1986	188	110.3	±1.2	292
1987	121	91.6	±2.8	109
1988	68	47.2	±0.6	124

TABLE 5. Numbers of individuals of benthic invertebrates collected at Tijuana Estuary (TJE) and Los Peñasquitos Lagoon (LPL). Taxa comprising less than 5% are presented as "others."

Taxon	TJE 1986–1988	LPL 1987–1988
Sipunculid worms		
Themiste sp.	17	0
Echinoid echinoderms		
Dendraster excentricus	6	3
Nemertean worms	93	3
Polychaete worms		
Capitellidae	814	399
Spionidae		
Boccardia spp.	68 (5 spp)	183 (4 spp)
Polydora cornuta	124	18
Polydora ligni	143	92
Polydora spp.	63 (2 spp)	210 (2 spp)
Spiophanes missionensis	117	0
Opheliidae		
Euzonus mucronata	0	162
Other taxa combined	437	161
Total polychaetes collected	1,698	1,207
Total families collected	13	11
Total species collected	35	20
Bivalve molluscs		
Tagelus californianus	797	40
Protothaca staminea	554	4
Macoma nasuta	221	6
Laevicardium substriatum	30	8
Spisula sp.	0	17
Other species combined	227	17
Total bivalves collected	1,799	92
Total species collected	18	12
Decapod crustaceans		
Callianassa californiensis	234	3
Phoronida		
Phoronis sp.	1	114
Total sampling area (cumulative area in m^2)	5.25 m^2	3.82 m^2
Total number quarterly samples	11	8

By comparison, 37 taxa of benthic invertebrates were collected from LPL (Table 5). There, the benthic assemblage was dominated by three taxa of polychaetes and had relatively few bivalves. Polychaetes were dominated by capitellids, spionids, and the opheliid, *Euzonus mucronata*. Only 95 individual bivalves representing 12 species were collected from LPL.

BIVALVES

At TJE, bivalve densities were greatest in September 1986 when as many as 2,500 m^{-2} were collected at station TJE2 (Fig. 10). Densities declined during the prolonged period of wastewater discharge. There were significant differences in bivalve densities among stations and on different dates

TABLE 7. Mean length (in mm) of the dominant bivalves collected from Tijuana Estuary November 23, 1986, and January 24, 1987. SE equals one standard error (from R. Duggan 1989).

	11/23/86			1/24/87		
Species	Mean	SE	n	Mean	SE	n
Tagelus californianus	40.3	2.2	302	38.4	0.4	164
Protothaca staminea	11.2	0.3	126	10.8	0.6	90

while *Protothaca staminea, Cryptomya,* and *Callianassa* had increased. In the three quarterly samples analyzed for 1988, *T. californianus* continued to decline and *P. staminea* continued to increase. *Cryptomya californica* and *Macoma nasuta* remained near 1987–1988 levels (Table 3).

A comparison of the mean sizes of the two dominant bivalve species (Table 7) suggests that the majority of the individuals encountered in this study were 0 to 1 year old with a few specimens slightly older (Shaw 1986; R. Duggan, SDSU, personal communication). Thus, newly recruited individuals comprised the majority of those collected.

POLYCHAETES

The abundance of polychaetes collected at TJE increased from 1987 to 1988, especially at station TJE3, nearest the Tijuana River (Fig. 13). The dominant taxa during this peak were capitellids and spionids, primarily *Polydora nuchalis* and *P. cornuta.*

At LPL, polychaetes were the dominant benthic form during the 2-yr study period. Capitellids, spionids (*Polydora* spp.) and the opheliid, *Euzonus mucronata,* dominated. Prior to the October 1987 flood, mean polychaete densities were highest near the mouth (station LPL3, Fig. 14). After flooding, mean densities fell to levels near zero at all sites. By September 1988, peak densities were encountered with the greatest values again at station LPL3.

A comparison of the annual relative abundances demonstrates the instability of both systems (Table 3). The relative abundance of each of the dominant taxa at TJE changed substantially, especially among the spionids where *Nephtys* spp. decreased and *Boccardia* spp. and *Spiophanes missionensis* increased from the previous year. The changes at LPL were less dramatic but included the decrease of *Boccardia* spp. and the sudden increase of *Euzonus mucronata.*

Discussion

Three lines of reasoning lead us to conclude that hydrologic disturbances, especially reduced salinity, are responsible for the patterns that have been found at both Tijuana Estuary (TJE) and Los Peñasquitos Lagoon (LPL). The trends over the course of the study are reduced species richness and abundances, population structures skewed toward young animals, and dominance by species with early reproductive maturity and prolonged spawning periods. First, an examination of historic data in southern California coastal wetlands, including TJE, shows that summer streamflows were rare or absent prior to the late 1970s. At that time, a very different benthic assemblage was present at TJE consisting of larger, and presumably older, bivalves (Hosmer 1977). Second, comparison of sampling sites within TJE indicates that the least-disturbed station (farthest from wastewater and not dredged) serves as a refuge for species that have been eliminated elsewhere. Finally, comparison of TJE with LPL, where reduced salinity is more severe due to annual impoundment of flood waters, shows that the fauna is most depleted where the hydrologic disturbances have been greatest. The history of impacts leads to concern regarding future planned modifications to regional streamflows.

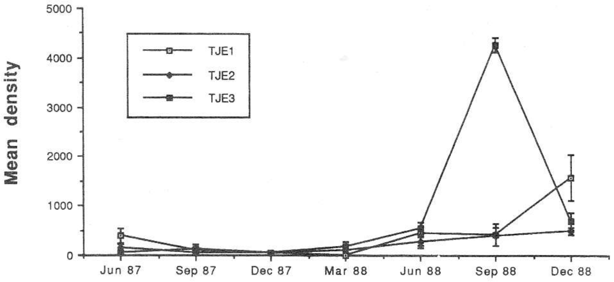

Fig. 13. Mean densities (no. m^{-2}) of polychaetes collected from each of three sampling sites at Tijuana Estuary (TJE). Error bars = ± one standard error.

HISTORIC COMPARISON

Weather and streamflow records for the San Diego area (Zedler et al. 1984) show that there were no major flood years between 1944 and 1978. Streamflow in the lower Tijuana River was minimal, even in winter, with many years of no measurable flow entering Tijuana Estuary. It is reasonable to assume that the channels were essentially

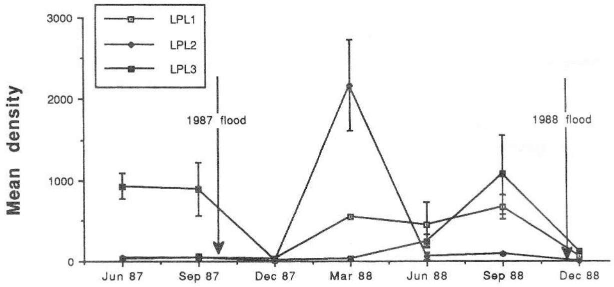

Fig. 14. Mean densities (no. m^{-2}) of polychaetes collected from each of three sites at Los Peñasquitos Lagoon (LPL). Error bars = ± one standard error.

marine at this time. The only historic salinity measurements were made by Purer (1942) in 1939 during a year of average (approx. 25 cm) rainfall and near-average streamflow. The lowest salinity she found at Tijuana Estuary in monthly sampling of three stations was 24‰ in March 1939. Even in a month with 10 cm of rainfall (March 1940), salinities were above 30‰.

The responses of the macrobenthic invertebrates of coastal wetlands to salinity reductions are more apparent than those of the fish assemblages, largely because of their inability to avoid exposure to unfavorable conditions. For this reason, we have concentrated our discussion of the historic comparison on the these assemblages. As previously mentioned, there was some disparity in sampling area with TJE1 and TJE2 equal at 110 m^2 and TJE3 at 70 m^2. While such disparity might have influenced fish distribution and abundance, it would not have affected benthic assemblages that were collected from equal areas and equal effort at all stations at all times. Thus, the strong intra-wetland patterns in the benthos at TJE are not artifacts of sampling design.

The benthos of Tijuana Estuary and Mugu Lagoon (34°N, 119°W) were sampled in the 1970s by Peterson (1972, 1975). His data for live bivalves characterize the low-disturbance assemblage in saline habitats. *Nuttallia (Sanguinolaria) nuttallii* and *Protothaca staminea* were the most abundant bivalves at both study sites. *Tagelus californianus, Cryptomya californica, Macoma nasuta,* and *Laevicardium substriatum* were also present but in lower numbers. Samples from Mugu Lagoon taken before and after the 1969 flood suggested that the population of *Tagelus californianus* was reduced by freshwater inflows (Peterson 1972). To test the tolerance of different bivalves to reduced salinity, Peterson simulated flood conditions in the laboratory (6-h periods with seawater diluted to increasing degrees). He found that *Tagelus californianus* and *Laevicardium substriatum* were intolerant of the lowest salinities (3–10‰) while *Protothaca staminea* and *Macoma nasuta* survived 0‰.

Our findings for Tijuana Estuary under continuous wastewater inflows are consistent with Peterson's conclusion that bivalve communities are strongly affected by lowered salinity. The species that are now dominant, *T. californianus, P. staminea,* and *M. nasuta,* were least abundant at TJE3, the site nearest the source of wastewater inflow (Fig. 11).

Hosmer (1977) examined bivalve composition and size structure at Tijuana Estuary before wastewater flows were a consistent problem. Large individuals were abundant. The mean sizes for the dominant bivalves were 71 mm for *Nuttallia nuttallii*, 22 mm for *Protothaca staminea*, and 27 mm for *Tagelus californianus.* His results contrast strongly with those of the present study. *Nuttallia nuttallii* no longer exists at Tijuana Estuary, and *P. staminea* is, on the average, half as large (Table 7). The mean size of *Tagelus californianus* in 1986–1987 was larger than that reported by Hosmer (1977), but he had problems in sampling this species and suggested that larger specimens may have eluded him.

While predisturbance data on fishes at TJE are lacking, the effects of a major winter storm on the fishes of Mugu Lagoon have been documented (Onuf and Quammen 1983). They found that *Atherinops affinis* and *Cymatogaster aggregatus* (shiner surfperch), the two dominant preflood fishes, suffered heavier reduction in numbers than did other species. They concluded that fishes that spend the majority of their time in the water column were more affected than were benthic fishes, and attributed this to the reduction of low tide volume within the lagoon as a result of flood-induced sedimentation. The sewage flows at TJE have not resulted in a noticeable decrease in tidal prism. The decline in *A. affinis,* the formerly dominant pelagic species, thus appears to be the result of salinity rather than loss of open water habitat.

COMPARISON OF STATIONS WITHIN TIJUANA ESTUARY

At TJE, continual wastewater inflows pose a threat to the channel biota. However, the influx of nonsaline water to this tidal wetland had less drastic impacts than the flooding at LPL when it is nontidal.

The importance of salinity reduction is suggested by comparisons of the sampling stations near to and far from the freshwater inflows. At the mouth station (TJE3), channel organisms declined throughout the study period but increased in late 1988. Bivalve densities declined drastically from highs of more than 2,500 m^{-2}, mostly *Tagelus californianus,* in September 1986 to much lower densities for the remainder of the study (Fig. 10). Bivalves at the other two stations did not show similar responses. Polychaete densities were low until September 1988, when mean densities greater than 4,000 m^{-2} were encountered (Fig. 13). Fishes likewise declined at TJE3 throughout the study until June 1988, with the assemblage shifting from one co-dominated by *Atherinops affinis* and *Clevelandia ios* to one in which *Clevelandia ios* was the sole dominant. The highest densities of fish encountered in the study occurred in June 1988 (Fig. 9). This increase may have been a response to the elimination of wastewater flows in Smuggler's Gulch. The Smuggler's Gulch sewage interceptor was completed in April 1988 and operated throughout the 1988 summer; however, it failed to return flows on several occasions in fall 1988.

Station TJE1, which was disturbed by dredging, also demonstrated a general decline in channel organisms. Overall bivalve density declined from peaks in 1986, with little recovery until December 1988. Polychaete densities rose in 1988 to a peak mean density greater than 1,500 m^{-2}. Fish densities declined from 1986 until spawning peaks in June and December 1988.

Analyses of sediments before and after the 1988 dune washover (Table 6) showed that the substrate at TJE1 changed little, possibly because sedimentation events have long recurred at this site. Any impacts to the channel organisms at TJE1 were probably due to conditions other than sediment type, such as changes in water quality or direct disturbance due to dredging.

Station TJE2 acted as a refuge for two of the three important bivalves, *Protothaca staminea* and *Macoma nasuta.* Although the channel was not formed naturally (it was dredged in the early 1900s to connect the former sewage lagoons to the main channel and, ultimately, the ocean), it has had several decades to develop a rich fauna. The strong site preference of *M. nasuta* and *P. staminea* for station TJE2 is not explained by sediment type, since all three species inhabit a wide range of sediment types at TJE (Hosmer 1977), and each of the sampling stations contained sediments suitable for all three species. The high bivalve abundances at TJE2 are more likely due to isolation from wastewater and dredging disturbances. Mean polychaete densities were lowest at TJE2, a pattern that may be explained by their preference for finer sediments.

Station TJE3, at the mouth of the estuary, was directly in the path of the wastewater conveyed by the Tijuana River. This site supported the lowest mean density of bivalves and, at least in September 1989, very high densities of opportunistic polychaetes. In addition, the fewest fish species were collected here.

Populations of southern California coastal wetland fishes have marked seasonality, with highest densities in summer and low densities in winter; however, there are inconsistencies in TJE populations that suggest that this system did not display typical seasonality. These include the low densities encountered in June 1986 and June 1987 (Fig. 8) and the low species richness in June 1987 and March 1989 (Fig. 7). We suggest that this departure from typical seasonal patterns can be attributed to the impacts of modified hydrology.

The shift in the structure of the fish assemblage at TJE to one dominated by *Clevelandia ios* may be due partly from reduced predation pressure. *Clevelandia ios* is preyed upon by a number of estuarine species including *Paralichthys californicus, Hypsopsetta guttulata, Leptocottus armatus* (Pacific staghorn sculpin), and *Fundulus parvipinnis,* according to MacDonald (1975). Although not reported as a predator of *Clevelandia ios, Gillichthys mirabilis* has been observed to be an aggressive predator and cannibal. All of these potential predators have declined in density following mouth closure in 1984 (Nordby 1987) and the multiple disturbances discussed herein. An additional factor that may allow *Clevelandia ios* to dominate disturbed areas is its life history strategy. *Clevelandia ios* matures within one year (Brothers 1975) and spawns from September through June. In 1981, peak spawning at TJE occurred in March, April, and May, with lesser peaks in September and January (Nordby 1982). Larvae were collected in densities greater than 60 m^{-3} in April 1981.

Other components of the channel assemblage are also quick to mature. The dominant polychaetes at both LPL and TJE were species that reach sexual maturity rapidly. Some capitellid species mature sexually in as little as one month and may reproduce year-round (Grassle and Grassle 1976).

High densities of capitellids and *Polydora* spp. may have been encouraged by sewage spills. Both taxa are associated with pollution. Capitellids are considered enrichment opportunists (Pearson and Rosenberg 1978) while *Polydora cornuta* has been reported from areas of high organic matter (Pearson 1975).

In Los Angeles Harbor, Crippen and Reisch (1969) found that *Capitella* sp. and *Polydora cornuta* were most abundant in polluted to very polluted areas. Capitellids have also been shown to increase in density when the source of disturbance ceases, for example, abatement of a pollution source (Rosenberg 1976; Sanders et al. 1980). Thus, the reason for their sudden increase at TJE3 in September 1988 does not necessarily indicate increased wastewater flows.

TIJUANA ESTUARY-LOS PEÑASQUITOS LAGOON COMPARISON

Hydrologic disturbances had a greater impact on the channel assemblage at LPL than TJE. During nontidal conditions at LPL, both fish and benthic invertebrate assemblages experienced seasonal storms and changes in water quality. Populations plummeted following flooding in fall 1987. In spring and summer 1988, the channel organisms recovered, until the December storm event in 1988, which again decimated populations.

There were few spatial patterns in fish and benthic invertebrate distributions within LPL despite stations specifically chosen near the mouth and near freshwater inflows. The small size of the lagoon and its usual closure made its waters relatively homogeneous. Polychaetes were generally more dense at the mouth (LPL3) but were also found in high densities at the other stations at some times of the year. *Gambusia affinis* was found in highest densities at the station most affected by freshwater (LPL1).

Freshwater input to LPL is increasing as the watershed is developed. Flows from Carmel Valley Creek continued throughout the summer and autumn of 1988, a period that is usually dry. This flow has resulted in the encroachment of brackish marsh into the salt marsh and introduced high numbers of *Gambusia affinis* to the landward edges of the lagoon. A long-term increase in freshwater input into the lagoon may jeopardize this coastal wetland.

FUTURE HYDROLOGIC DISTURBANCES

Several municipalities and water utility districts in San Diego County are proposing to discharge treated wastewater into coastal streams, since the ocean outfalls are now at capacity. The California Regional Water Quality Control Board, San Diego Region (1988) projects releases of 10 to 30 MGD by the year 2015 for 10 county streams. All of these streams have natural flow peaks in the winter and many have little or no flow in summer. While plans call for the reuse of treated wastewater for irrigation, streamflows would still be augmented in winter, and the period of heavy flow would no doubt be extended. Shifts in wetland vegetation from dominance by salt marsh halophytes to brackish marsh species (*Typha* and *Scirpus* spp.) have been predicted previously (Zedler et al. 1984). Based on our analyses of channel assemblage responses to hydrologic disturbances, we now predict major impacts to fishes and macroinvertebrates. Discharge of treated wastewater to small coastal wetlands such as LPL, which are frequently closed to tidal flushing, will likely result in the extermination of most or all of the channel biota or replacement with fresh/brackish water species. In many cases these include exotic fish species such as *Acanthogobius flavimanus* (yellowfin goby) and *Gambusia affinis* and invertebrates such as the Asian bivalves *Corbicula fluminea* and *Musculista senhousia.*

Conclusion

The two coastal wetlands compared in this study differ in types and degrees of disturbance. Tijuana Estuary (TJE) has been subjected to continuous, long-term wastewater inflows while Los Peñasquitos Lagoon (LPL) has had flooding once in 1987 and once in 1988. The channel biota of each system were altered by these events, but short-term recovery appears to be greater at TJE, where tidal flushing is now continuous.

At TJE, the structure of the fish assemblage has shifted toward dominance by species with an extended spawning season and rapid maturity. Bivalve populations are composed of young individuals as the result of disturbance events. Polychaete populations are dominated by taxa associated with pollution and that have prolonged spawning seasons and mature rapidly. The sampling station farthest from the wastewater inflows harbored significantly higher densities of bivalves than did the other sites. The sampling station nearest the source of wastewater supported the fewest fish species.

At LPL, the channel assemblage is dominated by species that can survive salinity shock and very low levels of dissolved oxygen, are easily reintroduced during brief periods of mouth opening, or are introduced from freshwater inflows. Density and diversity of all species mirrors the changes in water chemistry; both decrease as water quality deteriorates and increase after water quality improves.

Neither of these coastal wetlands has a channel assemblage that is characteristic of pristine tidal ecosystems. Long histories of disturbance have shifted their composition to a small group of species that is tolerant of reduced salinity. Resilience in the short term is conferred by opportunistic life histories and quick reestablishment following the return of tidal influence. Recovery in the long term would require elimination of the hydrologic disturbances and time for native species to reinvade from refuges within the region's coastal water bodies.

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This manuscript is dedicated to Jordan Dale Covin, friend and colleague, who passed away during its preparation.

LITERATURE CITED

BROTHERS, E. G. 1975. The comparative ecology and behavior of three sympatric gobies. Ph.D. Thesis, University of California, San Diego. 370 p.

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD, SAN DIEGO REGION. 1988. Staff report on stream enhancement and reclamation potential, 1988 through 2015. 32 p.

CITY OF SAN DIEGO. 1988. Final Environmental Impact Report for the Proposed South Bay Land Outfall—Phase I. EQD No. 87-0638. Planning Department, San Diego.

Crippen, R. W. and D. J. Reish. 1969. An ecological study of the polychaetous annelids associated with fouling material in Los Angeles Harbor with special reference to pollution. Bulletin of the Southern California Academy of Science 68:170–187.

Duggan, R. M. 1989. The bivalve community and potential role of *Laevicardium substriatum* in the Tijuana Estuary. M.S. Thesis, San Diego State University, San Diego, California. 131 p.

Emery, K. O. 1938. Rapid method of mechanical analysis of sands. *Journal of Sedimentary Petrology* 8:105–111.

Folk, R. L. and W. C. Ward. 1957. Brazos River bar, a study of the significance of grain-size parameters. *Journal of Sedimentary Petrology* 27:3–27.

Grassle, J. F. and J. P. Grassle. 1976. Sibling species in the marine pollution indicator *Capitella* (Polychaeta) *Science* 192: 567–569.

Hosmer, S. C. 1977. Pelecypod-sediment relationships at the Tijuana Estuary. M.S. Thesis, San Diego State University, San Diego, California. 119 p.

Krumbein, W. C. and F. J. Pettijohn. 1938. Manual of Sedimentary Petrology. Appleton-Century-Crofts, New York. 549 p.

MacDonald, C. K. 1975. Notes on the family Gobiidae of Anaheim Bay, p. 117–122. *In* E. D. Lane and C. W. Hill (eds.), The Marine Resources of Anaheim Bay. *California Fish and Game Fish Bulletin.*

Nordby, C. S. 1982. The comparative ecology of ichthyoplankton within Tijuana Estuary and in adjacent nearshore waters. M.S. Thesis, San Diego State University, San Diego, California. 101 p.

Nordby, C. S. 1987. Response of channel organisms to estuarine closure and substrate disturbance, p. 318–321. *In* Wetland and Riparian Systems of the American West. Proceedings of Society of Wetland Scientists' Eighth Annual Meeting, Seattle, Washington.

Nordby, C. S. 1988. Fish and benthic invertebrate dynamics: Responses to wastewater influxes. NOAA Technical Memorandum, NOS MEMD, Washington, D.C. 43 p.

Onuf, C. P. and M. L. Quammen. 1983. Fishes in a coastal California lagoon: Effects of major storms on distribution and abundance. *Marine Ecology Progress Series* 12:1–14.

Pearson, T. H. 1975. The benthic ecology of Loch Linnhe and Loch Eil, a sea-loch system on the west coast of Scotland. IV. Changes in the benthic fauna attributable to organic enrichment. *Journal of Experimental Marine Biology and Ecology* 20:1–41.

Pearson, T. H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment, p. 229–311. *In* H. Barnes (ed.), Oceanography and Marine Biology an Annual Review. Vol. 16.

Peterson, C. H. 1972. Species diversity, disturbance and time in the bivalve communities of some California lagoons. Ph.D. Thesis, University of California, Santa Barbara. 230 p.

Peterson, C. H. 1975. Stability of species and of community for the benthos of two lagoons. *Ecology* 56:958–965.

Purer, E. A. 1942. Plant ecology of the coastal salt marshlands of San Diego County. *Ecological Monographs* 12:82–111.

Rosenberg, R. 1976. Benthic faunal dynamics during succession following pollution abatement in a Swedish estuary. *Oikos* 27:414–427.

Sanders, H. L., J. F. Grassle, G. R. Hampson, L. S. Morse, S. Garner-Price, and C. C. Jones. 1980. Anatomy of an oil spill: Long-term effects from the grounding of the barge *Florida* off West Falmouth, Massachusetts. *Journal of Marine Research* 38:265–380.

Seamans, P. 1988. Wastewater creates a border problem. *Journal of the Water Pollution Control Federation* 60:1799–1804.

Shaw, W. N. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)—common littleneck clam. U.S. Fish and Wildlife Service Biological Report 82(11.46). U.S. Army Corps of Engineers, TR EL-82-4. 11 p.

Zedler, J. B. and P. A. Beare. 1986. Temporal variability of salt marsh vegetation: The role of low-salinity gaps and environmental stress, p. 295–306. *In* D. Wolfe (ed.), Estuarine Variability. Academic Press, New York.

Zedler, J. B. and C. S. Nordby. 1986. The ecology of Tijuana Estuary: An estuarine profile. U.S. Fish and Wildlife Service Biological Report 85(7.5). 104 p.

Zedler, J. B., T. Winfield, and P. Williams. 1980. Salt marsh productivity with natural and altered tidal circulation. *Oecologia* 44:236–240.

Zedler, J. B., R. Koenigs, and W. P. Magdych. 1984. Freshwater release and southern California coastal wetlands. Technical report. San Diego Association of Governments. SANDAG, San Diego. 177 p.

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SEASONAL ABUNDANCE, COMPOSITION, AND PRODUCTIVITY OF THE LITTORAL FISH ASSEMBLAGE IN UPPER NEWPORT BAY, CALIFORNIA

LARRY G. ALLEN[1]

ABSTRACT

This study was designed to characterize the littoral fish populations by 1) composition and principal species, 2) diversity and seasonal dynamics, 3) productivity, and 4) important environmental factors.

Monthly samples (January 1978 to January 1979) obtained with four quantitative sampling methods at three stations in upper Newport Bay yielded 55,561 fishes from 32 species which weighed 103.5 kg. The top five species made up over 98% of the total number of individuals. One species, *Atherinops affinis*, predominated in numbers (76.7% of all fishes) and biomass (79.8%). This dominance was reflected in the low overall H' diversity values for numbers ($H'_N = 0.89$) and biomass ($H'_B = 0.84$). Number of species, number of individuals, and biomass were greatest during the spring and summer.

Quantitative clustering of species based on individual samples revealed five species groups which reflected both microhabitat and seasonal differences in the littoral ichthyofauna. Species Group I was made up of five resident species—*A. affinis*, *Fundulus parvipinnis*, *Clevelandia ios*, *Gillichthys mirabilis*, and *Gambusia affinis*. Species Groups II-VI were composed of summer and winter periodics and rare species.

The mean annual production (9.35 g dry weight m^{-2} determined by the Ricker production model) of the littoral zone fishes was among the highest of reported values for comparable studies. This high annual production was mainly the result of the rapid growth of large numbers of juveniles that utilized the littoral zone as a nursery ground. Young-of-the-year *Atherinops affinis* contributed 85% of this total production.

Canonical correlation analysis indicated that temperature and salinity together may influence littoral fish abundance. These two abiotic factors accounted for 83% of the variation in the abundances of individual species. Emigration from the littoral zone, therefore, seems to be cued by seasonal fluctuations in temperature and salinity. I propose that this offshore movement forms an important energy link between the highly productive littoral zone and local, nearshore marine environment.

Semienclosed bays and estuaries are among the most productive areas on Earth, ranking with oceanic regions of upwelling, African savannas, coral reefs, and kelp beds (Haedrich and Hall 1976) in terms of animal tissue produced per year. Bays and estuaries harbor large stocks of nearshore fishes and are important feeding and nursery grounds for many species of fish, including commercially important ones. However, the high productivity of fishes is accompanied by low diversity (Allen and Horn 1975) which probably reflects the stressful ecological conditions in bays and estuaries and the high physiological cost of adaptation to them (Haedrich and Hall 1976). The few studies that have dealt with productivity in estuarine fishes were summarized by Wiley et al. (1972) and Adams (1976b).

Utilization of temperate embayments by juvenile and adult fishes is markedly seasonal with high abundances corresponding to the warmer, highly productive months of spring through autumn. Seasonal species typically spend one spring-autumn period in the shallows of a bay growing at an accelerated rate in the warm, highly productive waters (Cronin and Mansueti 1971).

Most studies to date dealing with composition and temporal changes of bay-estuarine fish populations have been conducted on the Gulf of Mexico and Atlantic coasts of the United States where estuaries are larger and more numerous than those on the Pacific coast (e.g., Bechtel and Copeland 1970; Dahlberg and Odum 1970; Derickson and Price 1973; McErlean et al. 1973; Oviatt and Nixon 1973; Recksiek and McCleave

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[1] Department of Biological Sciences, University of Southern California, Los Angeles, Calif.; present address: Department of Biology, California State University, Northridge, CA 91330.

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1973; Haedrich and Haedrich 1974; Targett and McCleave 1974; Livingston 1976; Moore 1978; Shenker and Dean 1979; Orth and Heck 1980). Although quantitative in nature, many of these investigations suffer from the inefficient (Kjelson and Johnson 1978) trawl sampling gear used and the high mobility of most fishes. Adams (1976a, b) used dropnet samples to accurately assess the density and productivity of the fishes of two North Carolina eelgrass beds. Weinstein et al. (1980) used a combination of block nets, seines, and rotenone collections to derive accurate quantitative estimates of fishes in shallow marsh habitats in the Cape Fear River Estuary, N.C.

Previous investigations of fishes in Newport Bay have included a species list (Frey et al. 1970), a general species account (Bane 1968), two individual species accounts (Fronk 1969; Bane and Robinson 1970), and two studies on the population ecology of the fauna based on juveniles and adults (Posejpal 1969; Allen 1976). An assessment of the ichthyoplankton and demersal fish populations during 1974-75 (Allen and White in press) is the most comprehensive work to date.

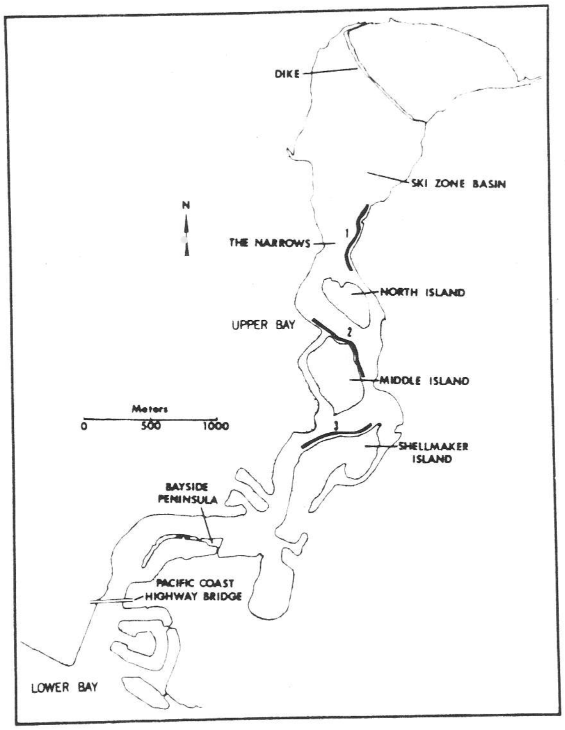

FIGURE 1.—Map of upper Newport Bay, Orange County, Calif., with the locations of the three sampling stations.

Despite these studies, a substantial component of the ichthyofauna, the littoral fishes of the upper bay (0-2 m depth from mean higher high water), had not been adequately sampled. In a study of the demersal ichthyofauna of Newport Bay during 1974-75 (Allen 1976), I found that three—*Atherinops affinis, Fundulus parvipinnis,* and *Cymatogaster aggregata*—of the five most numerous species were the ones that occurred in the shallow water over the mudflats which cover about 60-70% of the surface area of the upper bay reserve. Despite their high numerical ranking, the relative abundances of these littoral species were underestimated because sampling was carried out almost exclusively by otter trawls in the deeper channels of the upper bay. The recognition of this gap in our knowledge served as the impetus for the present study.

The main purposes of this study were to characterize the littoral ichthyofauna of upper Newport Bay quantitatively by 1) composition and principal species, 2) diversity and seasonal dynamics, 3) productivity, and 4) key environmental factors that are influencing this fish assemblage.

METHODS AND MATERIALS

Study Area

Newport Bay (lat. 33°37′30″N, long. 117°54′20″W) is located in Orange County, Calif., 56 km southeast of Los Angeles and 140 km north of the Mexican border (Fig. 1). The upper portion is the only large, relatively unaltered bay-estuarine habitat in California south of Morro Bay (lat. 34.5°N). The low to moderately polluted lower portion, commonly called Newport Harbor, has been severely altered by dredging activities, landfills, and bulkheads to accommodate more than 9,000 boats. The study area, the upper two-thirds of the upper bay, is bordered almost completely by marsh vegetation and mudflats. The California Department of Fish and Game purchased and set aside this area as an ecological reserve in 1975.

Three stations, about 0.5 km in length, were spaced evenly along the shore of the upper Newport Bay (Fig. 1). Sampling was stratified based on prior information on the uniqueness of the fish fauna of the three areas (Allen 1976). This design also allowed thorough coverage of the study area. Each station was situated on a littoral (intertidal) mudflat area adjacent to marsh vegetation

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and was divided into 10 numbered sections of equal size. Selection of the section sampled each month was random in order to satisfy statistical assumptions and minimize the impact of sampling on any particular section from month to month. Each station included a tidal creek or pool (panne) which was sampled on the marsh islands.

Sampling Procedures

Monthly samples were taken at the three stations during the 13-mo period from January 1978 to January 1979 for a total of 39 station samples. Sampling was carried out within ±3 h of daytime neap high tide to minimize tidal level effects. Two days were usually required to sample three stations, stations 1 and 2 the first day and station 3 the second.

Four types of sampling gear were employed at each station as follows:

1) A 15.2 m × 1.8 m bag seine (BS) with 6.4 mm mesh in the wings and 3.2 mm mesh in the 1.8 × 1.8 × 1.8 m bag was used twice at each station. Hauls were made by setting the net parallel to and 15 m off the shore at a depth of 1-2 m. The BS was then hauled to shore using 15 m polypropylene lines attached to 1.8 m brails on each end of the net. Each haul sampled an area of 220 m^2.

2) A 4.6 m × 1.2 m small seine (SS) with 3.2 mm mesh was pulled 10 m along and 2 m from the shore (at a depth to 1 m) and pivoted to shore. Two hauls were made in the inshore area and one haul in the panne at each station. Each haul sampled an area of 62.4 m^2. [One exception to the sampling routine occurred at station 3 panne in April 1978 when no sample was taken due to a dry panne.]

3) A 2.45 × 2.45 × 1.0 m dropnet (DN) with 3.2 mm mesh was used to sample the water column and bottom at 0.5-1.5 m depth. The DN was suspended from a 5.0 × 5.0 × 1.0 m aluminum pipe frame, released by pins at each corner. Two 19 l plastic buckets were attached to each corner of the frame for flotation. The net and frame were maneuvered into position, anchored, and left undisturbed for 10 min. After release the DN was pursed by the chain line and hauled to shore by nylon line. The DN sampled an area of 6.0 m^2.

4) A small, square enclosure (SE) was used in conjunction with an anesthetic (quinaldine mixed 1:5 with isopropyl alcohol) with the intent of sampling small burrow inhabiting fishes, especially gobies. The SE was constructed of heavy duck material mounted on a 1.0 × 1.0 × 1.0 m collapsible frame of 25.0 mm PVC pipe and sampled 1.0 m^2 of bottom. The SE was set at three randomly chosen positions in an undisturbed portion of each station section at a depth of 0.5-1.0 m. The bottom of the SE was forced into the upper few centimeters of substrate and the quinaldine mixture added to the enclosed water column. The enclosed volume and shallow substrate was then thoroughly searched for 10 min using a long-handled dip net of 1.0 mm mesh.

A detailed comparison of the effectiveness of these four methods is the subject of a separate paper (Horn and Allen[2]).

Ten samples were taken at each of the three stations each month (2 BS samples, 3 SS samples, 2 DN samples, 3 SE samples) for a total of 30 samples/mo and 289 samples over the study (minus one SS haul in April 1978 at station 3).

Catches were either frozen on Dry Ice[3] or preserved in 10% buffered Formalin. Specimens >150 mm SL were injected abdominally with 10% buffered Formalin. Subsamples of frozen specimens were oven dried (40°C) for 48-72 h for dry weight determination. Mean dry weights were based on a minimum of 20 individuals/size-class of each common species at each station each month.

Data on six abiotic factors were recorded or determined for each station: temperature, salinity, dissolved oxygen, sediment particle size, depth of capture (by individual samples), and distance into the upper Newport Bay from the Highway 1 bridge (see Fig. 1).

Production Estimation

Production is the total amount of tissue produced during any given time interval including that of individuals which do not survive to the end of that time interval (Ivlev 1966). Productivity is the rate of production of biomass per unit of time (Wiley et al. 1972). Production of a fish stock

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[2] Horn, M. H., and L. G. Allen. Comparison of methods for sampling shallow-water estuarine fish populations. Manuscr. in prep. California State University, Fullerton, Fullerton, CA 92634.

[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

is the product of the density of fish and the growth of the individuals (Ricker 1946).

An HP9100A program was developed with the aid of Joel Weintraub (California State University, Fullerton) to calculate the production of each recognizable size-class of the common species, those which were collected in at least 2 consecutive months at each station. The model used was that proposed by Ricker (1946) and modified by Allen (1950) and is calculated as follows:

$$P = G\bar{B}$$

where $G = \dfrac{\log_e \bar{w}_2 - \log_e \bar{w}_1}{\Delta t}$ is the instantaneous coefficient of growth;

$\bar{B} = \dfrac{B_1(e^{G-Z}-1)}{G-Z}$ is the average biomass over the time interval;

$Z = \dfrac{-(\log_e N_2 - \log_e N_1)}{\Delta t}$ is the instantaneous coefficient of population change of the immediate sampling area (station) attributable to mortality and migration;

B is the biomass density of fishes at t_1; w_1, w_2 are the mean weights of individuals at time t_1 and t_2; and N_1, N_2 are the numbers of fishes present at t_1 and t_2. $G-Z$ is the net rate of increase in biomass during Δt (1 mo).

The model assumes that production data need not be corrected for immigration and emigration of fishes in and out of the sampling area, provided the density and growth by size-class are estimated frequently enough to accurately assess the abundance and growth of fishes actually in the sampling area (Chapman 1968).

In the present study, growth increments were estimated from length-frequency data for fishes from all three stations each month for each size-class. The length data, therefore, were representative of the entire population of the size-class in the upper Newport Bay and served to minimize the effects which localized movements into and out of a particular station have on monthly growth values. The average weight, $\bar{w}$, of a size-class per month was calculated as follows: 1) Dry weight equivalent for the median length in a size interval (5 mm intervals) was determined using standard length to dry weight curves for each common species; 2) the proportion (range 0-1) of individuals represented in the size interval was multiplied by the dry weight equivalent for the interval; 3) the products were then summed for all size intervals contained within the particular size-class of the species yielding an average weight, $\bar{w}$. This method proved to be more accurate than simply taking the mean length of the entire size-class and determining the dry weight equivalent.

The "best estimate" of biomass density (B) for each discernible size-class was determined in the following manner: 1) The biomass density (wet weight) derived from the method (BS, SS, DN, or SE) shown to be most effective at sampling the particular species was used. Table 1 lists the species with corresponding collecting gear ranked by their effectiveness at capturing the species. This list is based on a comparative study of the sampling methods (Horn and Allen footnote 2); 2) if, as in a few cases, the biomass estimated was inordinately high, due to a large catch in one replicate sample, the estimate defaulted to the next gear type in the rank order; 3) the biomass estimate in wet weight was converted to a dry weight (DW) equivalent by a conversion factor determined for each species and entered into the production model as B_1 (g DW/m^2). Production is the total of all positive values for size-classes during a time period (1 mo in this case) at each station. Negative values were due to sampling error and emigration and were not included in production estimates.

Large individuals (>100 mm SL) of *Mugil cephalus* were not included in production esti-

TABLE 1.—Methods for best estimate of species densities ranked by effectiveness (Horn and Allen text footnote 2). BS = bag seine; SS = small seine; DN = dropnet; SE = square enclosure.

Species	Methods ranked by effectiveness
Atherinops affinis	BS, SS
Fundulus parvipinnis	SS, BS
Clevelandia ios	SE, SS, DN
Anchoa compressa	BS, SS, DN
Gambusia affinis	SS, BS
Cymatogaster aggregata	BS, DN, SS
Gillichthys mirabilis	SS, SE, BS
Anchoa delicatissima	BS, SS
Mugil cephalus	SS, BS
Engraulis mordax	BS, SS
Leuresthes tenuis	BS, SS
Quietula ycauda	DN, SS
Ilypnus gilberti	DN, SS
Syngnathus spp.	SS, DN
Hypsopsetta guttulata	SS, DN
Lepomis macrochirus	BS, SS
Lepomis cyanellus	BS, SS
All other species	BS, SS

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mates because quantitative estimates of densities could not be obtained for the large members of this mobile species.

Data Analysis

Cumulative Species Curve

The cumulative number of species in February (low fish density) and June (high fish density) was plotted against the number of samples taken in order to assess the adequacy of sampling. Two random sequences were used for the arrangement of the 30 samples taken each month by the four methods. Each method sampled a unique subhabitat within the littoral zone. Cumulative species curves (reflecting presence/absence) were based on a combination of methods to insure that all possible species occupying the littoral zone at a particular time were represented.

Diversity

Both the Shannon-Wiener information function (Shannon and Weaver 1949) and species richness were used as measures of diversity for pooled station and upper bay samples. The Shannon-Wiener index reflects both species richness and evenness in a sample.

Cluster Analysis and Canonical Correlation

The Ecological Analysis Package (EAP) developed by R. W. Smith was used at the University of Southern California Computer Center to determine species associations (cluster analysis), species abundance correlations to abiotic factors (multiple regression subprogram), and possible effects of abiotic factors on individual species abundance (canonical correlation).

The cluster analysis utilized the Bray-Curtis index of dissimilarity (Clifford and Stephenson 1975). This index allowed quantitative clustering without assuming normality in the sampled population. A square-root transformation of species counts was done to counter the tendency of this index to overemphasize dominant species.

Canonical correlation analysis was used to determine whether and to what extent abiotic factors interacted with individual species abundances in the 39 station samples over the study period. Two separate canonical correlation analyses were made: The first run included six abiotic factors—temperature (TEMP), salinity (SAL), dissolved oxygen (DO), distance into the upper bay from the Highway 1 bridge (DSTUPB), average particle size of the sediment (APRTSZ), and depth of capture (DPTHCAP); the second included only temperature and salinity to determine the amount of variation these two factors accounted for alone.

RESULTS

Temperature and Salinity Patterns

Water temperatures of the littoral zone at all three stations increased steadily during the period January-June from 14°-15°C to 26°-28°C (Fig. 2). The temperatures remained high (>25°C) throughout the summer months and then declined gradually until November. Between November and December the temperature dropped sharply at each station. Temperatures in the pannes were generally higher than the tempera-

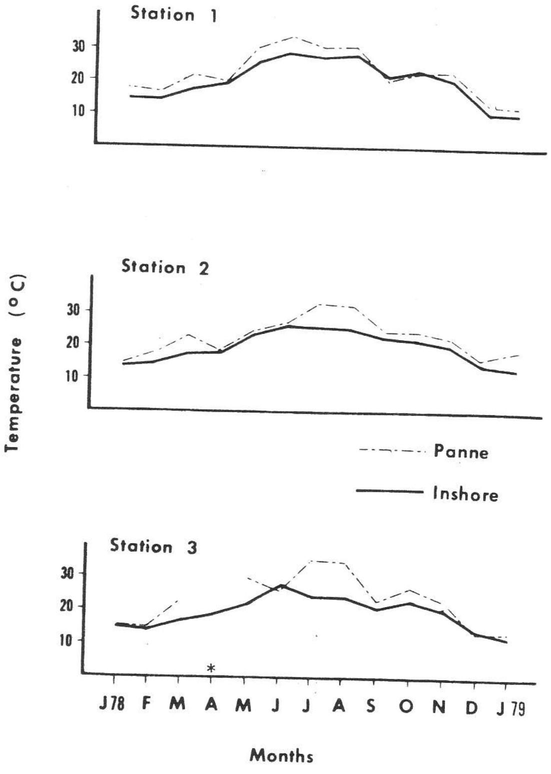

FIGURE 2.—Month-to-month variation (January 1978-January 1979) in water temperature (°C) for the alongshore area and panne at each of the three sampling stations. (* = panne dried-up.)

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tures along the shore especially in the summer months (July-September).

Salinity varied more than temperature (Fig. 3) due to rainfall and periodic runoff from surrounding urban areas. In general all stations had low salinities during January through March 1978, a period of heavy rainfall. After May 1978, salinities remained high (between 25 and 32 ppt) with decreases in June 1978 (stations 1 and 3, unknown cause), September 1978 (all stations due to heavy rainfall), and January 1979 (station 3 due to rainfall). Panne salinities at station 1 were consistently low (usually <6 ppt) indicating a constant freshwater input. The pannes at stations 2 and 3, however, usually had salinities equal to or higher than the alongshore area due to evaporation.

Total Catch

Sampling during the 13-mo period yielded 55,561 individuals of 32 species that weighed a total of 103.5 kg (Table 2).

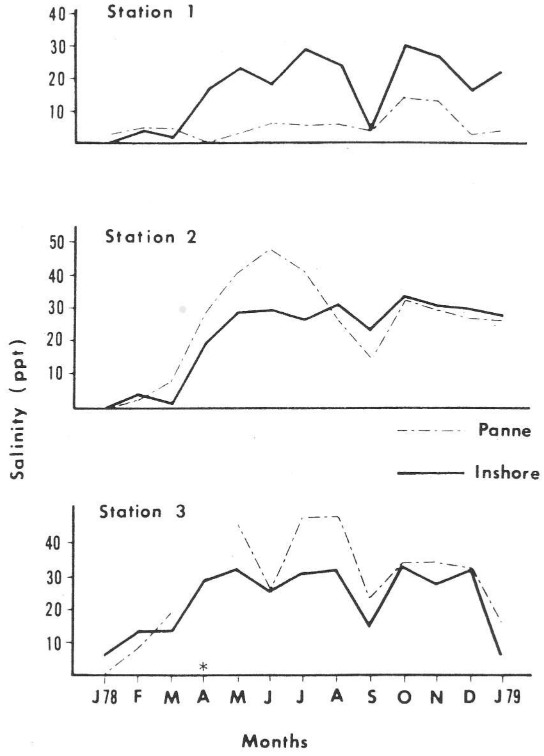

FIGURE 3.—Month-to-month variation (January 1978-January 1979) in salinity (ppt) for the alongshore area and panne at each of the three sampling stations. (* = panne dried-up.)

Atherinops affinis greatly predominated in numbers (76.7%) and biomass (79.9%). *Fundulus parvipinnis* ranked second in both numbers (12.1%) and biomass (7.6%), followed in order by *Gambusia affinis* (5.5% numbers), *Clevelandia ios* (2.4% numbers), and *Anchoa compressa* (1.2% numbers). These five species accounted for 98% of the total number of individuals and 96% of the total biomass (Table 2). The skewed distribution of number of individuals among species was reflected in the relatively low overall H' diversity values of 0.89 for numbers (H'_N) and 0.84 for biomass (H'_B). The vast majority of individuals of most species were either young-of-the-year or juveniles.

Station 1—A total of 13,859 individuals representing 19 species was collected during the year. The catch totaled 22.7 kg. All three of these totals were the lowest of those from the three stations. Overall H' diversity for numbers was 1.17 and for biomass, 0.89. *Atherinops affinis* ranked first in numbers (55.2%) and biomass (76.7%) but was less abundant here than at stations 2 and 3. *Gambusia affinis* (20.6%) and *Fundulus parvipinnis* (19.1%) were common at this station especially in the panne.

Station 2—The greatest number of individuals (24,813) and biomass (42.9 kg) were collected at this site. Although 27 species were captured, over 90% of these individuals were from one species, *Atherinops affinis*. The large number of attached eggs and small (<20 mm) fish caught in July (52% of all *A. affinis*) indicated that this area was a breeding site for *A. affinis*. *Fundulus parvipinnis* (4.4%) was second in numerical rank. H' for numbers (0.49) and biomass (0.70) were low.

Station 3—A total of 16,889 fishes belonging to 23 species were obtained at this station. *Atherinops affinis* made up 74.4% of the individuals and 78.8% of the 37.9 kg total biomass. Other important species in order of decreasing numerical abundance were *Fundulus parvipinnis* (17.6%), *Clevelandia ios* (3.4%), *Cymatogaster aggregata* (1.3%), and *Anchoa compressa* (1.3%). Overall, H'_N and H'_B were 0.87 and 0.85, respectively.

Cumulative Species Curves

Cumulative species curves from February and June (Fig. 4) reached an asymptote before 20 samples (about 66% of total samples), indicating

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TABLE 2.—Monthly abundance and biomass for fish species inhabiting the littoral zone of upper Newport Bay totaled for stations 1-3 (January 1978-January 1979).

Species	January 1978		February		March		April		May		June		July	
	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)
Atherinops affinis	15	70.5	5	158.3	4	92.0	15	59.1	322	1,212.1	6,296	2,377.6	19,817	19,093.3
Fundulus parvipinnis	377	315.7	208	198.3	181	90.4	17	20.7	35	92.2	89	112.3	758	854.8
Gambusia affinis	46	10.3	23	7.1	9	3.2	5	2.8	56	7.1	235	107.4	573	342.9
Clevelandia ios	49	21.4	39	14.3	80	12.9	47	6.1	100	22.4	74	15.8	485	109.0
Anchoa compressa	26	82.9	1	1.2	15	29.4	136	629.3	317	4,393.4	98	1,154.6	77	920.5
Cymatogaster aggregata							11	11.5	141	196.8	4	5.7		
Gillichthys mirabilis	12	2.4	38	5.9	14	3.5	5	10.0	17	39.6	49	127.1	52	141.4
Anchoa delicatissima	10	6.5	1	0.2	28	16.8	47	86.7	17	48.2			1	3.0
Mugil cephalus	41	78.0	11	7.1	1	1.5	1	555.5	1	550.0				
Engraulis mordax													81	89.4
Leuresthes tenuis														
Quietula ycauda	1	1.0							3	1.4	9	3.9	28	14.9
Ilypnus gilberti									3	0.5	10	1.0	24	6.5
Lepomis cyanellus			1	5.2										
Syngnathus auliscus									4	3.6	10	8.7	4	3.3
Hypsopsetta guttulata									10	1.9	4	12.9	2	18.2
Lepomis macrochirus	2	8.1	4	22.2	2	4.1								
Syngnathus leptorhynchus							1	2.1			2	2.6		
Leptocottus armatus					1	1.0			2	4.7	1	1.6		
Acanthogobius flavimanus							2	0.5	1	4.0				
Paralichthys californicus													2	5.4
Pimephales promelas			2	0.2										
Morone saxatilis											1	317.1		
Urolophus halleri														
Mustelus californicus													1	58.0
Seriphus politus														
Cynoscion nobilis													1	6.6
Sphyraena argentea														
Girella nigricans													1	0.4
Symphurus atricauda			1	0.2										
Porichthys myriaster														
Umbrina roncador														
Totals	579	596.8	334	420.2	335	254.8	287	1,384.3	1,029	6,577.9	6,882	4,248.3	21,907	21,667.6
n	10		12		10		11		15		14		16	
H'	1.29	1.46	1.33	1.27	1.37	1.55	1.61	1.22	1.76	1.07	0.44	1.24	0.46	0.56

TABLE 2.—*Continued.*

	August		September		October		November		December		January 1979		Totals			
Species	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)	No.	% No.	Wt (g)	% Wt
Atherinops affinis	4,645	13,181.2	4,122	9,606.2	2,902	14,016.0	2,474	12,409.8	1,143	5,738.8	831	4,650.1	42,591	76.67	82,665.0	79.86
Fundulus parvipinnis	312	250.1	1,707	2,323.0	1,023	2,638.8	1,356	738.0	593	259.7	66	26.5	6,722	12.10	7,920.5	7.65
Gambusia affinis	252	42.4	1,029	399.4	680	126.2	149	15.2	20	2.1			3,077	5.54	1,066.1	1.03
Clevelandia ios	68	16.4	151	41.8	66	16.3	142	31.3	28	3.9	5	1.1	1,334	2.40	312.7	0.30
Anchoa compressa	7	104.9	3	53.1	4	104.8							684	1.23	7,474.1	7.22
Cymatogaster aggregata	61	390.9	2	16.6			2	34.1	1	22.6	1	12.4	223	0.40	690.6	0.67
Gillichthys mirabilis	4	27.0	1	20.0	4	37.1	1	12.0			6	0.3	203	0.37	426.3	0.41
Anchoa delicatissima	64	234.4	26	71.7	1	3.5							195	0.35	471.0	0.46
Mugil cephalus									68	13.3	9	1.5	132	0.24	1,206.9	1.17
Engraulis mordax			29	58.6	2	7.2					1	—	113	0.20	155.2	0.15
Leuresthes tenuis	85	57.8	3	2.3									88	0.16	60.1	0.06
Quietula ycauda	5	1.9	4	1.5	2	0.4	1	0.1					53	0.10	25.1	0.02
Ilypnus gilberti							1	0.1					38	0.07	8.1	0.01
Lepomis cyanellus			31	49.3									32	0.06	54.5	0.05
Syngnathus auliscus	1	0.4			1	0.1							20	0.04	16.1	0.02
Hypsopsetta guttulata							1	2.9			2	0.2	19	0.03	36.1	0.03
Lepomis macrochirus													8	0.01	34.4	0.03
Syngnathus leptorhynchus	1	2.8	3	5.2							1	0.3	8	0.01	13.0	0.01
Leptocottus armatus													4	0.01	7.3	0.01
Acanthogobius flavimanus													3	0.01	4.5	<0.01
Paralichthys californicus													2	<0.01	5.4	0.01
Pimephales promelas													2	<0.01	0.2	<0.01
Morone saxatilis													1	<0.01	317.1	0.31
Urolophus halleri	1	430.0											1	<0.01	430.0	0.42
Mustelus californicus													1	<0.01	58.0	0.06
Seriphus politus					1	0.3							1	<0.01	0.3	<0.01
Cynoscion nobilis													1	<0.01	6.6	0.01
Sphyraena argentea							1	4.2					1	<0.01	4.2	<0.01
Girella nigricans													1	<0.01	0.4	<0.01
Symphurus atricauda													1	<0.01	0.2	<0.01
Porichthys myriaster							1	0.1					1	<0.01	0.1	<0.01
Umbrina roncador	1	44.2											1	<0.01	44.2	0.04
Totals	5,507	14,784.4	7,111	12,648.7	4,686	16,950.7	4,129	13,247.8	1,853	6,040.4	922	4,692.4	55,561		103,514.3	
n	14		13		11		11		6		9		32			
H'	0.69	0.55	1.10	0.77	0.99	0.54	0.92	0.27	0.90	0.23	0.42	0.06	0.89		0.84	

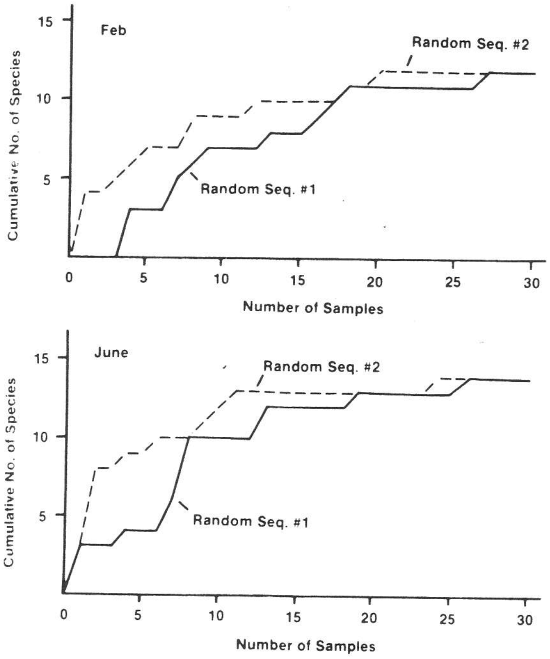

FIGURE 4.—Cumulative number of species as a function of the number of samples of all methods at stations 1-3 combined in upper Newport Bay for two different months (February and June 1978) during the study period. Curves were generated by two random sequences for each month.

that the range of fish species in the area had been adequately sampled by the four methods. Accumulation of species in June, however, was generally more rapid than in February.

Seasonal Abundance and Diversity

Fish abundance and diversity fluctuated markedly during the 13 mo of the study (Fig. 5). As a whole, the ichthyofauna of the littoral zone showed increased species richness from 10 species in January to 16 species in July 1978. The number of species was elevated (>14) for the entire spring-summer period from May to August 1978. Richness then decreased through the fall, reaching its lowest point of six species in December 1978. Diversity H' values fluctuated in a pattern opposite to that of species richness. H'_N decreased during the summer from a high in May of 1.76 to a low in June of 0.44. H'_B also decreased sharply in summer but unlike H'_N continued to decline for the remainder of the study. Both the number of individuals and biomass began to increase dramatically during May 1978 and reached peaks of 21,907 individuals and 21.7 kg in June. Both numbers and biomass decreased in August with number of individuals increasing again in September. Biomass declined once again in September during a period of rainfall and then increased in October. In the months from October 1978 to January 1979 a rapid decline in both numbers and biomass was evident and was especially pronounced from November to December. A greater number of individuals (992-579) and much greater biomass (4,692-597 g) was obtained in January 1979 than in January 1978.

Species Associations

Cluster analysis based on individual samples yielded five species groups which, upon further

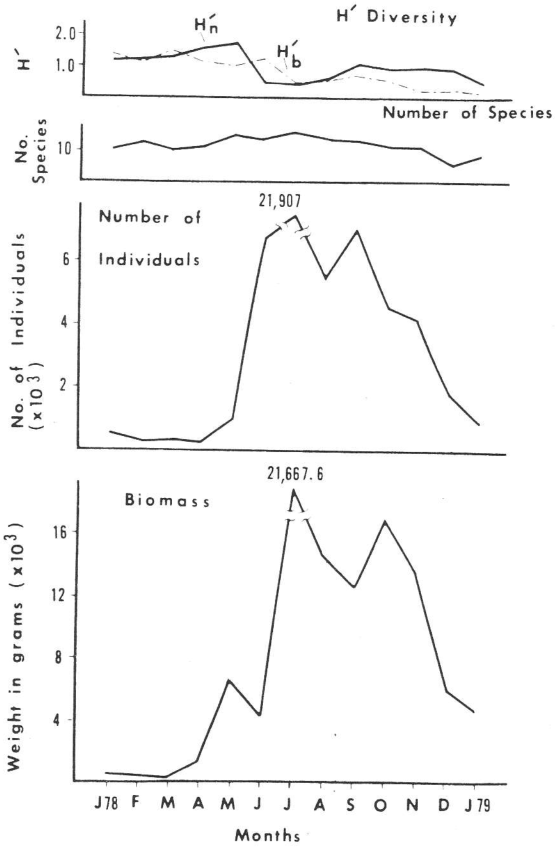

FIGURE 5.—Monthly variation (January 1978-January 1979) in total number of species, diversity H′ (for numbers, H'_N, and biomass, H'_B), number of individuals and biomass (g) for fishes collected by all methods at stations 1-3 combined in the littoral zone of upper Newport Bay.

examination, reflected both spatial (microhabitat) and seasonal differences in the littoral ichthyofauna (Fig. 6).

Group I was a loosely associated group of the five resident species (maintain populations year round in littoral zone) which could be further divided into three subgroups. Subgroup A had only one member, *Atherinops affinis*, an abundant schooling species. *Clevelandia ios* and *Gillichthys mirabilis* which comprised subgroup B are burrow-inhabiting gobiids of the shallows and pannes. Subgroup C included two species, *Fundulus parvipinnis* and *Gambusia affinis*, which inhabited pannes and other high intertidal areas. *Clevelandia ios*, *G. mirabilis*, and *F. parvipinnis* are residents of salt marshes in California and other west coast estuaries and are probably the species most threatened by alterations of these habitats.

Group II consisted of three midwater schooling species—*Anchoa compressa*, *A. delicatissima*, and *Cymatogaster aggregata*—most of which were caught mainly from January to August.

Group III was made up of three distinctly seasonal, benthic species: Two gobiids, *Quietula ycauda* and *Ilypnus gilberti*, and a cottid, *Leptocottus armatus*, which was relatively rare during 1978 compared with previous years (pers. obs.).

Group IV included an engraulid, *Engraulis mordax*; syngnathids, Syngnathus spp. (including *S. auliscus* and *S. leptorhynchus*); and the pleuronectid, *Hypsopsetta guttulata*. These species were seasonally present in mid- to late summer. Members of this group were only loosely associated (> 80% distance).

Group V was composed of four species which were collected at times of low salinities. *Lepomis macrochirus* and juveniles of *Mugil cephalus* were sampled together early in the year (January-March 1978). *Lepomis cyanellus* and *Leuresthes tenuis* were found together only in September.

Group VI included 12 rare species, most of which could be considered summer periodics in the littoral zone in 1978. These were *Umbrina roncador*, *Urolophus halleri*, *Paralichthys californicus*, *Mustelus californicus*, *Cynoscion nobilis*, *Acanthogobius flavimanus*, *Sphyraena argentea*, *Girella nigricans*, *Symphurus atricauda*, *Porichthys myriaster*, *Morone saxatilis*, and *Seriphus politus*.

Members of the species groups identified in the dendrogram (Fig. 6) are illustrated in dia

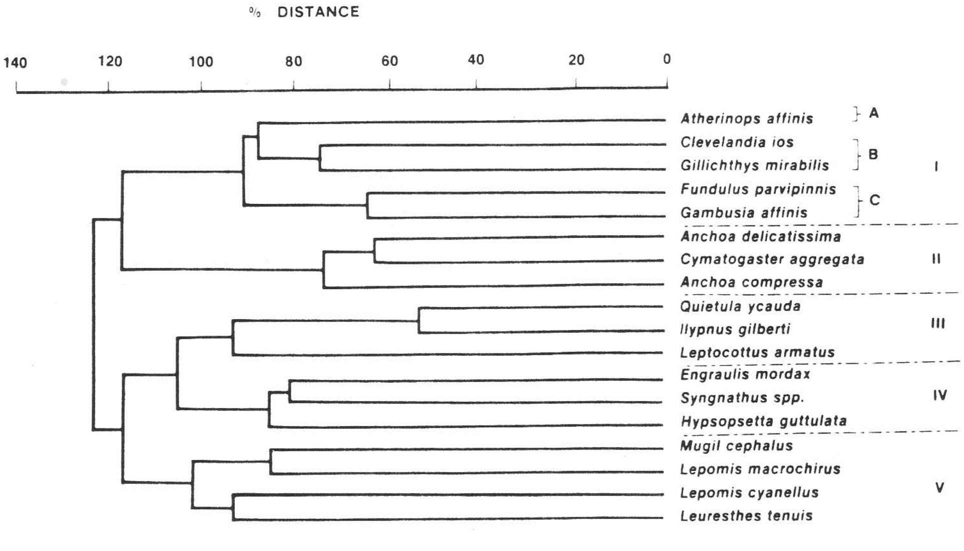

FIGURE 6.—Dendrogram of the clustering of littoral fish species by individual samples taken at stations 1-3 in upper Newport Bay, five species groups (Roman numerals) are recognized according to the Bray-Curtis index of dissimilarity (% distance). A, B, and C are subgroups of species Group I.

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grams (Figs. 7-9), depicting occurrences in the alongshore area or panne during three different time periods (January-March 1978, April-September 1978, and October 1978-January 1979). Only species with ≥5 individuals during each time segment were included in the diagrams. These diagrams illustrate the high degree of seasonality within this fish assemblage.

During the January-March 1978 period of heavy rainfall, members of three species groups (I, II, and V) were present in relatively low abundances (Fig. 7). A halocline existed at station 3 during this period, and *Atherinops affinis* was collected only seaward of the halocline at this station. Representatives of group V, *Mugil cephalus* juveniles and *Lepomis macrochirus*, were found associated with very low salinities. Large *M. cephalus* were observed in both the channel and littoral areas during most of the year.

The spring-summer period of April-September 1978 was characterized by increased water temperatures and salinities, accompanied by increased numbers of species and individual fishes (Fig. 8). Green algal beds, composed primarily of *Enteromorpha* sp., *Chaetomorpha linum*, and *Ulva lobata*, developed along the shore of the entire upper bay, and served as a nursery area for large numbers of juvenile fishes. All species groups, except V, were represented during this time. Juveniles of *Atherinops affinis* occurred in large numbers in the shallows with juvenile *Cymatogaster aggregata* also being abundant at station 3. Young-of-the-year *F. parvipinnis* were very abundant in the pannes, especially at stations 1 and 3.

By October the extensive algal beds had disappeared. The October 1978-January 1979 period was marked by decreased number of species and abundance (Fig. 9). The only common species were members of group I (residents) with a few juvenile *M. cephalus* representing group V.

Productivity

Annual production (mean of three stations by month) of the entire upper Newport Bay was 9.35 g DW/m^2 per year (Table 3). Young-of-the-year *Atherinops affinis* contributed 85.1% to total production followed by *Anchoa compressa* (4.9%) and *Fundulus parvipinnis* (4.2%).

Productivity was highly seasonal with the spring-summer period (April-September) accounting for 75.9% of the total annual production (Table 3, Fig. 10). Productivity, which was very

TABLE 3.—Monthly mean production (g DW/m^2) for individual species inhabiting the littoral zone (excluding panne) of upper Newport Bay (February 1978-January 1979).

Species	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Total annual	% total production
Atherinops affinis (adult)				0.0280	0.1049								0.1329	1.42
A. affinis (78 class)					0.0800	0.6764	5.1397		1.2942	0.6428		0.1307	7.9638	85.15
Fundulus parvipinnis	0.0005		0.0007	0.0240	0.0167	0.1323	0.0352	0.0826	0.1033				0.3953	4.23
Clevelandia ios	0.0003			0.0027	0.0051	0.0093	0.0068		0.0431			0.0145	0.0818	0.87
Anchoa compressa	0.0142		0.0045	0.1127	0.2524	0.0485	0.0154		0.0075				0.4552	4.87
Gillichthys mirabilis		0.0001	0.0014		0.0889	0.0361	0.0102	0.0020					0.1387	1.48
Hypsopsetta guttulata					0.0082	0.0020							0.0102	0.11
Mugil cephalus	0.0006	0.0004										0.0003	0.0013	0.01
Anchoa delicatissima	0.0030	0.0002	0.0039	0.0084	0.0013		0.0001	0.0017					0.0186	0.20
Quietula ycauda						0.0011							0.0011	0.01
Engraulis mordax							0.0046	0.0003					0.0049	0.05
Cymatogaster aggregata				0.0074	0.0072	0.0023		0.0101	0.0009				0.0279	0.30
Ilypnus gilberti						0.1197							0.1197	1.28
Lepomis macrochirus	0.0008												0.0008	0.01
Monthly total	0.0194	0.0007	0.0105	0.1832	0.5647	1.0277	5.2120	0.0967	1.4490	0.6428	0	0.1455	9.3522 g DW/m^2/yr	
													April-September 7.0948-75.86%	

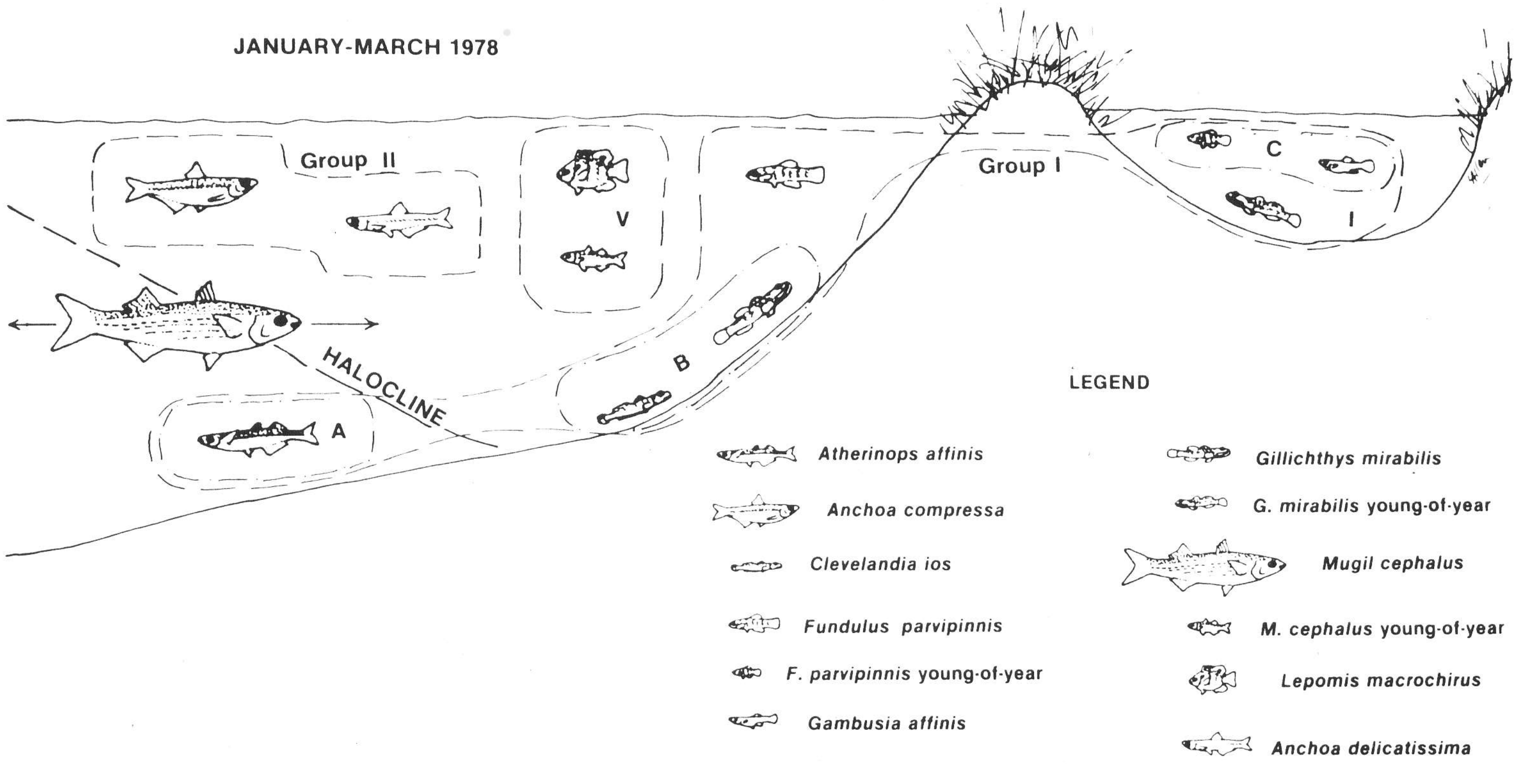

FIGURE 7.— Diagrammatic representation of the principal species inhabiting the littoral zone (alongshore and panne) of upper Newport Bay during January-March 1978. Inclusion level for species was ≥5 individuals in the samples during the period. Dashed lines enclose species from groups derived in the dendrogram of Figure 6. Arrows indicate inshore-offshore occurrence.

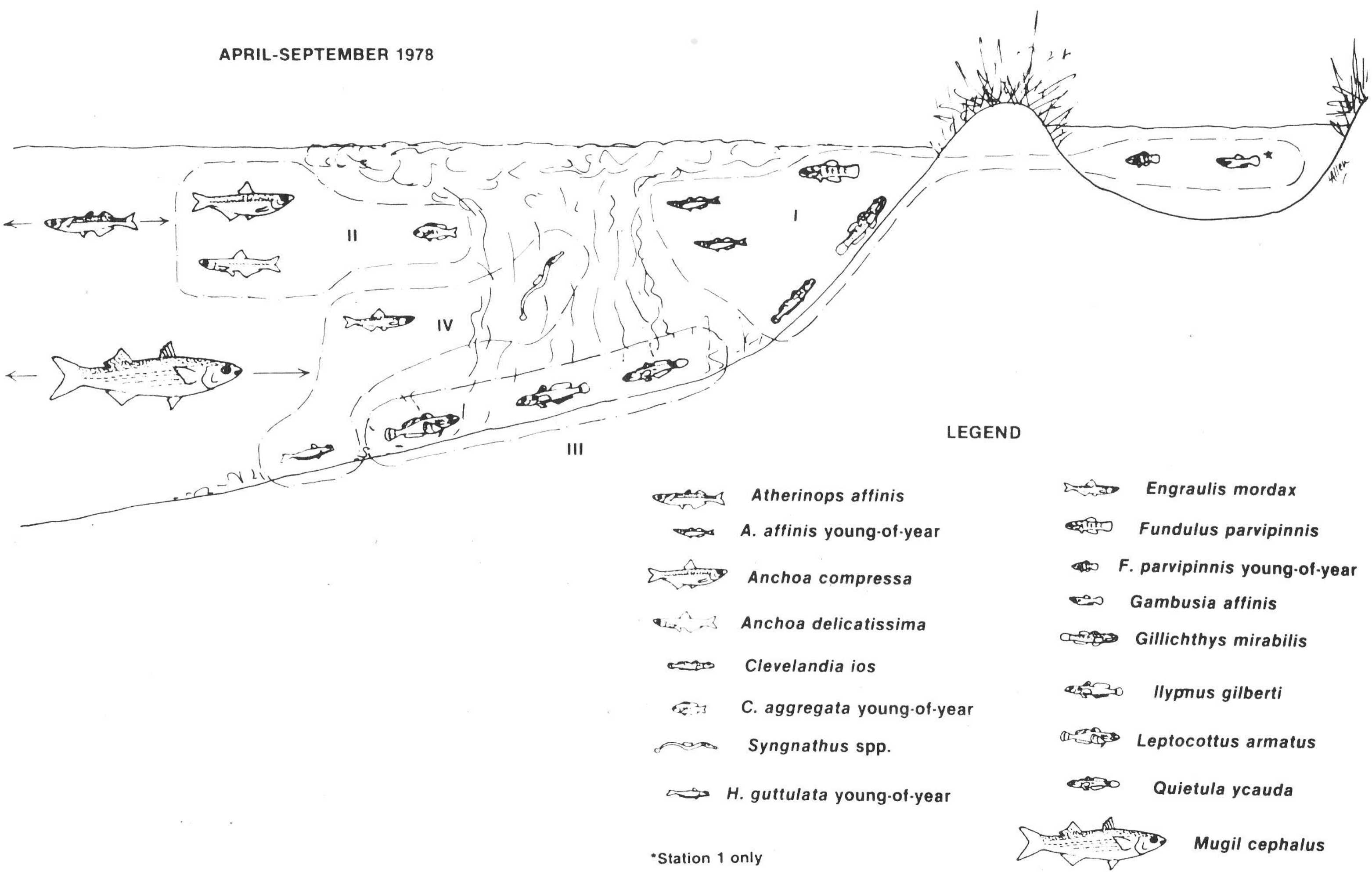

FIGURE 8.—Diagrammatic representation of the principal species inhabiting the littoral zone of upper Newport Bay during April-September 1978. Wavy vertical lines represent the large algal beds present during this period. Other information is the same as in Figure 7. (*Syngnathus* spp. includes *S. leptorhynchus* and *S. auliscus*.)

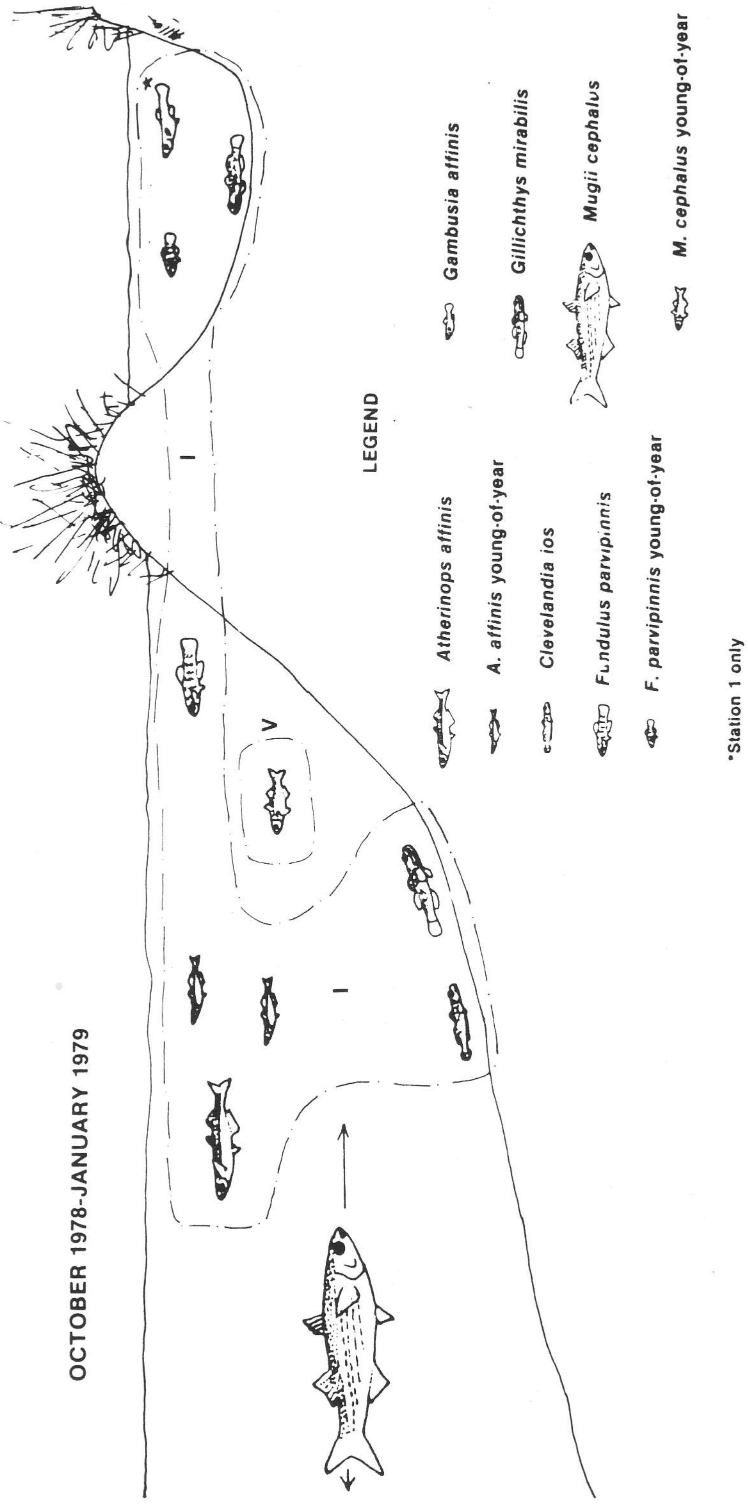

FIGURE 9.—Diagrammatic representation of the principal species inhabiting the littoral zone of upper Newport Bay during October 1978-January 1979. Other information as in Figure 7.

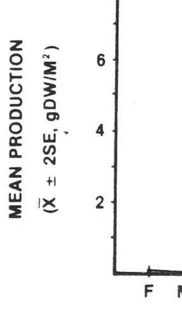

FIGURE 10.—Month
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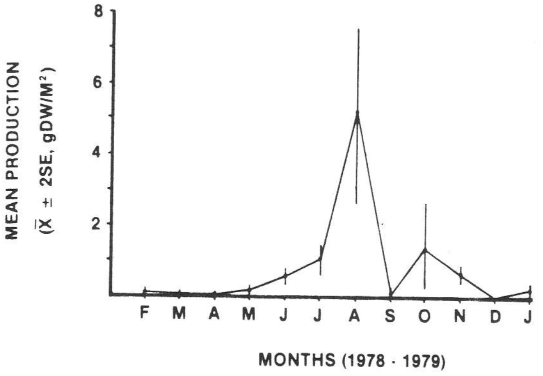

FIGURE 10.—Monthly variation in mean production ($\bar{x} \pm 2$ SE, g DW/m^2) of the littoral fishes from three stations in upper Newport Bay (February 1978-January 1979).

low from February to May 1978, increased rapidly from June to a peak in August (5.2 g DW/m^2). Monthly production then declined drastically in September, a period of heavy rainfall during which many of the larger young-of-the-year *Atherinops affinis* emigrated from the study area. Production increased in October but then showed a steady decline to zero in December, a time of a sharp decrease in mean water temperature in the upper bay.

Relationship of Abiotic Factors to Fish Abundance and Distribution

Temperature was found to have a significant, positive correlation ($P<0.01$, df = 37) with number of species ($r = 0.42$), number of individuals ($r = 0.48$), and biomass ($r = 0.54$) when station totals were considered. Similarly, salinity was significantly correlated with number of individuals ($r = 0.36$) and biomass ($r = 0.64$) (Table 4).

Temperature was the factor which yielded the highest number of significant correlations (6) with individual species, followed by salinity, dissolved oxygen, distance into the upper bay, and depth of capture, each with four (Table 4).

An analysis of intercorrelations among abiotic factors yielded three significant ($P<0.05$, df = 37) positive relationships: 1) Temperature and salinity ($r = 0.48$); 2) temperature and dissolved oxygen ($r = 0.53$); and 3) dissolved oxygen and distance into the upper bay ($r = 0.32$).

According to canonical correlation analysis, the six abiotic variables accounted for 93% of the variation in individual species abundances along the first canonical axis (Table 5). A second run indicated that 83% of the variation in species abundances could be accounted for by temperature and salinity alone. This finding strongly implies that interactive effects of temperature

TABLE 4.—Correlation coefficients (r) of individual species numbers and of total number of species, number of individuals, and biomass with six environmental factors. TEMP = temperature, SAL = salinity, DO = dissolved oxygen, DSTUPB = distance into upper Newport Bay from Highway 1 bridge, APRTSZ = average particle size of sediments, DPTHCAP = depth of capture.

	Abiotic factors					
Species	TEMP	SAL	DO	DSTUPB	APRTSZ	DPTHCAP
Atherinops affinis	0.55**	0.57**	0.21	0.00	−0.12	0.23
Fundulus parvipinnis	0.18	0.15	−0.31*	0.00	−0.06	0.03
Anchoa compressa	0.38*	0.21	0.35*	−0.01	0.05	0.24
Clevelandia ios	0.43**	0.22	0.08	−0.09	−0.16	0.23
Mugil cephalus	−0.62**	−0.29	−0.10	0.11	0.26	0.02
Gillichthys mirabilis	0.25	−0.22	0.44**	0.31*	0.01	0.00
Anchoa delicatissima	0.10	0.08	−0.22	−0.22	0.05	−0.02
Gambusia affinis	0.21	−0.25	0.16	0.58**	−0.07	−0.02
Hypsopsetta guttulata	0.30	0.21	0.43**	0.26	−0.10	0.28
Cymatogaster aggregata	0.14	0.28	−0.01	−0.34*	0.01	0.14
Quietula ycauda	0.46**	0.35*	0.19	−0.16	0.01	0.35*
Ilypnus gilberti	0.39*	0.31*	0.23	−0.10	0.11	0.33*
Lepomis macrochirus	−0.29	−0.44*	−0.23	0.10	0.09	0.04
Lepomis cyanellus	0.06	−0.27	−0.29	0.16	−0.20	0.05
Engraulis mordax	0.22	0.16	0.00	0.13	−0.07	0.33*
Leuresthes tenuis	0.16	0.14	−0.09	−0.15	0.10	−0.01
Leptocottus armatus	0.29	0.13	0.38	−0.09	−0.01	0.05
Syngnathus spp.	0.53	0.23	0.35	0.08	−0.07	0.33*
Species totals (by station)						
No. of species	0.42**	0.05	—	—	—	—
No. of individuals	0.48**	0.36*	—	—	—	—
Biomass	0.54**	0.64**	—	—	—	—

* = significant at 0.05 level.
** = significant at 0.01 level.

TABLE 5.—Summary of two canonical correlation runs of individual species abundances against environmental variables.

Axis	R^2	R	X^2	df
Run No. 1 (6 environmental; 18 species)				
1	0.93	0.96	212.9*	126
2	0.84	0.92	144.1*	102
3	0.73	0.85	96.3	80
Run No. 2 (temperature, salinity only, 18 species)				
1	0.83	0.91	77.8*	36
2	0.61	0.78	26.5	17

* = significant at 0.01.

and salinity were important in influencing species abundance.

The 18 most common species were ordinated along temperature and salinity axes using simple correlation values (r) as an index of relative influence of these two factors (Fig. 11). Thirteen of the 18 species were positioned in the upper right quadrant indicating that they were all positively correlated with temperature and salinity. Three species, *Gambusia affinis*, *Gillichthys mirabilis*, and *Lepomis cyanellus*, located in the upper left quadrant correlated positively with temperature, but negatively with salinity. The lower left quadrant includes two species, *Lepomis macrochirus* and *Mugil cephalus*, with negative temperature and salinity influences. No species were positioned in the negative temperature, positive salinity quadrant probably because this situation rarely occurred in the littoral zone in 1978.

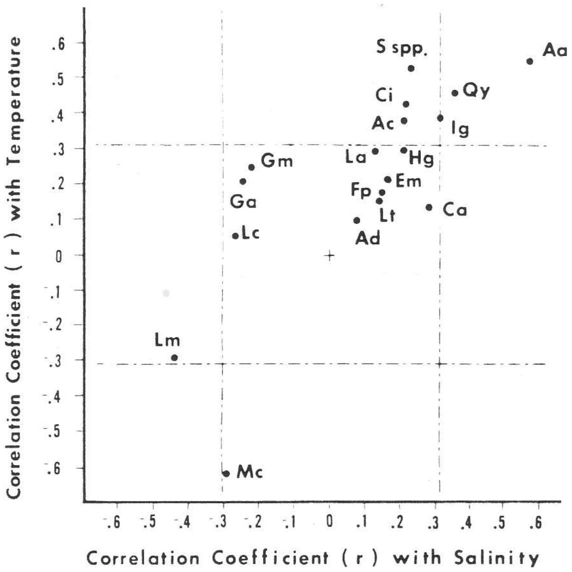

FIGURE 11.—Ordination of 18 common species of the littoral zone of upper Newport Bay on correlation coefficients (r) for temperature (y-axis) and salinity (x-axis). Dashed lines indicate 0.05 significance levels. Aa-*Atherinops affinis*, Ac-*Anchoa compressa*, Ad-*Anchoa delicatissima*, Ca-*Cymatogaster aggregata*, Ci-*Clevelandia ios*, Em-*Engraulis mordax*, Fp-*Fundulus parvipinnis*, Ga-*Gambusia affinis*, Gm-*Gillichthys mirabilis*, Hg-*Hypsopsetta guttulata*, Ig-*Ilypnus gilberti*, La-*Leptocottus armatus*, Lm-*Lepomis macrochirus*, Lt-*Leuresthes tenuis*, Mc-*Mugil cephalus*, Qy-*Quietula ycauda*, Sspp-*Syngnathus* spp.

DISCUSSION

Composition, Diversity, and Seasonal Dynamics

The ichthyofauna of the littoral zone in upper Newport Bay was numerically dominated by a few, low trophic-level species (five species accounted for >98% of all specimens collected), a situation similar to that found in many estuarine fish populations (Allen and Horn 1975). *Atherinops affinis* is an opportunistic feeder and has been characterized as both a herbivore/detritivore (Allen 1980) in upper Newport Bay and a low-level carnivore (Fronk 1969; Quast 1968). The second most abundant fish, *Fundulus parvipinnis*, is a low-level carnivore that feeds on small crustaceans and insects (Allen 1980; Fritz 1975). *Gambusia affinis*, *Clevelandia ios*, and *Anchoa compressa* are, likewise, low-level carnivores, feeding mainly on insects, benthic microinvertebrates, and zooplankton (Allen 1980).

Large individuals of *Mugil cephalus* were not sampled effectively, but probably constituted a significant proportion of biomass within these fish assemblages. Adult *M. cephalus* fed mainly on detritus and pennate diatoms (Allen 1980). This essentially herbivorous diet closely matches that described by Odum (1970) for *M. cephalus*.

The overall H' diversity values (H'_N range 0.42-1.76; overall 0.89) for the littoral zone were comparable to values derived from other studies of bay-estuarine fish faunas and to other studies in Newport Bay. Haedrich and Haedrich (1974) derived values of 0.33-1.03 for Mystic River Estuary, Mass.; Stephens et al. (1974) presented indices of 0.65-2.08 for Los Angeles Harbor, Calif.; Allen and Horn (1975) published values of 0.03-1.11 for Colorado Lagoon, Alamitos Bay, Calif.; and Quinn (1980) calculated values of 0.21-2.59 (overall 1.9) for Serpentine Creek in subtropical Queensland. Using otter trawl data, I calculated H'_N values of 0.20-1.96 (overall 0.98) for the upper Newport Bay in 1974-75 (Allen 1976). The concurrent bimonthly portion of this study (Horn

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and Allen 1981) obtained a bimonthly range for numbers of 0.48-2.17 (overall 1.05) when the deeper channel areas were also sampled. The relatively wide range of H'_N values in all of the above studies reflects the differential utilization of these embayments by fishes on a seasonal basis. At the same time, the low overall diversity reflects dominance both in numbers and biomass by a few species. The seasonal usage has the effect of increasing annual diversity, although only one or two species dominate numerically at any one time. The H' values for biomass (H'_B range 0.23-1.55; overall 0.84) were fairly close to those for numbers and, again, mainly reflected the dominance of *A. affinis* (~80%). In all, 26 of the 32 reported species had young-of-the-year fishes, making up a significant portion of their populations. Fluctuations in juvenile population levels had a substantial effect on the littoral fish populations. Juvenile recruitment plus the immigration of adult fishes presumably for reproduction or for exploitation of high productivity in warmer months were the principal causes for seasonal changes in the ichthyofauna. These activities reflect the widely recognized function of bay-estuarine environments as spawning and nursery grounds (Haedrich and Hall 1976).

The general pattern of increased number of species and numbers of individuals during the late spring through fall period in upper Newport Bay has been observed in many other studies of temperate bay-estuarine fishes (e.g., Pearcy and Richards 1962; Dahlberg and Odum 1970; Allen and Horn 1975; Adams 1976a). Several studies of estuarine fish populations have, in addition, detected summer depressions in abundance between peaks in spring and fall in other estuaries (Livingston 1976; Horn 1980) and in lower Newport Bay (Allen 1976).

Studies of subtropical estuarine fish populations have shown a trend in seasonal abundances that is 6 mo out of phase with the above observations. Fish abundances were highest during the winter months (November-March) in the Huizache-Caimanero Lagoon of Mexico due to increases in members of both demersal and pelagic fishes (Amezcua-Linares 1977; Warburton 1978). This coastal lagoon system is subject to a narrower range of temperatures over the year (18.3°-27.9°C) than most temperate systems. However, the Mexican system undergoes wide variation in salinity, especially during the rainy season from July to October (see section Influence of Abiotic Factors).

Species Associations

Species groupings were subject to strong seasonal influence and bore a striking resemblance to the classification scheme of Atlantic nearshore fish communities proposed by Tyler (1971). According to Tyler's classification the Atlantic nearshore fish communities can be divided into regular and periodic components. Periodic components can be winter seasonals, summer seasonals, or occasionals. The upper Newport Bay fish assemblage had regulars (group I) and periodics (groups II-V). The "anchovy" group (II), the "goby" group (III), and the "*Engraulis-Hypsopsetta*" group (IV) were all summer seasonals. Group V had both winter seasonals in *Mugil cephalus* and *Lepomis macrochirus* and summer seasonals in *Lepomis cyanellus* and *Leuresthes tenuis*. The latter group, however, could best be characterized by the affinity of its components to lower salinities rather than to a particular time of year. The occasional component was represented by the 12 species of group VI which also occurred in the summer. Thus Tyler's classification may have a broader application than he originally proposed, and perhaps holds true for many estuarine ichthyofaunas.

Species Densities and Productivity

Density estimates for some species of littoral fishes are particularly difficult to obtain. Such species include small, burrow-inhabiting fishes of the family Gobiidae and other small benthic fishes such as killifishes, flatfishes, and sculpins which escape under a seine or through the mesh of various nets. This study attempted to obtain density values for all littoral fishes, especially for the elusive species listed above. By setting up the procedure for choosing the "best estimate" of density from among four different sampling methods, actual densities of the species have been more closely approximated.

If the biomass density of *Atherinops affinis* for the entire study is calculated by dividing its total biomass by the total area of coverage by all four sampling gears, a biomass density of 3.3 g/m^2 (or about 0.83 g DW/m^2) is obtained. This density value is lower than the estimate of 1.16 g DW/m^2 derived through the best estimate process (Table 6). In this particular case, most densities were mean values of six bag seines which were very effective (99%) at capturing *A. affinis* (Horn and Allen footnote 2). Biomass density for the gobiid,

TABLE 6.—Grand mean estimate of biomass density (g DW/m^2) for common species in the littoral zone (excluding panne) over the 13-mo period (January 1978-January 1979) from the best estimate criteria.

Species	$\bar{X}$ g DW/m^2 ±1 SE
Atherinops affinis (adult)	0.1043±0.0602
A. affinis	1.1590±0.2573
Fundulus parvipinnis	0.1064±0.0223
Gambusia affinis	0.0015±0.0028
Clevelandia ios	0.0261±0.0117
Anchoa compressa	0.1195±0.0493
Cymatogaster aggregata	0.0167±0.0158
Gillichthys mirabilis	0.0131±0.0035
Anchoa delicatissima	0.0077±0.0053
Mugil cephalus	0.0024±0.0018
Quietula ycauda	0.0029±0.0025
Ilypnus gilberti	0.0021±0.0021
Hypsopsetta guttulata	0.0043±0.0035
Engraulis mordax	0.0019±0.0018
Lepomis macrochirus	0.0006±0.0005
Lepomis cyanellus	0.0003±0.0001
	1.5688 g DW/m^2

Clevelandia ios, determined by total area coverage was 0.013 g/m^2 (about 0.003 g DW/m^2). The value based on best estimate (using square enclosures and small seine estimates) was about 10 times higher at 0.03 g DW/m^2. This large discrepancy is due to the low efficiency of the bag seine for capturing this species. Since the bag seine covered the largest area of any of the sampling gears (220 m^2), its addition to the density determination for *C. ios* led to the large underestimate. The total biomass density of all species by total area was 4.13 g/m^2 (or about 1.02 g DW/m^2) which again was lower than the best estimate grand mean density of 1.57 g DW/m^2.

Average standing stock for the upper bay species during 1978 was 784 kg DW, based on an estimate of 50 ha of habitable littoral zone in upper Newport Bay. This is equivalent to 3,136 kg (wet weight) or 6,899 lb of fish. By the same procedure, the average standing stock of *A. affinis* was 631.6 kg DW and that of *C. ios*, 13.1 kg DW.

The annual production of 9.35 g DW/m^2 for the upper Newport Bay littoral zone in 1978 ranked among the highest values recorded for studies with comparable production determinations of production models (Table 7).

The Newport Bay production estimate in 1978 was surpassed only by the estimate for *Fundulus heteroclitus* (Meredith and Lotrich 1979), an estuarine species of the east coast of the United States. *Fundulus heteroclitus* represented a very efficient energy link between the marsh and the littoral zone in their study. However, as Meredith and Lotrich pointed out, the production value may be an overestimation due to the underestimation of the area of marsh utilized by the fish. The value 4.6 g DW/m^2 obtained by Adams (1976b) for fishes inhabiting east coast eelgrass beds, which are acknowledged as highly productive areas, is half the estimate for the littoral zone of upper Newport Bay.

Short food chains have been implicated as the primary reason for high production in estuarine fish communities (Adams 1976b), a contention which is supported by the findings of this study. Young-of-the-year *Atherinops affinis* accounted for 85% of the annual production and formed a direct link through their herbivorous/detritivorous diet to the high primary productivity of this estuarine system. The remaining, numerically important species of the littoral zone were low-level carnivores. There is little doubt that this assemblage represents an example of "food chain telescoping" as described by Odum (1970).

Even though the fish production in the littoral zone of upper Newport Bay was high compared with most comparable studies, the value presented here is undoubtedly an underestimate. The largest species of the system, adult *Mugil cephalus*, was not represented in the production estimates due to inadequate sampling. Inclusion of this species would have substantially increased the production value. It is unlikely, however, that productivity of adult *M. cephalus* could approach that of juvenile *Atherinops affinis* which were responsible for 85% of the annual fish production.

Influence of Abiotic Factors

The positive correlations between temperature and total abundance, biomass and number of species, and between salinity and total abundance and biomass indicate the general impor-

TABLE 7.—Comparison of annual fish production (P) for marine or estuarine studies with comparable production determinations. Wet weights were converted by multiplying by 0.25. Values are for all species except where noted.

Locale and habitat	Study	Estimated annual P (g DW/m^2)
Delaware salt marsh creek (*Fundulus heteroclitus*)	Meredith and Lotrich (1979)	10.2
Newport Bay littoral zone	present study	9.4
Mexican coastal lagoon	Warburton (1979)	8.6
Cuban freshwater lagoons	Holčik (1970)	6.2
No. Carolina eelgrass beds	Adams (1976b)	4.6
Bermuda Coral Reef	Bardach (1959)	4.3
Texas lagoon (Laguna Madre)	Hellier (1962)	3.8
English Channel pelagic and demersal fishes	Harvey (1951)	1.0
Georges Bank commercial fishes	Clarke (1946)	0.4

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tance of these factors to this assemblage. Individual correlations between abiotic factors and species abundances likewise emphasized the importance of temperature and salinity. The correlations between individual species abundances and dissolved oxygen as well as distance into the upper Newport Bay could be due to the intercorrelations of both dissolved oxygen and distance with temperature.

Intercorrelations among factors can confound the interpretation of relationships and introduce redundancy in multivariate analyses. The relationship between dissolved oxygen and distance into the upper Newport Bay is intuitive considering its shallow depths. The positive relationship between temperature and dissolved oxygen was probably due to photosynthesis by green algae during the summer. Winter rainfall in the basically Mediterranean climate of southern California was responsible for the positive correlation between temperature and salinity found in Newport Bay. This relationship is by no means absolute, as evidenced by the low salinities encountered during the tropical rains of September 1978 when temperatures were high.

The results of the second canonical correlation analysis indicate that interaction between temperature and salinity explained most of the variability in species abundance in this system. The correlation between these two abiotic factors probably inflated the R^2 value slightly, but does not negate the overall findings. Ordination of individual species by correlation coefficients with temperature and salinity underscores the influences of these factors on individual species. Furthermore, the substantial decrease in numbers of *A. affinis* at station 1 and the somewhat smaller decrease at station 3 during September rains (low salinity) and relatively high temperatures also illustrate this temperature-salinity interaction.

I propose that an important consequence of temperature-salinity influence found in the present study is the transfer of biomass and, therefore, energy from the littoral zone to the adjacent channel and ultimately to local offshore areas via migration of fishes. This mechanism for energy transfer was best illustrated by the apparent emigration of a large portion of the 0-age class *A. affinis* from the littoral zone from September to December 1978. The transfer also included the biomass produced by essentially all of the periodic species. Weinstein et al. (1980) reached a similar conclusion in their study of the fishes in shallow marsh habitat of a North Carolina estuary. An extensive mark and recapture study should be planned to test this hypothesis in the future.

Seasonal fluctuations of temperate bay-estuarine fish populations may have several causes, but temperature and salinity seem frequently to be the underlying factors. The pattern of increased number of species and individuals with increased temperature in temperate bays and estuaries has been reviewed by Allen and Horn (1975). Recently the large-scale influence of salinity on bay-estuarine fish populations has been demonstrated by Weinstein et al. (1980) for Cape Fear River Estuary, N.C. Unfortunately, any salinity interaction with temperature was not investigated or discussed in the above study.

Studies of subtropical estuaries (Amezcua-Linares 1977; Warburton 1978; Quinn 1980) indicate that salinity may have greater influence on fish populations, since annual temperature ranges are narrower than in temperate bays and estuaries. In each of the above studies on subtropical estuaries, increased abundances corresponded to the season of low rainfall and therefore high salinity. Blaber and Blaber (1981) concluded that turbidity and not temperature and salinity was the single most important factor to the distribution of juvenile fishes in subtropical Moreton Bay, Queensland. However, Blaber and Blaber (1981) did not present statistical evidence to support this contention. The most important environmental factors influencing tropical estuarine (eelgrass) ichthyofaunas are more difficult to identify (Weinstein and Heck 1979; Robertson 1980) and probably include biotic factors such as prey availability, competitors, predators, as well as abiotic factors. Biotic interactions are undoubtedly important in temperate estuarine systems including upper Newport Bay. However, their overall influence on the system is probably swamped by large fluctuations in the physical environment.

Fluctuations in rainfall and temperature regimes during a year and from year to year can have marked effects on the ichthyofauna of estuaries. Moore (1978) has identified long-term (1966-73) fluctuations in summer fish populations in Aransas Bay, Tex. He found that diversity values (H' range of 1.38-2.13) were quite variable from year to year probably as a result of major climatological changes (an unusually wet year; a drought and two hurricanes). These changes in diversity values were probably caused by changes in abundance within a set of resident estuarine species and of periodic species.

In 1978 the ichthyofauna of upper Newport Bay was subjected to rainfall twice that of a "normal" year (70.9 cm for 1978; mean 28.1 cm). The specific effects of this increased precipitation are difficult to assess due to a lack of data from previous years but some guarded comparisons can be made. Population densities of *Atherinops affinis* were lower in 1974-75 than those encountered during 1978 (Allen 1976). Also *Cymatogaster aggregata*, *Clevelandia ios*, and *Leptocottus armatus* occurred in lower numbers in 1978 than in previous years (Horn and Allen 1981). These discrepancies point out the strong year-to-year fluctuations that occur in the fish populations of upper Newport Bay. This conclusion is in complete agreement with the findings of Moore (1978) and sheds doubt on the possibility of completely characterizing a "normal" year in many estuaries because of unpredictable annual variations in climate.

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LITERATURE CITED

ADAMS, S. M.
1976a. The ecology of eelgrass, *Zostera marina* (L.), fish communities. I. Structural analysis. J. Exp. Mar. Biol. Ecol. 22:269-291.
1976b. The ecology of eelgrass, *Zostera marina* (L.), fish communities. II. Functional analysis. J. Exp. Mar. Biol. Ecol. 22:293-311.

ALLEN, K. R.
1950. The computation of production in fish populations. N.Z. Sci. Rev. 8:1-89.

ALLEN, L. G.
1976. Abundance, diversity, seasonality and community structure of fish populations in Newport Bay, California. M.A. Thesis, California State Univ., Fullerton, 108 p.
1980. Structure and productivity of the littoral fish assemblage of upper Newport Bay, California. Ph.D. Thesis, Univ. Southern California, Los Angeles, 175 p.

ALLEN, L. G., AND M. H. HORN.
1975. Abundance, diversity and seasonality of fishes in Colorado Lagoon, Alamitos Bay, California. Estuarine Coastal Mar. Sci. 3:371-380.

ALLEN, L. G., AND W. S. WHITE.
In press. Ecological aspects of the ichthyoplankton and demersal fish populations of Newport Bay, California: 1974-1975. Los Angeles Cty. Mus. Nat. Hist., Contrib. Sci.

AMEZCUA-LINARES, F.
1977. Generalidades ictiológicas del sistema Lagunar Costero de Huizache-Caimanero, Sinaloa, México. An. Centro Cienc. Mar. Limnol., Univ. Nac. Autón. México 4:1-26.

BANE, G. W.
1968. Fishes of the upper Newport Bay. Museum of Systematic Biology, Univ. Calif. Res. Ser. 3, 114 p.

BANE, G. W., AND M. ROBINSON.
1970. Studies on the shiner perch, *Cymatogaster aggregata* Gibbons, in upper Newport Bay, California. Wasmann J. Biol. 28:259-268.

BARDACH, J. E.
1959. The summer standing crop of fish on a shallow Bermuda reef. Limnol. Oceanogr. 4:77-85.

BECHTEL, T. J., AND B. J. COPELAND.
1970. Fish species diversity indices as indicators of pollution in Galveston Bay, Texas. Contrib. Mar. Sci. 15:103-132.

BLABER, S. J. M., AND T. G. BLABER.
1981. Factors affecting the distribution of juvenile estuarine and inshore fish. J. Fish Biol. 17:143-162.

CHAPMAN, D. W.
1968. Production. *In* W. E. Ricker (editor), Methods for assessment of fish production in fresh waters, p. 182-196. Blackwell Sci. Publ., Oxford.

CLARKE, G. L.
1946. Dynamics of production in a marine area. Ecol. Monogr. 16:322-335.

CLIFFORD, H. T., AND W. STEPHENSON.
1975. An introduction to numerical classification. Acad. Press, N.Y., 229 p.

CRONIN, L. E., AND A. J. MANSUETI.
1971. The biology of the estuary. *In* P. A. Douglas and R. H. Stroud (editors), A symposium on the biological significance of estuaries, p. 14-39. Sport Fish. Inst., Wash., D.C.

DAHLBERG, M. D., AND E. P. ODUM.
1970. Annual cycles of species occurrence, abundance and diversity in Georgia estuarine fish populations. Am. Midl. Nat. 83:382-392.

DERICKSON, W. K., AND K. S. PRICE, JR.
1973. The fishes of the shore zone of Rehoboth and Indian River Bays, Delaware. Trans. Am. Fish. Soc. 102:552-562.

FREY, W. W., R. F. HEIN, AND J. L. SPRUILL.
1970. The natural resources of upper Newport Bay and recommendations concerning the Bay's development. Res. Agency Calif. Dep. Fish Game, 148 p.

FRITZ, E. S.
1975. The life history of the California killifish *Fundulus parvipinnis* Girard, in Anaheim Bay, California. Calif. Dep. Fish Game, Fish Bull. 165:91-106.

FRONK, R. H.
1969. Biology of *Atherinops affinis littoralis* Hubbs in Newport Bay. M.S. Thesis, Univ. California, Irvine, 109 p.

HAEDRICH, R. L., AND S. O. HAEDRICH.
1974. A seasonal survey of the fishes in the Mystic River, a polluted estuary in downtown Boston, Massachusetts. Estuarine Coastal Mar. Sci. 2:59-73.

HAEDRICH, R. L., AND C. A. S. HALL.
1976. Fishes and estuaries. Oceanus 19(5):55-63.

HARVEY, H. W.
1951. On the production of living matter in the sea off Plymouth. J. Mar. Biol. Assoc. U.K. 29:97-137.

HELLIER, T. R., JR.
1962. Fish production and biomass studies in relation to photosynthesis in the Laguna Madre of Texas. Publ. Inst. Mar. Sci. 8:1-22.

HOLČIK, J.
1970. Standing crop, abundance, production and some ecological aspects of fish populations in some inland waters of Cuba. Vestn. Cesk. Spol. Zool. 34:184-201.

HORN, M. H.
1980. Diel and seasonal variation in the abundance and diversity of shallow-water fish populations in Morro Bay, California. Fish. Bull., U.S. 75:759-770.

HORN, M. H., AND L. G. ALLEN.
1981. Ecology of fishes in upper Newport Bay: seasonal dynamics and community structure. Calif. Dep. Fish Game, Mar. Res. Tech. Rep. 45, 102 p.

IVLEV, V. S.
1966. The biological productivity of waters. J. Fish. Res. Board Can. 23:1727-1759.

KJELSON, M. A., AND G. N. JOHNSON.
1978. Catch efficiencies of a 6.1-meter otter trawl for estuarine fish populations. Trans. Am. Fish. Soc. 107:246-254.

LIVINGSTON, R. J.
1976. Diurnal and seasonal fluctuations of organisms in a north Florida estuary. Estuarine Coastal Mar. Sci. 4:373-400.

MCERLEAN, A. J., S. C. O'CONNOR, J. A. MIHURSKY, AND C. I. GIBSON.
1973. Abundance, diversity and seasonal patterns of estuarine fish populations. Estuarine Coastal Mar. Sci. 1:19-36.

MEREDITH, W. H., AND V. A. LOTRICH.
1979. Production dynamics of a tidal creek population of *Fundulus heteroclitus* (Linnaeus). Estuarine Coastal Mar. Sci. 8:99-118.

MOORE, R. H.
1978. Variations in the diversity of summer estuarine fish populations in Aransas Bay, Texas, 1966-1973. Estuarine Coastal Mar. Sci. 6:495-501.

ODUM, W. E.
1970. Utilization of the direct grazing and plant detritus food chains by the striped mullet, *Mugil cephalus*. *In* J. H. Steele (editor), Marine food chains, p. 222-240. Univ. Calif. Press, Berkeley.

ORTH, R. J., AND K. L. HECK, JR.
1980. Structural components of eelgrass (*Zostera marina*) meadows in the lower Chesapeake Bay—Fishes. Estuaries 3:278-288.

OVIATT, C. A., AND S. W. NIXON.
1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution and abundance. Estuarine Coastal Mar. Sci. 1:361-378.

PEARCY, W. G., AND S. W. RICHARDS.
1962. Distribution and ecology of fishes of the Mystic River estuary, Connecticut. Ecology 43:248-259.

POSEJPAL, M. A.
1969. The population ecology of the benthic ichthyofauna of upper Newport Bay. M.S. Thesis, Univ. California, Irvine, 146 p.

QUAST, J. C.
1968. Observations on the food of the kelp-bed fishes. Calif. Dep. Fish Game, Fish Bull. 139:109-142.

QUINN, N. J.
1980. Analysis of temporal changes in fish assemblages in Serpentine Creek, Queensland. Environ. Biol. Fishes 5(2):117-133.

RECKSIEK, C. W., AND J. D. MCCLEAVE.
1973. Distribution of pelagic fishes in the Sheepscot River—Back River Estuary, Wiscasset, Maine. Trans. Am. Fish. Soc. 102:541-551.

RICKER, W. E.
1946. Production and utilization of fish populations. Ecol. Monogr. 16:374-391.

ROBERTSON, A. I.
1980. The structure and organization of an eelgrass fish fauna. Oecologia (Berl.) 47:76-82.

SHANNON, C. E., AND W. WEAVER.
1949. The mathematical theory of communication. Univ. Illinois Press, Urbana, Ill., 117 p.

SHENKER, J. M., AND J. M. DEAN.
1979. The utilization of an intertidal salt marsh creek by larval and juvenile fishes: abundance, diversity and temporal variation. Estuaries 2:154-163.

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 (editors), Marine studies of San Pedro Bay, California, Part IV, Environmental field investigations. Allan Hancock Found. Publ., USC-SG-6-72:1-42.

TARGETT, T. E., AND J. D. MCCLEAVE.
1974. Summer abundance of fishes in a Maine tidal cove with special reference to temperature. Trans. Am. Fish. Soc. 103:325-330.

TYLER, A. V.
1971. Periodic and resident components in communities of Atlantic fishes. J. Fish. Res. Board Can. 28:935-946.

WARBURTON, K.
1978. Community structure, abundance and diversity of fish in a Mexican coastal lagoon system. Estuarine

Coastal Mar. Sci. 7:497-519.

1979. Growth and production of some important species of fish in a Mexican coastal lagoon system. J. Fish Biol. 14:449-464.

WEINSTEIN, M. P., AND K. L. HECK, JR.

1979. Ichthyofauna of seagrass meadows along the Caribbean coast of Panamá and in the Gulf of Mexico: composition, structure and community ecology. Mar. Biol. (Berl.) 50:97-107.

WEINSTEIN, M. P., S. L. WEISS, AND M. F. WALTERS.

1980. Multiple determinants of community structure in shallow marsh habitats, Cape Fear River Estuary, North Carolina, U.S.A. Mar. Biol. (Berl.) 58:227-243.

WILEY, J. L., T. S. Y. KOO, AND L. E. CRONIN.

1972. Finfish productivity in coastal marshes and estuaries. *In* Proceedings of the Coastal Marsh and Estuary Management Symposium, Louisiana State Univ., p. 139-150.

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[1]Department of W
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[2]Bodega Marine L
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Laboratory, National
Box 271, La Jolla, CA
[3]Division of Envir
nia, Davis, CA 95616

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